Assessing the Sustainability of Bioenergy Projects in Developing Countries

A Framework for Policy Evaluation

Edited by *Jaime M. Amezaga, Graham von Maltitz and Samantha Boyes*

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Assessing the Sustainability of Bioenergy Projects in Developing Countries

A Framework for Policy Evaluation

A resource book for practitioners and local decision-makers based on the findings of the EuropeAid Cooperation Office funded RE-Impact project

Edited by: *Jaime M. Amezaga, Graham von Maltitz and Samantha Boyes*

Prepared in collaboration with:

- Centre for Land Use and Water Resources Research (CLUWRR), Newcastle University, UK
- Winrock International India (WII)
- The Indian Institute of Technology, Delhi (IIT)
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Newcastle University
Kings Gate
Kings Walk
Newcastle upon Tyne
NE1 7RU
Tel: + 44 (0) 191 246 4882, fax: + 44 (0) 191 246 4961
http://www.ncl.ac.uk

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Foreword

It is abundantly clear that the global energy system is not sustainable, both because of the climate impacts of greenhouse gas emissions, and the over-reliance on a declining stock of fossil fuels. However, the sufficient and reliable supply of energy is a crucial success factor for the development of the billions of people currently living under unacceptable conditions. The solution to this apparent paradox lies in the development and deployment of renewable, environmentally less-damaging energy sources. Biomass, in its many forms and variants, is a leading candidate.

Biomass energy is not automatically either sustainable or free of adverse impacts, however. The outcomes depend on the specifics of the biomass resource used, the technology applied to convert it to energy and the circumstances under which it is deployed. In the rush-to-market, many exaggerated claims have been made both for and against biomass energy. How is a policymaker to sift the beneficial from the bogus?

This book provides a framework within which the main issues can be evaluated, specifically in developing countries. Taking the tried-and-tested Strategic Environmental Assessment process as the starting point, it incorporates current thinking on planning for sustainability as a pathway to integrate specific assessment methodologies. It is aimed at the regional or national policy level rather than at the scale of individual projects, although many of the principles have application at local scale as well. It provides guidance and examples relating to the process of assessment itself, and evaluates the impacts on water supply, biological diversity, greenhouse gas sources and sinks, the social fabric and the economy.

The approach to quantifying and assessing the positive and negative impacts and their tradeoffs can be extended to other types of impacts, not explored here.

I hope that this book provides a sufficiently-rigorous, yet practical approach to informed decision-making on this complex, important and urgent issue

Dr Bob Scholes
Chair: Group on Earth Observation Biodiversity Observation Network
South Africa

Executive Summary

Fulfilling the promise of sustainable development has become a major concern for proponents of modern bioenergy projects. The global land area dedicated to feedstock production, be it for liquid biofuels, solid biomass or biogas, has expanded greatly over the past decades; increasingly so in developing countries. Current first generation bioenergy feedstocks, particularly for commercial scale production, demand large areas of land and in many cases have extensive labour requirements. Where marginal or degraded lands are not used, feedstock production could compete with food crops for land or labour, may impact negatively on biodiversity and alter local hydrology, or create a multitude of other direct or secondary social and environmental impacts. The expanding global demand for bioenergy products provides many opportunities for socio-economic benefits and rural development in developing countries; however there are also numerous tradeoffs and potential negative impacts that must be taken into account. The need to assess and find a balance between both positive and negative impacts of bioenergy production and use is therefore apparent. Whilst some existing initiatives are proving to be robust and effective from a western, market-oriented perspective, a concern is that the assessments are limited in scope and often only conducted after projects are designed and initiated. A strong need has been identified for approaches with a developing country perspective which assess impacts both in a locally oriented, context specific way as well considering how they might relate to wider national or international agendas.

This volume provides an introduction to a selection of suitable approaches that can be used to assess individual aspects of bioenergy production, based on up to date knowledge, and worked out examples from a developing country perspective. It is aimed at the regional or national policy level rather than at the scale of individual projects, although many of the principles are applicable at local level as well. The methodologies and framework are based on findings from the EuropeAid Cooperation Office project RE-Impact, including examples from India, Uganda and South Africa. Some Chapters have a clear liquid biofuel focus; however most of the approaches are also applicable to other forms of biomass for energy, as is shown in the examples.

Chapter 1 introduces the global drivers and concerns behind bioenergy production and use. A key aspect is the consideration of the sustainable development concept and how it relates to bioenergy. A developing country perspective on implementation is considered even though often the main driver for biofuel development in developing countries is the demand from developed countries.

Chapter 2 deals with the concept of planning for sustainability and outlines a framework for applying this approach to bioenergy projects. Conceptual consideration is given to the likely institutional home for the framework in each of the case studies respectively, taking the contexts of each into account.

Chapter 3 provides a step by step guide to performing an evaluation of the impacts of bioenergy projects on catchment water resources using the case study of South Africa. A range of potential bioenergy feedstocks are assessed and it is shown that the approach to conducting such assessments differs depending on the scale of assessment required.

Chapter 4 looks in detail at full Life Cycle Assessment of bioenergy projects, considering carbon sequestration and flows for a system in Uganda. Here the need to carefully consider the emissions from the baseline scenario as well as those from the specific bioenergy project is emphasised, as is the importance of long versus short term and direct versus indirect impact evaluation.

Chapter 5 introduces a methodology for assessing the impacts of biofuel projects on biodiversity, using South Africa as a case study for testing. A number of tools with different levels of detail are presented and it is concluded that careful planning, both at strategic level and plantation levels, can greatly reduce the level of biodiversity loss due to biofuel feedstock production.

Chapter 6 considers the social impacts of bioenergy projects and suggests a predominantly qualitative method for assessing them and engaging with stakeholders, using a case study of the Indian Biofuels Programme. The analysis shows that bioenergy feedstock production can have both positive and negative social impacts; the former should be used as indicators for monitoring, the latter to assist in formulating alternative strategies.

Chapter 7 goes into considerably more detail on the economic aspects of biofuel feedstock production, drawing on southern African experience. The contribution of multiple feedstocks for both bioethanol and biodiesel production towards ameliorating crop price volatility, reducing income poverty and increasing productivity is modelled and the most effective at achieving each in South Africa is identified based on the parameters and processes used.

Finally, Chapter 8 provides a concluding evaluation of the RE-Impact methodologies and considers the future in impact assessment of bioenergy projects.

Overall this book provides an informed resource for practitioners and local decision makers with an interest in the evaluation of bioenergy initiatives. It is a central concept in the proposed framework that the assessment of sustainability has to start at the early stages of policy design and cannot be left to individual projects.

Acknowledgements

This book is dedicated to the memory of Professor Ian Rainy Calder, former Director of the Centre for Land Use and Water Resources Research at Newcastle University, and original Principal Investigator on the RE-Impact project. Ian was a world authority on Integrated Land and Water Resources Management, and an inspiration to everyone who was fortunate enough to have worked with him.

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Author Affiliations

Jennifer Harrison is a Research Associate for CLUWRR at Newcastle University, UK. Her current research focus is on strategies to enhance rural livelihoods and protect the natural environment through participatory resource management; and she has particular expertise in understanding stakeholder dynamics of rural bioenergy production in developing countries.

Lorren Haywood is a Senior Researcher within the Natural Resources and the Environment Unit at the Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa. Lorren focuses on exploring sustainability challenges from the context of a social-ecological systems perspective.

Benita de Wet is a Researcher at the CSIR in Johannesburg, South Africa. She comes from a background in environmental assessment and management and is currently engaged in finding and designing approaches to effectively incorporate sustainability thinking into development planning.

Mark Gush is a Senior Researcher in the Natural Resources and Environment Division of the CSIR in Pietermaritzburg, South Africa. Mark has expertise in the measurement and modeling of plant wateruse, and has worked on numerous projects related to land-use hydrology and water-use efficiency over the last 13 years.

Neil Bird is a researcher at Joanneum Research, a member of the CDM AR Working Group and leader of IEA Bioenergy Task-38. His research includes: influence of surface albedo changes on benefits of agriculture, forestry and other land-use (AFOLU) projects; evaluating emission reductions from improved land management and biomass use; and development of unique CDM A/R projects.

Francesco Cherubini is a researcher at the Industrial Ecology Programme, within the department of Energy and Process Engineering at the Norwegian University of Science and Technology. His main research interests are in the field of Life Cycle Assessment of bioenergy and biorefinery systems, with a particular focus on atmospheric CO_2 fluxes and their impact on the planet climate system.

Naomi Pena is a researcher at Joanneum Research. Naomi has specialized in analysis of existing, and identification and evaluation of proposed, climate instruments, particularly for the land use sector. She also has decades of experience in rendering scientific information and results relevant to policy makers and other stakeholders.

Giuliana Zanchi is a researcher at Joanneum Research. Her main areas of expertise include assessment of GHG impacts of bioenergy use, specifically forest-based bioenergy, and assessment of sequestration potential of agricultural and forestry carbon projects.

Alecia Nickless is a Researcher in the Natural Resources and the Environment Unit of the CSIR. Her speciality is the statistical analysis of environmental data, particularly focused on savanna systems.

Ryan Blanchard is a Biodiversity PhD student at working at CSIR in South Africa, and registered at the University of Stellenbosch Town. Ryan is currently investigating potential biodiversity impacts from biofuel introduction.

Sunandan Tiwari is Senior Programme Officer at Winrock International India, New Delhi. His focus is community based natural resource management for livelihood and environmental security, institutional assessment, and developing monitoring, impact assessment and learning protocols.

Nicholas Ngepah is a Poverty and Development Economist, PhD Research Intern at NRE (with the CSIR) and Senior Economist at The Competition Commission of South Africa.

Acronyms and Abbreviations

BAU	Business as usual
BII	BII Biodiversity Intactness Index
BOD	Biological Oxygen Demand
CBA	Cost Benefit Analysis
CBD	Convention on Biological Diversity
CGIAR	The Consultative Group on International Agricultural Research
CHP	Combined heat and power
CREDA	Chhattisgarh Renewable Energy Development Agency
DBT	Department of Biotechnology
DDGS	Dried distillers grains with solubles
EA&M	Environmental Assessment and Management
EIA	Environmental Impact Assessment
EU	European Union
EU-ETS	The EU Emission Trading Scheme
EU RED	The EU Renewable Energy Directive
GBEP	Global Bioenergy Partnership
GHG	Greenhouse gas emissions
HCV	High Conservation Value Network Approach
HRU	Hydrological response unit
IAS	Invasive Alien Species
IDB	Inter American Development Bank
IOC	Indian Oil Corporation
IPCC	Inter-governmental Panel on Climate Change
LAI	Leaf area index
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
(d/i)LUC	(direct/indirect) Land use change
MA	Millennium Ecosystem Assessment
MAE	Mean Annual Evapotranspiration
MAP	Mean Annual Precipitation
MBIPL	Mission Biofuels India Private Limited (also MB)
MNC	Multi-National Corporation
MNRE	Indian Ministry for New and Renewable Energy
MSP	Minimum Support Price
NDVI	Normalized Difference Vegetation Index
NGO	Non Governmental Organisation
NOVOD	Indian National Oilseeds and Vegetable Oils Development Board
NREGS	India National Rural Employment Guarantee Scheme
NTFP	Non Timber Forest Products
OMC	Oil Marketing Company
PCI	Principles, Criteria and Indicators
PPP	Policies, Plans, Programmes
RCA	Responsible Cultivation Area
REDD +	Reducing Emissions from Deforestation and Forest Degradation "plus" (includes conservation, sustainable forest management & enhancement of forest carbon stocks)
RLS	Reliance Life Sciences Limited
RSB	Roundtable on Sustainable Biofuels
RSPO	Roundtable on Sustainable Palm Oil
SCF	Structured and Corporate Finance Department
SEA	Strategic Environmental Assessment
SECCI	Sustainable Energy and Climate Change Initiative
SFRA	Streamflow Reduction Activity
SIA	Social Impact Assessment
SRC	Short Rotation Coppice
TBO	Tree Borne Oilseed
UNFCCC	United Nations Framework Convention on Climate Change
WRA	Weed Risk Assessment
WSSD	World Summit on Sustainable Development
WWF	World Wide Fund for Nature

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Chapter 1
Introduction to Sustainable Bioenergy for Developing Countries

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1.1 Sustainable Development and the Bioenergy Boom

Sustainable development is a diverse and evolving expression which, despite its definition not being universally agreed, is the ultimate objective of most development projects (Buchholz et al. 2007). Intended to incorporate social, environmental and economic aspects over generational timescales, the concept gained popularity with political and academic audiences in 1987 with the report of the World Commission on Environment and Development (Brundtland 1987). Since then many hundreds of authors, practitioners and commentators have encouraged its adoption as a development goal. Sustainability itself is not an indicator, however, and is subjective so that it can mean different things in different contexts to different people (Bell and Morse 2008). Achieving sustainable development in practical terms means meeting criteria and principles set by local people who have a stake in the process (stakeholders), in such a way as the natural environment is either unaffected or enhanced. Of course achieving this is not easy, although many vehicles have been suggested, one of which is bioenergy production and use.

Fulfilling the promise of sustainable development has become a major concern for bioenergy proponents. The global area dedicated to feedstock production, be it for liquid biofuels, solid biomass or biogas, has increased greatly over the past decades. This change in land use was initiated predominantly in developed countries, with the notable exception of Brazil; however more recently biofuel feedstock production in developing countries has experienced rapid growth (Berndes et al. 2003; FAO 2008). This has largely been driven by mandated renewable energy targets and growing markets for liquid biofuels in the developed world, with many Oil Marketing Companies (OMCs) and Multi-national Corporations (MNCs) taking the opportunity to invest on a large scale in developing countries to meet this demand (Kammen et al. 2002; Heinimö and Junginger 2009). Many developing countries are seriously considering the use of liquid biofuels in order to buffer high fossil fuel prices, meet local liquid fuel demands and potentially provide export income. The real success that Brazil has had in this regard highlights the potential (Goldemberg and Guardabassi 2009).

The main consumers of liquid biofuels, and therefore biggest markets, are in the USA and Europe (Heinimö and Junginger 2009), however in the accelerated-growth economies such as India and China there are already targets and mandates relating to biofuels which require vast amounts of feedstock (Weyerhauser et al. 2007; Kumar Biswas et al. 2010). Due to these high levels of interest and investment, and the increasing concerns regarding climate change, the profile of liquid biofuels has risen dramatically; however the use of biomass for energy is not new to the developing world. For many developing countries traditional forms of bioenergy make up the dominant proportion of the energy balance and have been used for thousands of years with little modernisation (Chaturvedi 2004; Demirbas and Demirbas 2007). In the majority of cases more modern and efficient forms of bioenergy, such as bioelectricity, do exist but are either too expensive, unreliable, or unevenly distributed so that people in more remote areas cannot access them (Goldemberg and Lucon 2010).

1.1.1 Bioenergy drivers and concerns

The main global and national level drivers for increased use of energy from biomass include (FAO 2008):

- Possibility of reduced carbon emissions and meeting climate change commitments through both sequestration of carbon during biomass growth, and avoided emissions through reduction in fossil fuel consumption;
- Rural development through employment and increased livelihood and market opportunities;
- Security of supply through local production and/or processing; and
- Technological development, whereby bioenergy could be used to bridge the gap between current reliance on fossil fuels and future technologies.

The benefits of bioenergy production and use provided above as drivers are by no means assured in every context. Searchinger and colleagues (2008) famously cast doubt on the greenhouse gas (GHG) balance of bioethanol production in the US, and studies have suggested direct and indirect links between bioenergy production and, amongst others, deforestation and global food price rises (Gallagher 2008). These concerns have highlighted the need for effective assessment of bioenergy production in individual cases because, evidently, there are multiple variables determining the overall sustainability of each project or programme.

Since most developing countries have relatively low commitments to GHG reduction targets, it is the fuel security and rural development potential of biofuels that tends to be of most interest. At the micro (household, community, village) scale, however, the drivers tend to be socio-economic in nature including, for example: livelihood diversity, employment opportunities and cash crop profits (Buchholz and da Silva 2010; Woods et al. 2006). At the regional or district 'meso' scale the drivers are more likely to include: meeting national targets; attracting investment; and increasing land productivity/output. With such diverse and cross-cutting drivers, in terms of both scale and sector, it is clear that to some extent tradeoffs are inevitable.

The local rural development outcomes often expected from bioenergy projects depend heavily on the success of the feedstock cultivation, but also very much on the political or market structures and degree of planning behind the project implementation (see Chapter 6; Dalal-Clayton et al. 2003). Current first generation liquid biofuel feedstocks, particularly for commercial scale production, demand large areas of land and in many cases have extensive labour requirements. Where marginal or degraded lands are not used, feedstock production could compete with food crops for land or labour, may impact negatively on biodiversity and alter local hydrology, or create a multitude of other direct or secondary social and environmental impacts. The expanding global demand for bioenergy products provides many opportunities for socio-economic benefits and rural development in developing countries; however there are also numerous trade-offs and potential negative impacts that must be taken into account as the level of production increases (Domac et al. 2005; Ewing and Msangi 2009; Mathews and Tan 2009).

1.2 Methodologies for Assessing Sustainability

1.2.1 Distinguishing features of assessment methodologies

Currently, long established techniques such as Environmental Impact Assessment (EIA) are mandatory in many countries prior to any large scale project being implemented (Abaza et al. 2004). Such procedures aim to identify and mitigate negative environmental consequences of the proposed action prior to the onset of the project/programme/plan/policy (Carroll and Turpin 2002; Morrison-Saunders and Fischer 2006). The type of initiatives that might be subject to EIA would include macro hydropower, large scale commercial land transformation and big infrastructure projects. The laws on impact assessment are customarily made at the national level, often as a result of international conventions (Hacking and Guthrie 2008). Since the introduction and uptake of EIA as a central tool in planning, there have been many advocates but also opposition, particularly within the past decade or two (Becker 2001; Gibson 2006; Harrison et al. In Press). The criticisms of the approach include that it is traditionally only completed after project design and can therefore have little influence on the final product; instead strategies to ameliorate the environmental impacts that are likely as a result of implementation are suggested (Noble 2000). In addition, it is thought that the focus on environmental issues results in too little or no attention being given to the range of social impacts that can be caused by such projects (Tiwari et al. 2010). Such evaluations have resulted in many alternative (some complementary, others competing) approaches to improving the overall sustainability of programmes, policies and projects from the outset including Social Impact Assessment (SIA) (Barrow 2000; see also Chapter 6), Strategic Environmental Assessment (SEA) (Dalal-Clayton and Sadler 2005) and Sustainability Assessment (SA) (Gibson 2005; See also Chapter 2).

1.2.2 A framework for classifying assessment methodologies

Hacking and Guthrie (2008) presented a very useful framework for comparing and/or reconciling emerging forms of assessments focusing on sustainable development (see Figure 1.1). In this approach a spectrum of three axes is used to distinguish between different assessment methods, in terms of:

1. **Comprehensiveness** – how fully the sustainable development themes (environmental, social and economic) are covered;

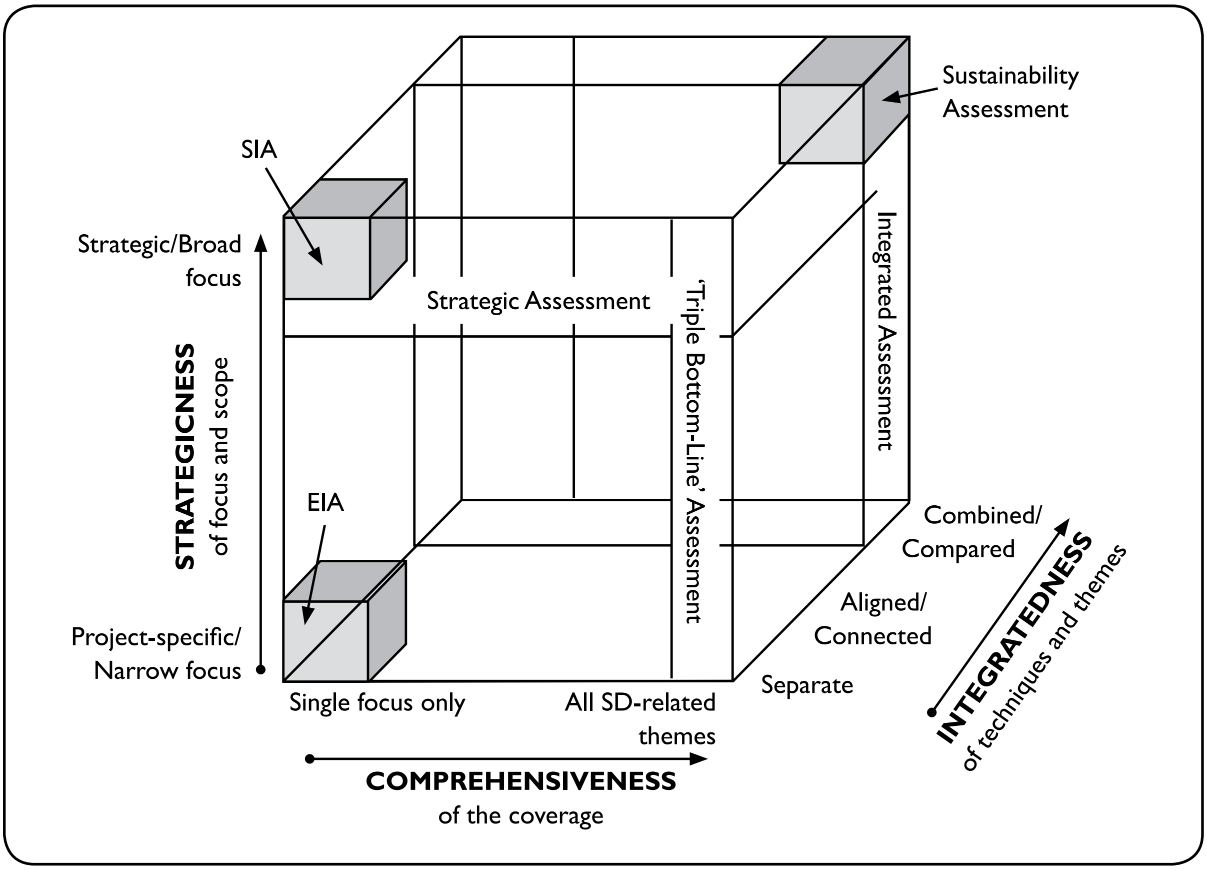

Figure 1.1: **Spectrum of multiple assessment procedures across 3 axes, adapted from Hacking and Guthrie (2003).**

2. **Integratedness** – to what extent the different themes are aligned/connected/compared/ combined;
3. **Strategicness** – whether the focus or perspective of the approach is narrow and short term or broad and future-oriented.

The framework shows clearly that none of the approaches considered are able to cover the whole spectrum. Figure 1.1 shows how SIA, one of the assessment methodologies that will be considered in this volume, fits in Hacking and Guthrie's framework although it was not included in the original.

1.2.3 Planning: top-down versus bottom-up

Dalal-Clayton and colleagues (2003) identified that the rural planning process in developing countries is often a top-down one. This essentially means that the policy making and planning takes place at central government level and is implemented according to national mandate, without the involvement of locals who would be affected if there were to be negative social or environmental consequences (Hartter and Ryan 2010). This practice is well established and allows for strategic, national level, long-term planning. In contrast, bottom-up planning is described as that which is locally initiated and actively involves the community from the identification of development priorities right through to the implementation. Whilst proponents of planning for sustainable development demand that this sort of participatory decision making is necessary for successful programmes; there are certainly many difficulties and barriers which must be overcome in order to achieve it fully (Dalal-Clayton et al. 2003).

1.3 Assessing the Sustainability of Bioenergy Projects

The need to assess the impacts of bioenergy production and use has been widely reported (Elghali et al. 2007; Vis et al. 2008), and many institutions and networks have devoted much time to developing approaches and techniques for quantification or qualification (IRGC 2008; RSB 2008; Bernal and Berndes 2009). Initiatives such as the Global Bioenergy Partnership (GBEP), the Roundtable on Sustainable Biofuels (RSB), the Roundtable on Sustainable Palm Oil (RSPO) and others (summarised in Harrison et al. In Press) have appeared in recent years. So, why the need for another suite of impact assessment methodologies such as those proposed in this book? Whilst many of the existing initiatives are proving to be robust and effective, they have predominantly western, market-oriented perspectives which are primarily based, as is the case with EIA, on biophysical aspects and initiated only after projects are designed and started (Harrison et al. In Press). Studies have identified a strong need for approaches with a developing country perspective which assess impacts in a locally oriented, context specific way as well as how they might relate to wider national or international agenda and be applicable at a range of spatial scales (Dalal-Clayton et al. 2003; Buchholz and da Silva 2010).

1.3.1 Diversity in bioenergy projects

When considering bioenergy projects there is huge diversity in terms of species and scale of feedstock, processing chain, market end use and scale; as well as the drivers behind their implementation as outlined above (Berndes et al. 2003; von Maltitz and Setzkorn, In Press). In practise this means that projects range in all dimensions from: community scale forest plantations for gasification; to tree-borne oilseeds such as Jatropha curcas on field bunds and along roadsides for biodiesel; or thousand hectare plantations of high sugar-content crops for bioethanol. As a result, "one-size-fits-all" type assessments are unlikely to be able to effectively cover all aspects.

1.3.2 Working over a multitude of spatial scales

As discussed, bioenergy production can have impacts that potentially span multiple spatial and temporal scales. One driver behind increased interest in bioenergy production has arisen in response to global concerns regarding carbon emissions and resultant climate change. However, whilst local communities are likely to be impacted by climate change, their ability to influence carbon sequestration on a global scale through engaging in bioenergy projects is minimal. Degradation of biodiversity from increased rates of land transformation is equally an issue of global concern, although to local communities this may have anything from negligible to large impacts on the environmental services that sustain their livelihoods. Poor communities are, however, subject to a multitude of both positive and negative impacts from bioenergy expansion that may not be experienced beyond the bounds of the individual household or village. Other, more widespread, impacts such as reduced streamflow can directly impact on a downstream village or ecological system. National level priorities such as overall economic growth might or might not be aligned with local communities' rights to access to local land. Figure 1.2 illustrates the nature of some of the potential trade-offs as one moves between scales.

Some funding streams for bioenergy projects are based on specific desirable outcomes. For instance the European Union (EU) has created an artificial market for liquid biofuels through the use of mandatory blending, but only if positive climate change impacts are being achieved and can be proven through

SCALE	WATER	BIODIVERSITY	CLIMATE CHANGE (Greenhouse gas emissions/sequestration	SOCIO-ECONOMICS
GLOBAL TRANSBOUNDARY	Change in large system ecological processes and social services Change in transboundary water systems	Change in biodiversity - Species extinction - Biome loss - Biodiversity richness	Net greenhouse gas forcing - Carbon sequestration - Albedo change - Gaseous/aerosol emissions - Life cycle - Net radiative forcing	Millennium Development Goals Poverty alleviation Global food security Global polilitical stability Impacts on global food and fuel markets (World Trade Organization)
NATIONAL PROVINCIAL/STATE	Change in ecological reserve for rivers Change in total streamflow and available water to downstream users Movement towards Catchment Closure Irrigation need	Change in biodiversity - Species extinction - Intactness of habitat - Introduction of alien invasive species	Power density (Wm^{-2}) Energy Return on Energy Investment (EROEI)	Macro-economic indicators (e.g. GDP, GBI, balance of payments) National food security Employment indicators - Jobs/ha vs Jobs/W (i.e. employment measured either by jobs created per unit of land or per unit of energy produced)
LOCAL GOVERNMENT CATCHMENT COMMUNITY HOUSEHOLD	Change in seasonality of streamflow Change in security of supply Change in depth to groundwater or yield of groundwater Change in water quality	Change in ecosystem services provided by biodiversity - Provisioning (food, wood) - Regulating impacts (floods, droughts) - Regenerative capacity (supportive services) - Soil degradation	Ability to access and use CDM funds (i.e. Clean Development Mechanism, and arranement for carbon credit accounding under the Kyoto Protocol)	Household income Equity of distribution (i.e. winner/losers across class, gender, age and urban/rural distinctions, for full product life cycle) Household food security (producing food vs earning money) Employment indicator - Jobs/village Risk of failure Human health impact (e.g. poisons from Jatropha) Vulnerability

Figure 1.2: **Matrix of potential impacts of bioenergy production and use across spatial scales**

certification (Amezaga et al. 2010). Developing countries might do the same or similar, but more likely for the objective of stimulating rural development. Understanding the sustainability of bioenergy production therefore means that there are trade-offs involved that span scales from local to global, as well as from short term needs to long term considerations for future generations.

1.4 The RE-Impact Approach

This volume is the product of a EuropeAid Cooperation Office funded initiative entitled "RE-Impact: Rural Energy production from bioenergy projects – providing regulatory and impact assessment frameworks, furthering sustainable biomass production policies and reducing associated risks"[1]. The interdisciplinary RE-Impact project team consists of seven international partners with a strong track record of collaboration in related fields. From the School of Civil Engineering and Geosciences at Newcastle University, UK, the lead partner is the Centre for Land Use and Water Resources Research (CLUWRR). The only other western partner is the Austrian research organisation Joanneum Research. From Africa the project has partners in Uganda (UNIQUE Forestry Consultants East Africa) and South Africa (the Council for Scientific and Industrial Research, CSIR, South Africa); from India the Indian Institute of Technology (IIT) Delhi and Winrock International India; and finally from China the Centre

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[1] See project website at: http://www.ceg.ncl.ac.uk/reimpact for more information on the RE-Impact initiative

for Mountain Ecosystem Studies (CMES), daughter institute of the World Agroforestry Centre (ICRAF), Kunming Institute of Botany and the Chinese Academy of Sciences.

The RE-Impact Consortium were tasked with providing a technologically and socially sound approach to the assessment of bioenergy options in rural areas of developing countries using a framework based on sustainability principles. In order to robustly develop the methodologies required to formulate such an approach, four case study countries spanning Africa and Asia at different stages of bioenergy production in terms of policy, implementation and momentum were chosen; namely South Africa, Uganda, India and China. Within the project different work packages were designed to address what were seen to be the main issues relating to the sustainability of bioenergy feedstock production: water resource, biodiversity, socio-economic and carbon stock protection and enhancement (see Figure 1.2). Relevant assessment methodologies have subsequently been developed and tested within the case studies, and are summarised in Chapters 2 to 7 along with worked out examples. Considering the diversity in bioenergy projects outlined in section 1.3.1: the existing range of assessment methodologies discussed in section 1.3; and the importance of scale in both planning and monitoring (section 1.3.2); it was deemed important to avoid replicating existing methodologies, rather produce a generic approach that could be used to cover all dimensions from a developing country perspective. Within this approach tools are suggested which address individual aspects of bioenergy projects, and these have been tested in different case study situations with a view to being more widely applicable. Figure 1.3 shows how the assessments of the different aspects of bioenergy production fit within the overall objective of meeting goals set by local stakeholders for sustainable development.

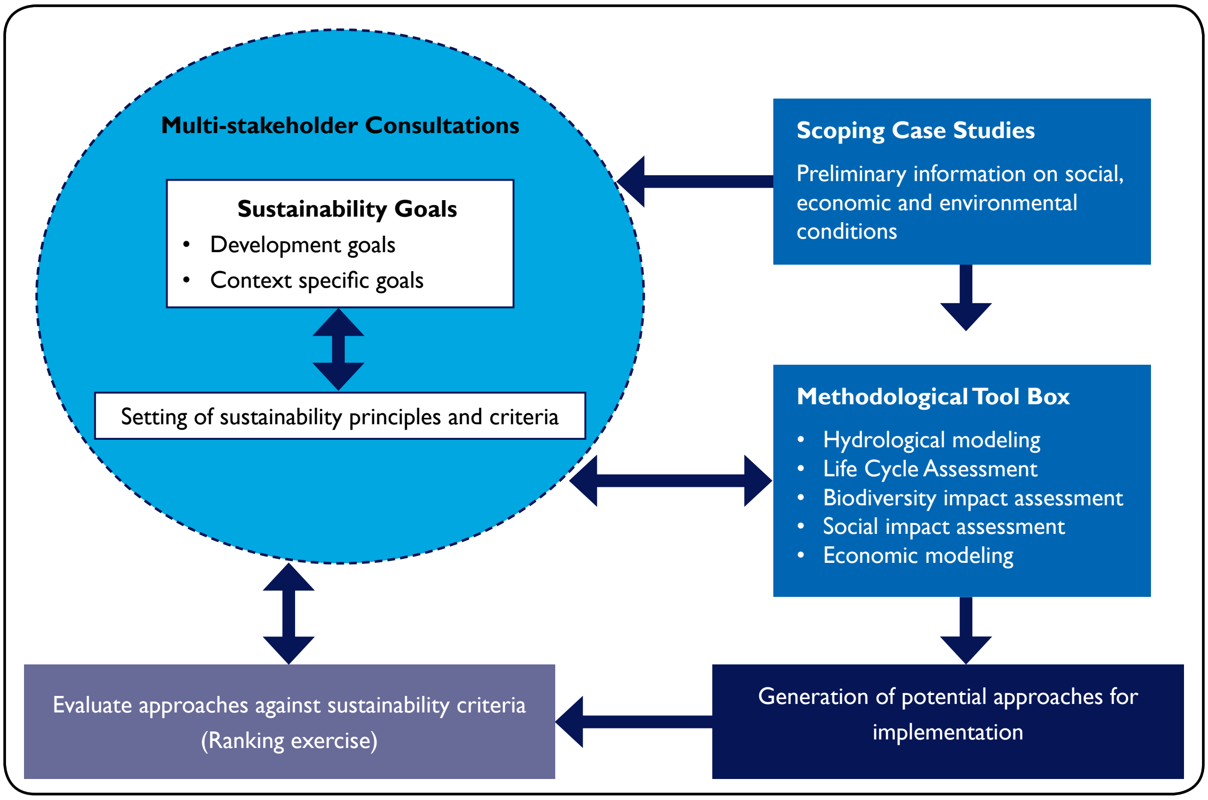

Figure 1.3: **RE-Impact framework for integrating the specific assessment methodologies with sustainability planning**

1.5 Structure of the Book

This book consists of seven further chapters. Chapter 2 deals with the concept of planning for sustainability and outlines a framework for applying this approach to bioenergy projects. Chapter 3 provides a step by step guide to performing an evaluation of the impacts of bioenergy projects on water resources using the case study of South Africa. Chapter 4 looks in detail at full Life Cycle Assessment of bioenergy projects, considering carbon sequestration and flows for a system in Uganda. Chapter 5 introduces a methodology for assessing the impacts of bioenergy projects on biodiversity, considering the South African perspective. Chapter 6 considers the social impacts of bioenergy projects and suggests a predominantly qualitative method for assessing them, using a case study from India. Chapter 7 goes into considerably more detail on the economic aspects of bioenergy projects, drawing on southern African experiences. Finally, Chapter 8 provides a concluding evaluation of the RE-Impact methodologies and considers the future in impact assessment of bioenergy projects.

The structure of the book provides a summary of what this collaborative effort strives to achieve. What is not expected is for this volume to be used as a "cook book" type manual for a layperson to follow. Instead, it provides an introduction to the most suitable approaches that can be used to assess individual aspects of bioenergy production, based on up to date knowledge, thorough assessment and worked out examples from developing country perspectives. It is aimed at the regional or national policy level rather than at the scale of individual projects, although many of the principles have application at the local level as well. Indeed, it is a central concept in the proposed framework that planning for sustainability has to start at the early stages of project design. The approaches discussed and proposed comprise numerous elements, with the overall thread being a pathway or road map that should be followed when planning bioenergy projects from the point of view of developing countries; whereby only the aspects relevant in individual contexts and situations are undertaken in the sort of detail given in the specific examples. It is also not suggested that this encompasses every conceivable angle; there are of course other useful techniques available which have been referenced and often form the basis for certain elements of the methodologies.

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Chapter 2
Planning for Sustainability for Bioenergy Programmes, Plans and Projects

Lorren Haywood, Benita de Wet and Graham von Maltitz

2.1 Introduction

2.1.1 Sustainability and the role of environmental assessment and management tools

The need to consider the environmental consequences of development had been discussed for some time before the publication of the Brundtland report (Brundtland 1987), but it was one of the first to introduce the concept of sustainable development, or sustainability (Mebratu 1998). In response to the global impact of human society on natural resources, this report highlighted that the rate of human consumption of natural resources was exceeding the rate of replenishment, and defined sustainable development as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Mebratu 1998). The sustainable development aspirations of the United Nations, as outlined at the World Summit for Sustainable Development (WSSD) in 2002 and in the Millennium Development Goals, are dependent on effective Environmental Assessment and Management (EA&M) (United Nations 2000; United Nations 2003). The Johannesburg Declaration on Sustainable Development, a key output of the 2002 WSSD, further highlighted this necessity and called for greater use of environmental assessment tools, to address the challenges associated with unsustainable patterns of consumption and production (United Nations 2003).

Since the late 1960s the primary focus of EA&M was on environmental impact prediction of proposed projects (Pope et al. 2004). Environmental Impact Assessment (EIA) has been widely used over a period of 50 years to predict and address potential environmental impacts of proposed development projects. However, over time the need emerged to develop EIA further and also to develop new techniques within EA&M, which could more effectively deal with the complex and integrative concepts of sustainability, and at a minimum, to include social and economic aspects during assessment. A range of EA&M tools has since been developed including environmental / ecological risk assessment, cumulative effects assessment, health and social impact assessment, economic / financial assessment, environmental management systems and the more integrative and strategic approaches such as Strategic Environmental Assessment (SEA). Even though these EA&M tools are also now in common use in many countries across the world, only EIA is currently a legal requirement in the majority of these countries. The more advanced EA&M tools in particular, are less consistently used in developing countries. Importantly, despite over 40 years of EIA requirements and practice, all global indicators of sustainability point to an increased un-sustainability in development, emphasizing that humans are using more natural resources than can be replenished.

To deal with the complexity of the interactions between nature and human society, a fundamental change is needed in the way that EA&M is approached and conducted (Du Plessis 2008). Approaches to incorporating sustainability considerations into EA&M thus far, have been based on a presumed ability to be able to predict probabilistic responses to external drivers (Walker et al. 2002). As predictability remains a challenge, due to the complexity and uncertainty of external global drivers, traditional methods for analyzing potential environmental impacts have become overwhelmed, and the goal of sustainable development less likely to be achieved (Fiksel 2003). One of the main reasons that efforts at improving the sustainability performance of developments are failing is that scientists, decision makers and those who implement the decisions which have been made, are trying to find solutions to complex environmental and development problems from within the same paradigm, using the same tools and adopting the same worldviews that threaten sustainability in the first place (Fiksel 2003; Du Plessis 2008). In this regard, there is a need to change the paradigm within which environmental assessment is conducted, from that of a mechanistic and modernist worldview to that of a systemic worldview (Du Plessis 2008).

To be able to respond to the challenges of achieving sustainability, we first need to know and be able to understand what a sustainable system might look like. What characteristics would it have? Sustainability is not an end state to which we can aspire, but rather it is a constantly emerging characteristic of a dynamic, evolving system (Fiksel 2003). So, when conducting an environmental assessment, we need to understand and appreciate that individual human beings and human society are embedded in the complex interactive processes of the social-ecological system within which they are situated (Capra 1997). New ideas emerging from resilience theory suggest that sustainability in linked social-ecological systems is not a single static endpoint, but rather a dynamic state which evolves over time, where the totality of the system is maintained and able to absorb stresses and disturbances without losing its functionality (Walker et al. 2004).

When planning for sustainability, there must be an appreciation of the close links between ecological processes and ecosystem services on the one hand and human society on the other, and the relationships and feedback loops between them (Hopwood et al. 2005). In Sustainability Assessment, social and environmental equity are fundamental tenets. Sustainability Assessment is increasingly being viewed as a useful method to aid in the shift in thinking towards enhanced sustainability of development. Sustainability Assessment thinking has in large measure been developed by EIA and SEA practitioners and is often considered to be the "next generation" of environmental assessment (Sadler 1999). Planning for sustainability, which incorporates Sustainability Assessment, requires a clear definition of sustainability and corresponding sustainability principles and criteria which can be used in the development and evaluation of proposed projects. What sustainability means is context specific (situational) and it is thus imperative that a context specific definition is agreed through a deliberative participatory process.

Sustainability Assessment is not intended to replace other forms of environmental assessment such as EIA or SEA. Rather, Sustainability Assessment has an altogether different purpose to these other tools, viz. the focus is on planning for sustainability rather than to identify and mitigate potential individual environmental impacts. It is an adjunct to these other tools which adds substantive value, when applied within an existing decision-making framework, to ensure that the outcomes of decision-making are in fact sustainable in real terms. Ideally Sustainability Assessment should be conducted in a regional context, or perhaps within the context of a particular economic sector, since as is the case with objective-led SEA, the power of Sustainability Assessment is in integrating across developments rather than being linked to a single development. However, this does not mean that Sustainability Assessment cannot be applied to project level planning. The tool can also be used retrospectively to evaluate the sustainability performance of existing practices or developments. Sustainability Assessment can and should be applied broadly to both proposed and existing practices, and at all levels of decision making. Ongoing monitoring linked to adaptive management is required since unintended consequences, imperfect understanding of system dynamics or influences outside the system, could all impact on the *de facto* long term resilience of the system.

In this chapter, we explore the need to address the sustainability of bioenergy policies, plans, programmes and projects (PPP) in a comprehensive and systemic manner, where long term sustainability is the focus of feasibility investigation and planning from the outset. We briefly discuss some of the key environmental challenges with regards to biofuel development, and how this spawned the move towards the concept of planning for sustainability. The benefits of a comprehensive planning framework for bioenergy development are explained, and the relationship of the range of existing EA&M tools to such a framework is described. The approach to planning for sustainability outlined in this chapter embodies the concept of systems thinking. We propose a social-ecological systems approach in Sustainability Assessment, which is focused on the building and maintenance of the resilience of the system. The planning for sustainability framework for the bioenergy sector, presented in this chapter, is intended as a prototype to be tested and improved over time and it is expected to evolve based on real life, situation-specific application. Some preliminary considerations for its implementation are also given.

2.2 Sustainability Issues Related to Bioenergy

2.2.1 Bioenergy as a renewable energy source

The world is facing looming energy shortages in the light of ever increasing energy demand, coupled with both population growth and increased affluence. Oil is the largest single source of energy consumed, exceeding the use of coal, natural gas, nuclear, hydro and renewables (Energy Information Administration 2005). By 2030, global demand for oil is expected to have increased by 50% (Johnston and Hallaway 2007; Rooney et al. 2007). The rate at which conventional oil production can be increased has been constrained by the lack of refining capacity, and the fact that nearly 50% of the world's proven and probable conventional light crude oil reserves have already been consumed (USGS 2004). Given the trends and persistently high crude oil prices, the concern about future energy security and awareness of the impact of climate change as a result of the combustion of fossil fuel, has sparked an interest in rapidly finding alternative energy sources to crude oil based products. Bioenergy, i.e. energy derived from organic matter such as energy crops, agricultural and forest residues, wood, manure and other biogenic material, is a potential alternative energy source.

In this chapter, we focus on liquid biofuels, specifically bioethanol and biodiesel. The production of biofuels triggers a number of social, economic and environmental problems and this emphasises the need to address sustainability in the production of and trade in biofuels.

2.2.2 The need for sustainability in biofuel production and use

The advancement of bioenergy technologies has created a situation where the implementation of biofuel development programmes, or specific biofuel development projects, is proceeding at a pace which outstrips that of conventional development planning and feasibility evaluation. It is not enough for an energy source to be renewable; it must also meet the requirements of sustainability and as a minimum response to the objectives of the Johannesburg Plan of Implementation and the Millennium Development Goals.

Research into proven sustainable biofuel production systems is scarce. Consequently few studies are available and data, whether empirical or field derived, are limited. This is especially true in developing countries which have only recently started considering biofuel production as an alternative to fossil fuels. As a number of key concerns about the long term sustainability of the biofuel industry have been raised, both from a global environmental perspective as well as from a local socio-economical perspective, it is clear that careful, case specific assessment and planning must underpin any proposed biofuels development initiative (Elghali et al. 2007; The Royal Society 2008; Gallagher 2008; Groom et al. 2008). Unless a number of measures are successfully put in place to ensure sustainable agricultural practices and sustainability in biofuel conversion practices, particularly during the feasibility investigation for a biofuel development project, regardless of the technological advances made in the conversion of feedstock, the ecological and social damage caused by the biofuel industry may far outweigh the potential benefits.

There are currently several approaches being employed to drive sustainability in biofuels development and production, as discussed in more detail in Harrison et al. (In Press). These approaches include:

Certification and standards

A number of voluntary certification schemes have been developed in response to the negative concerns about biofuel production in relation to sustainability. These include the Round Table on Sustainable Palm Oil, the Round Table on Sustainable Biofuels, the Round Table on Responsible Soy, and the Better Sugar Cane initiative (Harrison et al. In Press). The social and economic impacts referred to in most certification and standards schemes, relate to working conditions (wages, child labour), land rights, health and safety, and gender equity (Harrison et al. In Press). Certification and standards are most effective in an environment where other related laws and policy already exist, since to achieve national or global sustainability of biofuels requires a range of local and global policy inputs.

Legislative approaches and biofuel policies

National legislation should be the main driver of sustainable biofuel production within a country, as it is the mechanism through which incentives and disincentives are provided for, and processes such as environmental assessment or land zoning are formalised (Harrison et al. In Press). However, as is the case in most developing countries, pressure from foreign investors is ensuring that biofuel production is generally forging ahead of the promulgation of, or changes to, relevant national legislation, or the development of a national biofuel strategy. As a result many developing countries are unprepared, due to the lack of legislation and regulation governing the development of renewable energy, thereby rendering them unable to protect their natural resources and the interests of their citizens (Harrison et al. In Press).

Environmental Assessment

Most countries have some form of legislation that requires an EIA to be undertaken when a proposed development activity may threaten the receiving environment. Environmental concerns at project level are brought to the fore in EIA processes, but the process is not adequate for addressing sustainability. In developing countries, where legislation, strategic planning and land use mapping to support biofuel development and production is limited; EIAs are less effective due to the inadequate planning for and data availability on biodiversity, ecosystem types, available water resources, carbon sinks, climate variability, local community reliance on natural resources and likely future threats to ecosystems (Harrison et al. In Press).

Sustainability Assessment

Sustainability Assessment is a relatively new tool that differs from an EIA or SEA in that it is inherently about achieving sustainability as a desired outcome, rather than merely identifying and mitigating environmental impacts. It is about understanding the social-ecological system into which the proposed biofuel activity will be placed. The methods of Sustainability Assessment are still being developed and hence the approach lacks an institutional framework to legislate and fund its implementation (Harrison et al. In Press).

In the sections to follow, we discuss the Sustainability Assessment approach in the context of a framework we have developed to plan for sustainability in any proposed biofuel policy, plan/programme or project.

2.3 Planning for Sustainability from a Social-ecological Systems Perspective

2.3.1 Sustainability and Sustainability Assessments

Sustainability is not a measureable target or an accurate science. Interpretations of what sustainability means, and what might constitute sustainability in biofuel production, are subjective and will be determined to some degree by the desired outcomes of the end user. It is vital to the understanding of Sustainability Assessment that sustainability is not interpreted as merely meeting individual and separate targets for ecological, economic and social components of the environment, by modifying a development proposal to avoid adverse effects and maximise benefits for each of the components separately. Perhaps more important is to consider the relationships between social, ecological and economic factors. Gibson (2006) strongly advocates that Sustainability Assessment must be focused on these interrelationships and that their character, resilience to change and adaptability, and their sustainability goals should reflect such an orientation. He asserts that: "because sustainability is an essentially integrative concept, it is reasonable to design Sustainability Assessment as an essentially integrative process that can act as a framework for better decision-making on all undertakings – PPP as well as physical undertakings – that may have lasting effects" (Gibson 2006). Sustainability Assessment is a relatively new method and is still being developed through feedback on experiences in its application. Some might say it is as much an art as it is a science.

Taking a Sustainability Assessment approach is therefore both intellectually and practically challenging; but to ensure that planning for sustainability can become a reality this must be the future path taken by development planners. The objective of planning for sustainability from the outset is to maintain the social-ecological system in which the PPP is to occur, so that it remains dynamic, adaptive, resilient and, therefore, durable through time. Some systems are more valuable to humans in their original equilibrium state than in their alternate state, and therefore it is in society's interest to prevent the system from flipping into the alternate state. From a biofuels development perspective, understanding the impacts of biofuel expansion on the resilience of the social-ecological systems in which it is being implemented is an important component of understanding sustainability. The combined social-ecological system will change as a consequence of large scale land use change, as would be the case from biofuel introduction. The key questions to be addressed in a Sustainability Assessment is around whether change is desirable and whether there will be any primary or secondary impacts that negatively affect the resilience of the system or, in the worst case scenario, move the system into a new and undesirable domain from which it cannot recover.

2.3.2 Social-ecological systems

Traditionally ecosystems, or environmental systems, and social systems have been studied in isolation. However, humans are an integral component of the environmental system, and strong drivers of environmental change. Equally, humans are dependent on the environmental system for a wide range of environmental goods and services. Not only does the environment provide food, fuel and water (provisioning services), but it also provides regulatory services such as flood control, pest control and climate regulation as well as cultural services (Millennium Assessment 2005). There are complex interplays between the social drivers which cause human impacts on the environment, the way the environment responds and the impacts of a changed environment on humans. Sustainability is about maintaining this complex social-ecological system in a healthy state so that it can continue to provide environmental goods and services into the future. The nature of the environmental goods and services may, however, change over time; for instance we may choose to enhance the provision of biofuels at a cost to regulatory services or fibre provision. These coupled social-ecological systems are complex, with complex feedbacks and responses. These systems are also dynamic and their nature, resilience and stability change over time as both social and ecological conditions change. This makes the understanding of how a system may respond to perturbations challenging. Unintended consequences of any action are, therefore, likely. Though all possible precautions should be taken to avoid negative consequences of development, planners need to be aware that unintended consequences might occur due to only partially understanding the complex system dynamics. Ensuring that a comprehensive as possible understanding of the social-ecological system is developed at the outset of planning is thus an imperative, and the participation of all interested and affected parties in this process will assist greatly in developing an accurate picture of the system in question. Once projects are implemented it is also important to monitor for potential unintended effects and to correct practices that are causing these effects.

2.3.3 Resilience, thresholds and tradeoffs in social-ecological systems

Both social systems and ecosystems, in isolation or when linked, tend to respond in a non-linear manner to stresses and disturbances (Walker and Meyers 2004). In many instances there is a critical threshold and if the system is pushed beyond this then there is catastrophic change. However, if the system does not exceed this threshold then, although there might be negative consequences, these may remain within acceptable limits. Understanding how systems respond to change is important for the development of sustainability principles, criteria and indicators as in a Sustainability Assessment. Well thought through principles will allow development that is socially acceptable and also ensure that critical environmental thresholds are not exceeded.

Tradeoffs must often be made in the planning of developments (Hildebrand et al. 2005). To achieve positive benefits from the development there are often some negative consequences. Environmental costs in terms of the loss of environmental goods and services are common, and even in agricultural projects where intensification of one provisioning service such as food or biofuel is achieved, this tends to be at the cost of other environmental services such as biodiversity or ecological regulatory functions. In social terms there are both winners and losers, with some individuals receiving a net benefit whilst others carry a net cost. However, development is unavoidable if the world is to provide for both a growing population as well as increased demand for material goods. Some tradeoffs might be acceptable and these are the accepted costs of development. Some tradeoffs can be mitigated through modifying the nature of the intervention. Other tradeoffs are no-go areas, situations where the negative consequences do not justify the positive gains, and these should be avoided if at all possible. The Sustainability Assessment process is designed to ensure that development does not enter these no-go areas. In some situations there are positive tradeoffs (synergies) where a win-win situation is created. These win-win situations are where we should be focusing development.

2.4 Key Characteristics of a Sustainability Assessment

2.4.1 Participation

An essential characteristic of the process of planning for sustainability is that it is fundamentally and broadly participative from the beginning throughout every step. This means that it should draw on the inputs of as many interested and affected parties and stakeholders as possible. The complexity of dealing with the concept and issues of sustainability means that the process of planning for sustainability in biofuel policies, plans/programmes and projects must involve a full range of stakeholders to ensure that all the social-ecological issues and the relationships between them are both identified and investigated. Without such a comprehensive involvement, there is a high risk of not identifying and, therefore, excluding important considerations, and consequently of failure to effectively plan for sustainability. The planning process is iterative and should engage participants in a deliberative process (a process of deliberation, discussion, debate) which can include workshops, discussion groups, and participatory rural appraisal, throughout all stages of the process. Gibson (2006) refers to this as a process that "creates spaces for deliberation in which a range of views may be expressed or heard; qualitative data, values and perceptions are considered alongside technical data; and identification of modifications or alternatives to a proposal that would deliver more sustainable outcomes is encouraged".

A further characteristic of planning for sustainability is that participants learn within, and from, the process of planning and engagement with other stakeholders, and from progressive exposure to information throughout the entire process. This learning is cumulative and iterative, and includes the technical specialists who are either engaged in facilitating the planning process, or involved in specific technical investigations which feed into the assessments. Exposure to new and different perspectives, information and insights in the process of planning for sustainability, induces a reframing and learning process in the participants (Nilsson 2006). It is only in this way, that it becomes possible to 'map the terrain' for which planning for sustainability is being conducted. By 'mapping the terrain' is meant: being able to describe the critical social-ecological and economic components, characteristics, and relationships between components that make up an environment within which a potential biofuels development is intended to take place. Identifying the key system processes will enable the identification of the processes which, if affected, will have the greatest influence on the social-ecological system's resilience.

At the level of a proposed biofuels development policy, the social-ecological system could be the interacting natural and social components of an entire country. The analysis should be expected to be conducted in a more abstract sense. In the case of a plan or programme, the social-ecological system could be limited to a specific catchment, or geographic region, or to the social ecological systems in a range of different non-contiguous geographical regions / locations, or a specific vegetation or ecological zone. At the level of a biofuels development project, the social-ecological system will likely be primarily bounded by the immediate environment in which the project would be situated. The analysis can be expected to be less abstract and based more on direct empiricism.

2.4.2 Sustainability vision

The most significant step in the process is to define a sustainability vision, which will be translated into several practical actions to be taken so that it can be achieved. The vision is a joint expression by all interested and affected parties, developed in a deliberative and participatory process, of a desired resilient state or sustainability scenario for the social-ecological system in question – in this case related to a particular biofuels development intervention. Evaluating whether a proposed biofuel development will be sustainable or not requires that sustainability principles and criteria be defined, which will be used to determine whether the sustainability vision can or cannot be met. The sustainability vision, sustainability principles, sustainability criteria and sustainability indicators are of necessity context specific, taking into account local social, economic and ecological conditions and the relationships between them, as well as the unique group of stakeholders who form part of that social-ecological system. Creating a sustainability vision and determining principles and criteria for the achievement of sustainability at the start of a sustainability assessment process provides robustness to the analytical process required for decision making later in the process.

2.4.3 Tradeoffs

It is often the case that for social and economic gain (which is the conventional required outcome for any development) there will be a tradeoff against biophysical or ecological elements. However, when planning for sustainability and in Sustainability Assessment, the one essential rule is that tradeoff decisions must not compromise the fundamental objective of net sustainability. As the sustainability framework is based on full public participation, all tradeoffs and compromises identified must be openly discussed and explicitly justified and the most desirable option chosen by all. In the context of planning for sustainability, it is recommended that the following rules should be applied in discussing tradeoffs (Gibson 2006):

- No tradeoffs or compromises will be permitted unless approved by all relevant stakeholders; or
- Only undertakings that are likely to provide neutral or positive overall effects for each core sustainability requirement can be acceptable; or
- No significant adverse effects in any core category[2] can be justified by compensations of other kinds, or in other places.

Tradeoff discussions and agreements must happen early in the process of planning for sustainability, preferably in conjunction with the deliberation on formulating the joint sustainability vision. Any tradeoffs agreed should then be revisited for confirmation / rejection when determining the sustainability principles, criteria and indicators. Once the tradeoffs are finally agreed they will be implicitly incorporated into the sustainability principles and criteria for the PPP, thereby forming part of the frame of reference for the remaining tasks in planning for sustainability. No tradeoffs should be made in subsequent stages of the planning process, especially not at the level of project appraisal (refer to the tradeoff rules above). In other words, the acceptable limits for a biofuels development PPP against all principles and criteria should be fixed, and once they have been fixed they should be regarded as absolute[3].

An important consideration in making tradeoffs is that the overall resilience of the social-ecological system must not be compromised. Critical thresholds must not be exceeded, and to ensure this they must be buffered sufficiently to cover both the uncertainty of accurately determining the threshold, as well as to accommodate possible environmental extremes that may push the system closer to thresholds than would ordinarily occur under normal conditions. It must be kept in mind that the costs of recovery from exceeding a threshold could be substantial and long term, and recovery may not be possible at all.

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[2] A core category is the biophysical, or human / social, or economic component of the environment.

[3] Changes (to tradeoffs, principles and criteria) should only be made, in a process of deliberation with all stakeholders, in cases where changes in the PPP or the social ecological system over time require responses in the form of adaptive management.

2.4.4 Application of the planning for sustainability framework

The trigger for starting the process of planning for sustainability which includes the Sustainability Assessment would potentially be some form of legislation promoting sustainable development principles, environmental management best practice and natural resource protection. However, since the relevant legislation worldwide currently only enforces the conduct of EIA for activities such as biofuels development which could have potentially negative impacts, the Sustainability Assessment would be done voluntarily to assist a proponent of a biofuels PPP and the people within the particular social-ecological system to plan towards a desired outcome which reflects their interpretation of sustainability. Another trigger for the use of the framework could be international biofuel sales. Due to the potential negative effects of biofuel production such as loss of biodiversity, changing land use patterns, socio-economic impacts and greenhouse gas emissions, production that takes sustainability into account is becoming an imperative for market access. There is strong support for the setting of standards and establishment of certification systems. However, a process that promotes rigorous planning for sustainability for the life span of the PPP could help strengthen trade agreements.

Ideally, this tool should be used for PPPs that address the entire biofuel value chain (Figure 2.1) to plan for sustainability throughout the life cycle of biofuel production. Alternatively the tool may be applied to regional land use planning where biofuel is just one of numerous competing land use activities.

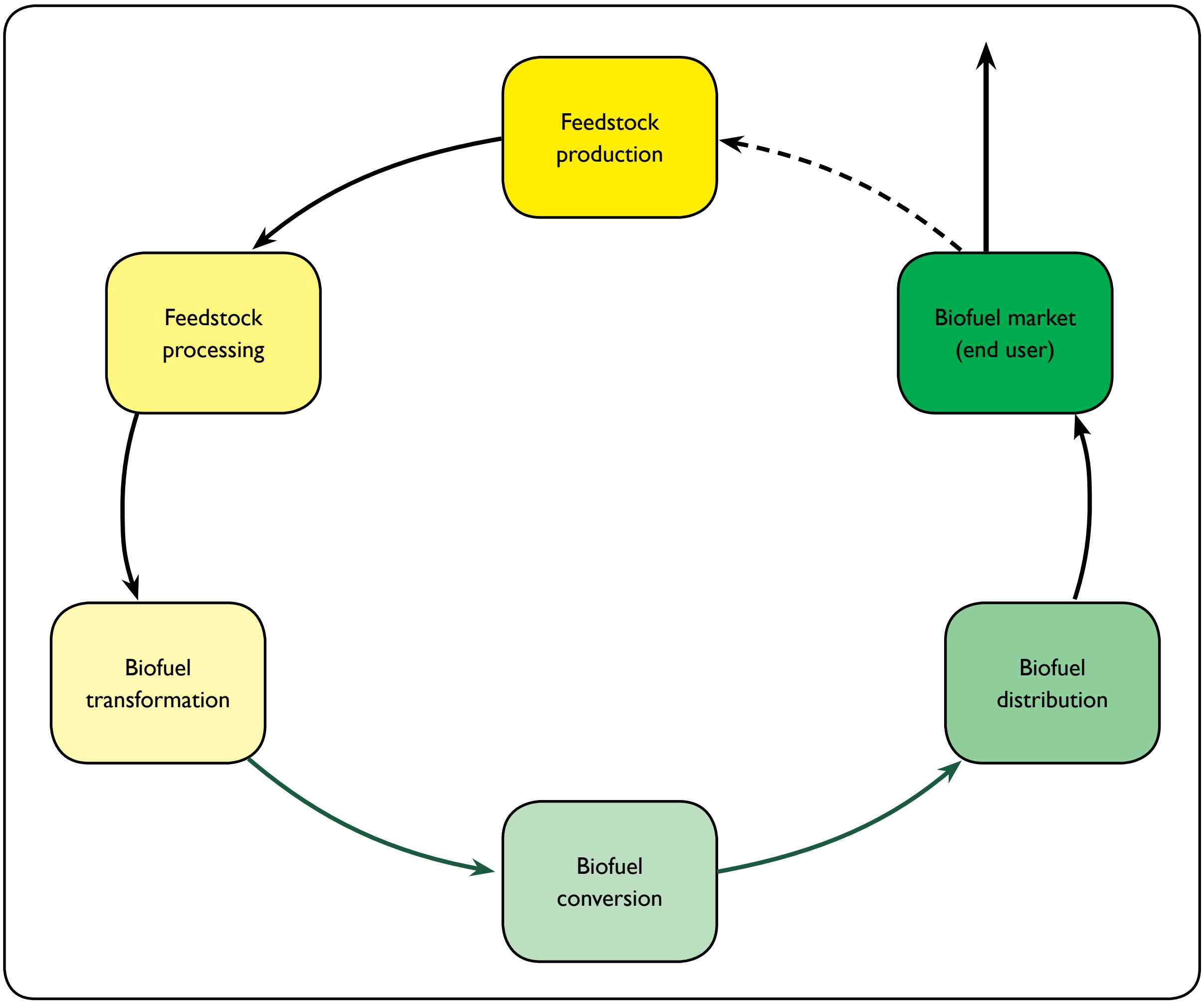

Figure 2.1: **The biofuel value chain**

However, since there may be several different project proponents throughout the value chain it is likely that sustainability issues will be addressed in different plans and projects for different aspects along the value chain. For example, a project proponent may only be interested in planning for sustainability for the feedstock production component of the value chain. Since this is a planning decision support tool it can be used to plan for sustainability for one or all stages in the value chain. Furthermore, the Sustainability Assessment framework can be used for both proposed and existing PPPs. The framework can be used to assist in conceptualising and formulating a new / proposed PPP to ensure that sustainability is at the core of the new proposal. Where a PPP has already been conceptualised and may even already have been designed, the framework can be used to improve the sustainability performance of the proposed PPP by aligning it more closely with the sustainability vision for the particular social ecological system within which it is to be developed.

2.5 The Framework for Planning for Sustainability

A generic framework is presented here (illustrated in Figure 2.2) to be used to guide and support planning and decision making for sustainability in biofuel production. The method is a mix of process and practices, and should be seen more as a guide to sound planning than a hard and fast procedure. Applying the process and its various components should aim to combine participation and societal interests with evidence based understanding of social, economic and ecosystem processes within the social-ecological system of the proposed biofuel production site.

The core aim of the application of the framework is to generate, in a deliberative and participative process, a set of principles and criteria against which the sustainability performance of a biofuel development PPP can be evaluated. This performance will be measured by means of a series of sustainability indicators. To be acceptable, i.e. deliver net sustainability, these policies, plans/programmes and/or projects must meet the agreed sustainability criteria entirely and across the board. Unlike conventional environmental assessment where ranges of acceptability may be applicable, in Sustainability Assessment the proposal either meets or does not meet the criterion. This process effectively constitutes an initial screening of proposals for sustainability performance, and only those proposals that pass the test should be pursued further and then subjected to the necessary conventional environmental assessment as required by law or other imperatives.

The framework for planning for sustainability is intended to assist planners in preparing proposals for policies, plans/programmes or projects with sustainability at their core. The preparation and improvement process does not take the place of EIA or other analyses. However, in making sustainability a core requirement of the proposals particularly for projects, it can be expected that assessments required later in the process, such as EIA, will be significantly streamlined and the number and nature of potential negative impacts identified should be substantively reduced and less significant respectively.

2.5.1 Planning for sustainability process

The framework for planning for sustainability or Sustainability Assessment framework comprises three substantive and sequential tasks:

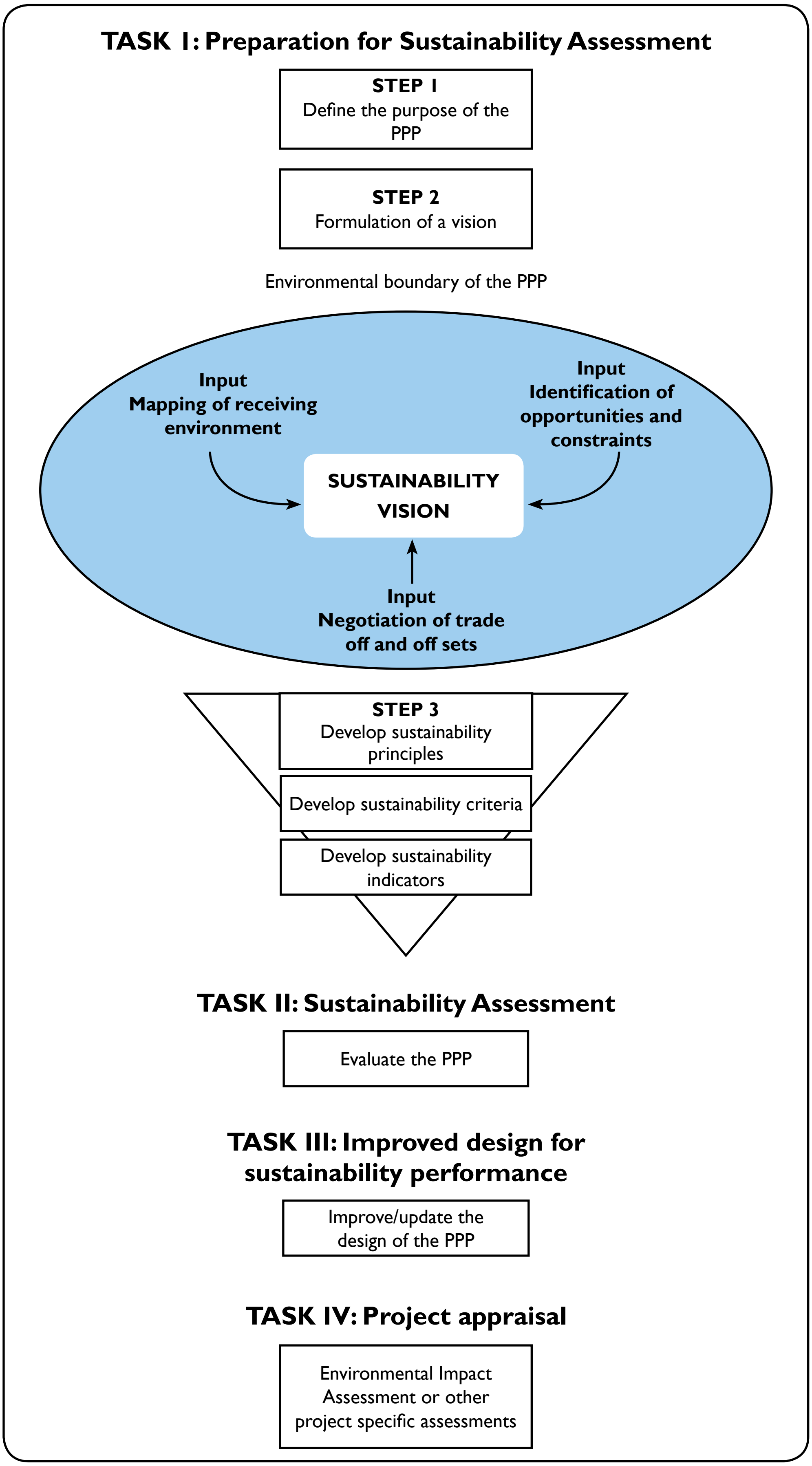

Figure 2.2: **Sustainability Assessment framework for planning for sustainability**

- Planning for sustainability for the proposed biofuel PPP (preparation for Sustainability Assessment).
- Sustainability Assessment for the proposed biofuel PPP.
- Redesign or modification of the proposed PPP to improve sustainability performance.
- Project appraisal (if required, e.g. EIA mandated by legislation).

The preparatory task (Task I: Planning for Sustainability) forms the foundation for assessments or further work in subsequent tasks (II – IV) and must always precede any work being done as part of these tasks in the process. Any assessment conducted without this foundation will not deliver a biofuel development PPP with sustainability as its focus, but merely one in which the prevention, tradeoff and mitigation of potential environmental (social, economic and ecological) impacts might have been identified and addressed.

The preparatory task (Task I) provides the context for all subsequent decisions regarding the PPP i.e. the sustainability principles and criteria to be used to guide decision making in formulating or improving the proposed or existing PPP. It ensures alignment with the sustainability vision, as agreed upon by stakeholders at the outset. It is possible that a single Sustainability Assessment conducted on a biofuel policy or plan, programme or strategy, could provide the context for several project level decisions, all subject to a common set of sustainability principles and criteria. Pope et al. (2004) assert that the primary purpose of Sustainability Assessment of specific development projects is to improve the development proposal from a sustainability perspective, before any detailed appraisal takes place. The same applies to the improvement of a proposed development plan (or programme or strategy) or policy.

2.5.2 TASK I: Planning for sustainability for proposed PPP for biofuels development (Preparation for Sustainability Assessment)

STEP 1: *Defining the purpose of the PPP and understanding the focus of analysis*

It is a critically important step for proponents of biofuel development PPPs, and their key stakeholders such as investors and relevant government officials, to define precisely what they want to achieve via the particular PPP for biofuel development. Expressed in another way: what need is the proposed PPP intended to satisfy? The intended purpose of the PPP will determine the corresponding sustainability issues and they will differ from one initiative and context to the next. The identified purpose of the PPP provides the platform for discussion on formulating the vision for the PPP for biofuel development. After the visioning process and interaction with an extended stakeholder group, it is possible that the purpose of the biofuel PPP may need to be revisited so that the purpose and vision are aligned.

STEP 2: *Formulating a vision of the PPP*

The vision must be formulated in an intensive deliberative process in which all relevant stakeholders participate, which could range from the local land chief or land owners, to government officials. Relevant stakeholders must be identified in relation to the intended purpose of the PPP for biofuels development and the context within which it is proposed to be developed. The search for relevant stakeholders should be broad based and comprehensive to ensure that there is sufficient encounter of, and opportunity for, integration of different worldviews and sources and forms of knowledge, into visioning.

The rules of engagement and for the conduct of both the planning process and the Sustainability Assessment (i.e. for the whole process of planning for sustainability), must be presented to all participating stakeholders at this point i.e. at the start of the process. Agreement (consensus) must be reached between all stakeholders on the rules, as they will guide all further work in planning for sustainability of the proposed PPP for biofuel development.

Visioning is a process of defining the 'desired end state' for a specific social-ecological system from a sustainability perspective, should the proposed PPP for biofuel development be implemented. If a common vision for biofuel development cannot be created amongst the stakeholders and there is no consensus on the vision, then this is where the Sustainability Assessment process stops. The PPP for biofuel development may thus not be appropriate for the specific area or regional / national context, and the desired state of sustainability will not be achieved. The proponent may need to reassess and reconceptualise the intended purpose of the PPP (return to Step 1).

There are three main inputs to be used in formulating the vision, these include:

Input: *Mapping the receiving social ecological system / context*

Formulating a vision for the area or context, in which it is proposed that a biofuels development PPP will be implemented, requires knowledge and understanding of the context and/or social ecological system into which the PPP will be introduced.

Mapping the social-ecological system entails describing and characterising in detail, the baseline status quo of the specific social ecological system / context within which the PPP for biofuel development is proposed. The outcome of this task should be a comprehensive description ('map'[4]) of the receiving social ecological system or context in which the biofuels PPP is to be implemented; and all internal and external influences on it. At the level of a proposed biofuels development policy, the social ecological system could be the interacting natural and social components of an entire country. The analysis should be expected to be conducted in a more abstract sense. In the case of a plan or programme, the social-ecological system could be limited to a specific catchment or geographic region, or to the social-ecological systems in a range of different non-contiguous geographical regions / locations, or a specific vegetation or ecological zone. At the level of a biofuels development project, the social-ecological system will likely be primarily bounded by the immediate environment in which the project would be situated. The analysis should be expected to be less abstract and based more on direct empiricism.

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[4] The map referred to here is not limited to a spatial representation of the social ecological system but is a full description taking many forms, of the social ecological system. It means being able to accurately and comprehensively describe all the social-ecological and economic components, characteristics and relationships between components, which make up an environment within which a potential biofuels development is intended to take place. This description may include narrative, spatial and non-spatial data, and other forms of information.

Specialists/scientists/experts within the Sustainability Assessment team will be required to verify and obtain relevant information on the following:

- Current state of the environment (social, ecological, economic and the status of the links between them);
- Legal and institutional background of the local area, region, country;
- Drivers of change in the social ecological system (e.g. specific economic development policies);
- Trends in changes in the social ecological system (e.g. year on year deterioration of water quality in a catchment); and
- Future development scenarios and/or actual proposals (e.g. catchment development plans that include several other land use changes and other developments, to enable the consideration of cumulative effects or conflicts and competition for ecosystem services).

The information will provide baseline values and trends against which to assess the sustainability performance of the PPP for biofuel development. Mapping the social- ecological system / context will require that the Sustainability Assessment practitioner works in collaboration with the stakeholders to determine the drivers of change in the social ecological system, trends and changes, and future development scenarios in the specific area or related to the context for which a biofuels development policy is being proposed.

Input: *Identifying and characterising opportunities and constraints that the social-ecological system / context presents for the PPP for biofuel development*

The purpose of this analysis is to identify characteristics of the social-ecological system or context that provide opportunities for achieving a sustainability vision for the PPP for biofuel development, and characteristics that would constrain achieving the vision. The analysis should again be conducted in a process of deliberation with all stakeholders. Where possible the opportunities and constraints should be captured and illustrated visually, and in combination, to assist in determining the potential for the implementation of the PPP for biofuels development, i.e. whether the vision is realistic and achievable.

Input: *Negotiating tradeoffs for realisation of vision*

In the conventional practice of environmental assessment, tradeoffs are often made between ecological, social and economic components of the environment i.e. natural, social and economic capitals are considered to be substitutable. This framework focuses on planning for sustainability from the outset, and the focus of the enquiry is planning for the continued maintenance of resilience of complex social-ecological (including political / institutional) systems within which biofuels development is proposed. This means that not only are the individual social, ecological and economic components considered in the analysis, but the relationships between them, and the issues and properties emerging from their interaction, are vitally important in the analysis. It can therefore be very difficult to meaningfully tradeoff any single component or element of a complex social-ecological system or context, against any other.

However, tradeoffs can be made at this point in the preparation for the Sustainability Assessment, bound by the requirements of the sustainability vision already formulated and agreed, and the realities evident in the social ecological system or context. The discussion on tradeoffs should again be broadly participative. Underlying the achievement of the vision will be the maintenance of the integrity of the components of the social-ecological system or context and relationships between them. Tradeoffs for achievement of the vision will therefore embody implicit tradeoffs between certain components of the social-ecological system – inevitably incorporating some sacrifice/loss in the social ecological system. The tradeoff rules (See Box 2.1) in planning for sustainability should be strictly applied, since making tradeoffs should only be used as a last resort option once all other avenues have been exhausted. Tradeoffs made at this stage in process of planning for sustainability cannot be amended later in the process.

Box 2.1: **Basic sustainability assessment tradeoff rules (Gibson 2006)**

Maximum net gains
Any acceptable tradeoff or set of tradeoffs must deliver net progress towards meeting the requirements for sustainability; it must seek mutually reinforcing, cumulative and lasting contributions and must favour achievements of the most positive feasible overall results, while avoiding significant adverse effects.

Burden of argument on tradeoff proponent
Trade off compromises that involve acceptance of adverse effects in sustainability-related areas are undesirable unless proven (or reasonably established) otherwise; the burden of justification falls on the proponent of the tradeoff.

Avoidance of significant adverse effects
No trade off that involves a significant adverse effect on any sustainability requirement area (for example, any effect that might undermine the integrity of a viable social-ecological system) can be justified unless the alternative is acceptance of an even more significant effect.

Protection of the future
No displacement of a significant adverse effect from the present to the future can be justified unless the alternative is displacement of an even more significant negative effect from the present to the future.

Explicit justification
All tradeoffs must be accompanied by an explicit justification based on openly identified, context specific priorities as well as the sustainability decision criteria and the general tradeoff rules.

Open process
Proposed compromises and tradeoffs must be addressed and justified through processes that include open and effective involvement of all stakeholders.

STEP 3: Development of sustainability principles, criteria and indicators

The sustainability vision must be translated into a more practical and case specific form through the drafting of a number of context specific sustainability principles (refer to Box 2.2 for definition). Each PPP would need to be revised and adapted appropriately according to sustainability principles that are context specific to the PPP and the relevant social ecological system. These principles are a set of benchmarks ('minimum requirements') to determine expected sustainability performance of the proposed PPP for biofuels development.

Box 2.2: **Definitions of sustainability terms used in the framework**

Sustainability Principle: Broad based statement for achieving a sustainability vision. A principle is a fundamental truth or law as the basis for reasoning.

Sustainability Criteria: The management objectives that are set in order to achieve the broad goals set out in the principles (equivalent to minimum requirements or benchmarks).

Sustainability Indicator[5]**:** A measure that shows whether a criterion is being met or not.

The sustainability principles may be qualitative or quantitative but, in both cases, there will be a threshold below or above which sustainability will either have been achieved or not against the relevant criteria.

Sustainability criteria must be developed for each sustainability principle. Sustainability criteria are the essential elements that must be present, and which will show whether the sustainability principles have been achieved or not and consequently whether the sustainability performance of the proposed PPP for biofuels development is satisfactory. To add depth and integrity to the assessment to follow, the criteria should address global, national and local level issues. All the sustainability criteria that have been set must be satisfied to ensure that the sustainability principles and vision will be achieved in the implementation of the proposed PPP for biofuels development. No tradeoffs can be made between criteria when the PPP is evaluated, since this would mean that some of the sustainability principles would not be adhered to. This would mean that planning for sustainability of the proposed PPP would have failed.

Practical, meaningful and measurable indicators should be identified for each of the criteria, so that it is possible to measure whether individual sustainability criteria have been met or not. Indicators may be qualitative or quantitative in response to the specific criterion. These indicators will form a critical component of Task II.

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[5] Our definition of indicator assumes that a defined level or target is specified against which projects can be assessed. It needs to be explicit, but could be either quantitative or qualitative, so that there is no ambiguity as to if there is compliance or not. The indicator, therefore, includes what are sometimes referred to as standards or verifiers.

Examples of sustainability principles, criteria and indicators (PCI) in corresponding to the three drivers of sustainability in biofuel production, are given in Table 2.1. The PCIs examples have been drawn and adapted from the Sustainable Sugarcane Farm Management System[6], the Roundtable for Sustainable Biofuel Global Principles and Criteria Version 1[7]. These PCIs are examples developed by the authors to illustrate the concept and give more insight to the reader. They are based on the common sustainability challenges as discussed in this chapter and illustrate the type of PCIs that could come out of a participatory process. Since the PCIs presented in the table are mere examples they are not specific to a policy, plan or project, and may apply in one instance at a policy level and in another instance at project level. Specific indicators cannot be provided as they are context specific but, where possible, broad based indicators are suggested. The generic principles and criteria are intended to form the basis

Table 2.1: **Examples of sustainability principles, criteria and indicators** (Note: these were developed by the authors for illustrative purposes only and should be fully reworked or created from new through a participative process before being considered for any policy, program or project specific application)

Driver for sustainability in biofuels development: Improved rural and social economic development		
Sustainability Principles	**Sustainability Criteria**	**Sustainability Indicators**
Food security Biofuel production shall not impair food security	Biofuel producers implementing new large-scale projects shall assess the status of local food security and shall not replace staple crops if there are indications of local food insecurity	Local food production stays constant or increases
	Biofuel production shall minimize negative impacts on food security by giving particular preference to waste and residues as input (once economically viable), to degraded/marginal/underutilized land as sources, and to yield improvements that maintain existing food supplies	No biofuel crops are grown on good quality agricultural land
Land rights Biofuel production shall not violate land rights	Land use rights for the land earmarked for the biofuel production shall be clearly defined and established, and not be legitimately contested by local communities with demonstrable rights, whether formal or customary	Compliance with Land Reform Act
	Local people shall be fairly and equitably compensated for any agreed land acquisitions and relinquishments of rights. Free prior and informed consent and negotiated agreements shall always be applied in such cases	Proof of free and informed community consultation Land compensation based on Nett Present Value of agricultural production over 50 years
Human rights Biofuel production shall not violate human rights or labour rights, and shall ensure decent work and the well-being of workers	Workers will enjoy freedom of association, the right to organise, and the right to collectively bargain	Process in place to report any violations.
	No slave labour or forced labour shall occur	Salary scales meet or exceed national benchmarks
	No child labour shall occur, except on family farms and then only when work does not interfere with the child's schooling	Zero child labour except on family farms
	A working environment that is safe and without risk to the health of employees is provided and maintained	Farmers comply with legislation dealing with occupational health and safety

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[6] http://www.srdc.gov.au/pages.aspx?id=6

[7] http://energycenter.epfl.ch/page84341.html

Driver for sustainability in biofuels development: Land use is appropriate for maximising resilience against adverse environmental change		
Ecosystems Natural assets are conserved, critical ecosystems services are maintained and agricultural resources are sustainably used	Biodiversity assets and threatened ecosystems are conserved	No projects on identified threatened sites / sensitive ecosystems
	Critical ecosystem services and processes are maintained and protected	Critical ecosystems services and processes are identified and plans for their maintenance and conservation such as the creation of buffer zones and ecological corridors are included in a Land Use Plan
	Buffer zones shall be protected or created	
	Ecological corridors shall be protected or restored	
Soil Biofuel production shall promote practices that seek to improve soil health and minimize degradation	Soil organic matter content shall be maintained at or enhanced to its optimal level under local conditions	Soil organic matter content is maintained at or enhanced to its optimal level under local conditions.
	The physical, chemical, and biological health of the soil shall be maintained at or enhanced to its optimal level under local conditions	The physical, chemical, and biological health of the soil is maintained at or enhanced to its optimal level under local conditions
	Wastes and by products from processing units shall be managed such that soil health is not damaged	Wastes and by products from processing units are managed such that soil health is not damaged
Water Biofuel production shall optimize surface and groundwater resource use, including minimizing contamination or depletion of these resources, and shall not violate existing formal and customary water rights	There shall be no depletion of surface or groundwater resources	Biofuel production includes a water management plan appropriate to the scale and intensity of production
	The quality of surface and groundwater resources shall be maintained at or enhanced to their optimal level under local conditions	Water quality is maintained at optimal levels and is regularly monitored
Air Air pollution from biofuel production and processing shall be minimized along the value chain	Air pollution from agrochemicals, biofuel processing units, and machinery shall be minimized	Air quality is maintained at optimal levels and is regularly monitored
	Open-air burning shall be avoided in biofuel production	
Greenhouse gases Biofuels shall contribute to climate change mitigation by significantly reducing GHG emissions as compared to fossil fuels	Producers and processors shall reduce GHG emissions from biofuel production over time	Life cycle assessments are conducted to highlight the GHG reduction potential
	Land conversion of carbon rich vegetation for feedstock must not have a negative carbon sink in comparison	Better performance than IPCC default values can be proven through models or field experiments
Driver for sustainability in biofuels development: Energy security is enhanced thereby providing economic stability to the country		
Economically viable feedstock production is maintained or enhanced	The agronomic and mechanisation practices of the particular feedstock are integrated with the climate, soils, water availability and topography to obtain an optimum and sustained economic crop production	A land use plan that promotes sustainable biofuel production exists
Biofuels shall be produced in the most cost-effective way. The use of technology must improve production efficiency and social and environmental performance in all stages of the biofuel value chain	Biofuel projects shall implement a business plan that reflects a commitment to economic viability	A business plan that shows commitment to economic viability is in place
Governments take measures to ensure an equitable field for small scale farmers	Government includes equity principles for small scale farmers in biofuels strategy	A national biofuel strategy is in place which provides for small scale farmers

of further discussion and customisation in the context of particular PPPs i.e. the principles and criteria here are given as a guide and would need to be customised within the context of a particular social ecological system within which a PPP is proposed.

2.5.3 Task II: Sustainability Assessment

Evaluation of the sustainability performance of the PPP

The PPP for proposed biofuel development must now be evaluated for its sustainability performance against the sustainability principles, and whether it satisfies the sustainability criteria, using the sustainability indicators as the measures of success in meeting the criteria. This evaluation constitutes an integrated assessment for sustainability and will determine whether the sustainability performance of the PPP is acceptable as it stands or whether the PPP should be reconceptualised, redesigned or redrafted to improve its sustainability performance. If no improvement can be made to the PPP from a sustainability perspective, then alternative scenarios for achieving sustainability which are consistent with the vision and sustainability goals, other than the particular PPP for biofuels development, may need to be considered and evaluated. This process of evaluation is again, a deliberative participative process with all stakeholders.

It is required, in the Sustainability Assessment process, to pay attention to integration from several perspectives (Lee 2002; Sadler and Dalal-Clayton 2004; Pope et al. 2004), viz.

- Vertical integration in the planning process e.g. the vision and principles set in the preparation phase for the sustainability assessment (see Steps 2 and 3 above) must be consistent with/ correspond to those applied at later levels (e.g. project level EIA). For example, if a sustainability assessment is conducted on a policy or plan/strategy for biofuel development in a specific region, then any subsequent proposal for a biofuel development project should at least be evaluated according to the original vision and goals set in the original policy or plan/strategy. Should this not be done, then the likelihood of achieving sustainability according to the vision and/or the principles will be significantly compromised.
- Horizontal integration between sustainability principles;
- Scale integration (global, national, local);
- Temporal integration (the 'now' and 'then' issue – short, medium and long term future).

2.5.4 Task III: Revisit proposed PPP to improve sustainability performance

Improve / update design of PPP for sustainability performance

Based on the evaluation of the sustainability performance of the PPP for biofuels development, the design and specifications of the proposed PPP may need to be revisited. The purpose of this step is to improve as far as possible the sustainability performance of the proposed PPP i.e. to ensure that the sustainability vision and principles are met and the sustainability criteria are achieved, without any tradeoffs being made between sustainability criteria. Once there is agreement amongst all stakeholders that the proposed PPP for biofuel development has met all the sustainability criteria, the PPP can be implemented. In the case of a proposed biofuels development project, further detailed analysis can ensue (See Task IV: Project Appraisal). For proposed biofuels development projects, it will more than likely be necessary to proceed to project appraisal (conventional assessment), probably required by environmental and development planning legislation.

2.5.5 Task IV: Project Appraisal

Environmental Impact Assessment

Proposed projects for biofuel development will have to be subjected to further detailed environmental assessment e.g. mandatory Environmental Impact Assessment if this is required by law.

Sustainability Assessment should ideally be linked to an ongoing process of monitoring and evaluating change in the environment. Ideally the same indicators proposed in the assessment should be measured on the ground, though in practice this might prove to be difficult, and indicators from processes such as State of the Environment and other ongoing national monitoring frameworks might have to suffice.

2.6 Experiences and Reviewing

Testing and refining the framework is an ongoing and iterative process and, as new insights are gained, these may be used to improve the framework and enhance the tools available to support it. Since RE-Impact projects were not linked to direct project implementation, piloting of this framework was difficult under the project. However, the potential utility of the framework was tested with partners in South Africa, China, India and Uganda. Some overarching differences in the ability to use the tool in different country situations have emerged. Elghali et al. (2007) provide an example of a similar approach applied in the UK.

It is clear that the ability to embrace participatory planning processes differs significantly between countries. In both South Africa and India there is a strong ethic of early and broad based participation during project and programme planning. Introducing a tool of this nature, therefore, fits in with the existing ethos of development planning in these two countries. Stakeholders understand well the process of debating developments before these are implemented and appreciate early inclusion in project planning, accepting that details and issues will emerge and be worked through during the ongoing process.

In China the current paradigm of development planning is based on a process of first assimilating information and development of a sound proposal. This activity is typically done in a relatively autocratic and state led fashion. Chinese government agencies are making a slow transition from policymaking, based on pilot projects and dual track implementation, toward more evidence-based decision-making that draws on qualitative or quantitative policy research. Environmental indicators have only recently gained greater currency. The Chinese government has already developed strict criteria for first generation biofuels, which effectively culled the ethanol industry. The autocratic Chinese approach leads to great efficiency in the planning and project implementation, but could easily lead to unsustainable practices. This type of planning is unlikely to consider some of the environmental or social consequences due to the narrow level of consultation and inputs into the planning process. For instance in Yunnan province the government was able to re-afforest vast areas over a very short time but long term management and the linking of the forests to local livelihood needs has received limited consideration. Introducing the planning for sustainability framework into a country such as China will be far more challenging than introducing it into South Africa or India, and may require some customisation of the process. For example, the participation of interested and affected parties or stakeholders in the early phases of planning will largely take the form of data gathering through one-on-one interviews rather than true broad based multi-stakeholder consultation. If broad based consultation can be included it is likely to be only once plans have been well developed; and more directly focused on the project under consideration rather than more general land use planning.

India has made a strong commitment to participation in policy formulation and project planning. Vested interests and power relations often tend to lead to participation being passive rather than active, however, since the requirements for participation are poorly defined. Despite this, and unlike in China, the introduction of a Sustainability Assessment process as defined in this chapter would fit the Indian ethos of development planning. India has a Federal structure where national policies are implemented by State governments. Moving from the generic national biofuels policy to state level policy and situation specific plans could be facilitated by a tool such as the Sustainability Assessment. The national policy already contains some sustainability principles such as restricting biofuel feedstock production to non-food producing lands. At the state level there is a need to adapt the national policy so as to fit in with state level contexts, aspirations and concerns. For instance dealing with customary land rights might be a critically important implementation issue not covered in the national strategy. Clearly at the local level a key priority is poverty alleviation and access to basic services. The Sustainability Assessment would need to both embrace the development priorities as well as provide checks and balances to reduce the risk of long term unsustainable practice. Unfortunately the national biofuel policy makes no provision for overall sustainability, with sustainability being used only in a more narrow sense such as when referring to sustained feedstock production. There are, however, many uncertainties as to how a framework of this nature could be implemented, and who would take responsibility for that process in the Indian context. Since Sustainability Assessment is not legislated, it is not clear how it would be funded or who would be responsible for implementation. Ideally the framework should be integrated into standard planning procedures, and the Planning Commission could potentially play a role in facilitating this, although they have no long term involvement after policy is formulated. This may make them a poor long term home for sustainably planning where monitoring and evaluation processes exceed the planning lifespan. Alternatively the framework could potentially be linked to the Ministry of Environment and Forests which is already responsible for administering Environmental Impact Assessments. Linking sustainability to an environmental ministry does, however, run the risk of downplaying the importance of social, economic and institutional aspects of sustainability, and in this regard other ministries such as those for social justice, rural development and finance, would also need to be actively involved in the implementation and monitoring of the Sustainability Assessment framework.

Uganda and many other African countries probably fit between the two extremes above. Although the administrations of these countries are relatively autocratic, foreign aid has been forcing a move towards more participatory practices. Herein lies a key challenge to Sustainability Assessment, and that is how to integrate it into a landscape where there are already a number of other participatory processes and consultation requirements. Within this are two underlying problems, firstly the need for an institutional housing for Sustainability Assessmen and secondly the need for coordination between different planning processes, both within the environmental field and with other aspects of development. Furthermore there is a need to integrate principles and criteria emerging from sustainability planning with principles and criteria used in other spheres of environmental management in biofuels development.

A key concern about the planning for sustainability framework presented in this chapter is that it is fairly generic, and more specific guidance might be required. This however, is a key difference of a process based approach versus a technical approach. Whilst greater detail in methodology will obviously emerge over time, it is adherence to an overarching process rather than specific steps that is considered most important. The process should not be prescriptive in its detail, rather only in a few overarching issues such as the need for transparent and accessible consultation.

2.7 Concluding Remarks

Bioenergy, particularly in the European Union, is being promoted largely around issues of sustainability. It is seen as a partial solution to the growing levels of greenhouse gas emissions from the large amounts of fossil fuel being used to meet society's energy needs. Biofuels in particular are gaining a lot of interest as the transportation industry is a major carbon emitter. In addition, biofuel feedstock production has the potential to enhance rural development by providing new markets for agricultural and forestry commodities. Despite these potential positive benefits, biofuel expansion carries the threat of a number of possible negative consequences in both the socio-economic and ecological domains. Even the anticipated greenhouse gas benefits are not guaranteed under many scenarios.

Although modern interest in bioenergy emerged largely out of developed countries' concerns around fuel self sufficiency and global green house gas emissions, it is in developing countries where some of the most rapid expansion of biofuel feedstock plantations is taking place. Developing countries have a number of unique sustainability concerns relating to biofuel expansion, especially as much of the pressure for biofuels comes from outside the countries concerned. Poverty, food insecurity and underdevelopment leads to a situation where potential development options such as biofuels can be hastily accepted without due concern to long term sustainability. Environmental issues such as the extensive biodiversity typically found in developing countries or downstream hydrological impacts, can easily be overlooked in the enthusiasm to adopt new and potentially lucrative technologies. Social aspects such as tenure rights are also easily ignored. Biofuels by their nature require large plantations of feedstock. This therefore requires high levels of land use modification with an associated social and ecological consequence, which is typically a combination of both positive and negative impacts. Many impacts may be secondary, unintentional or as a result of complex feedback loops within or between the social and environmental components of the coupled social-ecological system.

Sustainability science is a new and developing science aimed at increasing sustainability in such coupled social-ecological systems. It is based on a systems approach that recognises the need to consider the system in an integrated manner where the social, the economic, the institutional or the ecosystem components can be considered in isolation. Experience from EIA and SEA has been a key driver for Sustainability Assessment, which builds on these approaches but also attempts to address many of their inadequacies. An aspect common to all three approaches is the fundamental requirement for extensive stakeholder involvement and participation, and the use of a broad stakeholder base to set the parameters of the assessment and ensure transparency.

The Sustainability Assessment approach presented here has strong roots in objectives-led SEA, with a key difference being that it is designed specifically to assess sustainability in its totality, rather than a more narrow focus on environmental issues. It is an emerging approach and will likely undergo refinement in the future, and eventually be replaced by new approaches as the science of sustainability matures. This is in keeping with an adaptive management philosophy. The approach takes a strongly anthropocentric view to sustainable development. It also assumes that the overall resilience of the system, and ensuring that it can adapt into the future, is important. As such the core of the entire process is the development of a long term vision that is agreeable to all key stakeholders. The vision is then underpinned by specific principles which are further described through criteria, indicators and minimum measures for the indicators which must not be exceeded. A key point is that all measures must be achieved for a development to be sustainable. Tradeoffs need to be made when defining the measures, i.e. a decision needs to be made upfront as to what is an acceptable change in any variable. If the standard for acceptable change is too high this will hamper the rate of development, but if too low then it could lead to the collapse of the system. A key feature of the framework is that the tradeoffs are defined up front and not in relation to a specific project proposal. When a bioenergy project proposal is reviewed against the Sustainability Assessment framework, it is only considered sustainable if it meets all the minimum requirements in the form of sustainability criteria.

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Chapter 3
Assessing Hydrological Impacts of Tree-based Bioenergy Feedstock

Mark Gush

3.1 Introduction

This chapter provides a methodology for assessing the hydrological impacts of tree-based bioenergy feedstock. Based on experience gained in South Africa, it discusses the tasks required to reach an understanding of the likely water resource impacts associated with the development of a tree-based bioenergy industry, from individual tree water use rates to national-scale impacts on water resources. It is intended to be a generic methodology not just for South Africa but with more general applicability to tree-based bioenergy developments worldwide. Why is such a methodology important? Firstly, because large-scale changes in land-use (e.g. changes from existing vegetation to future bioenergy feedstock plantations) constitute a change in plant species, and consequently a change in the structure and functioning of the vegetation growing on the land. This has implications in terms of how different vegetation types use water, and how changing patterns and amounts of water-use impact the availability of water in rivers, and the resultant downstream users of that water. Secondly, there may be legal requirements specific to a particular country for determining the water resource impacts of a proposed future land-use. Finally, the growing importance of sustainable, integrated water resource management is acknowledged globally, and proven methods that strive towards this end, through the quantification of land-use driven water resources impacts, are increasingly required.

3.2 Streamflow Reductions

When considering the implications of different vegetative land-use types on water resources in general, and streamflow in particular, it is useful to refer to the concepts of 'blue' and 'green' water (Falkenmark et al. 1999). 'Green water' generally represents water supplied by rainfall that is lost from a system (e.g. a catchment area) in gaseous form (evapotranspiration), while 'blue water' represents water losses in liquid form (streamflow and groundwater recharge). One caveat is that evapotranspiration only equates to 'green water' use if no irrigation takes place. If crops or trees are irrigated then a component of 'blue water' is incorporated in evapotranspiration amounts, the use of which is dependent upon evaporative demand and the availability of adequate green water for the plant. More recently, the concepts of 'virtual water' (Allan 1998) and the 'water footprint' of a crop or nation (Hoekstra and Hung 2002) have gained popularity, accounting for all forms of water-use that contribute to the production of goods and services associated with a particular crop. Evapotranspiration of that crop is usually the single greatest contributor to its 'water footprint'. This terminology consequently emphasises the importance of evaporative (water-use) losses from land surfaces, particularly in dry countries such as South Africa, where evapotranspiration from vegetation accounts for the greatest loss of water from catchments. Accurate estimates of 'green water'-use are therefore fundamental for gaining a good understanding of the hydrological impacts of a specific plant species or vegetation type. Where large-scale changes in vegetation cover are proposed, this aspect becomes particularly important because the differences in evapotranspiration ('green water' use) between the current and the proposed vegetation ultimately translate into changes in available streamflow ('blue water') from that catchment. Stream-flow changes associated with vegetative land-use changes may consequently be calculated using a simplified water balance equation, namely:

$$Q = P - Et$$

where Q = streamflow, P = precipitation and Et = evapotranspiration. This simplified version of the equation is best applied over a suitably long time period (e.g. several years), where changes in soil water storage / ground water levels are likely to balance out, and longer term climate change impacts will not be detectable. A change in Et (caused by a change from the natural vegetation to a bioenergy feedstock plantation for example) will consequently equate to a change in stream-flow from that catchment or hydrological response unit (HRU) (Figure 3.1). Consequently, large-scale changes in land use could have significant hydrological implications if the water use of the introduced species were significantly different to that of the vegetation it would replace.

3.3 Legislative Framework

In South Africa, a robust and scientifically defendable methodology for assessing the hydrological impacts of land-use/vegetation changes is a legal requirement, established in the Water Act of 1998 (NWA 1998). Section 36 of the Act calls for a means of assessing whether an activity (in this case the establishment and growth of bioenergy feedstock) would constitute a "Streamflow Reduction Activity" (SFRA). The Act defines a SFRA as any activity "that is likely to reduce the availability of water in a watercourse to the Reserve[8], to meet international obligations, or to other water users significantly."

By means of clarification, in section 36 the Act states that: "in making a decision [about declaring an SFRA] the Minister must consider:

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[8] The "Reserve" refers to both a Basic Human Needs Reserve and an Ecological Reserve. The former requires sufficient water to be present in rivers and streams to meet basic human needs such as for drinking, food preparation, health and hygiene. The Ecological Reserve refers to the quantity and quality of the water, required to maintain the resource in an ecologically healthy condition, and needs to be determined for all or part of any significant water resource such as rivers, streams, wetlands, lakes, estuaries and groundwater.

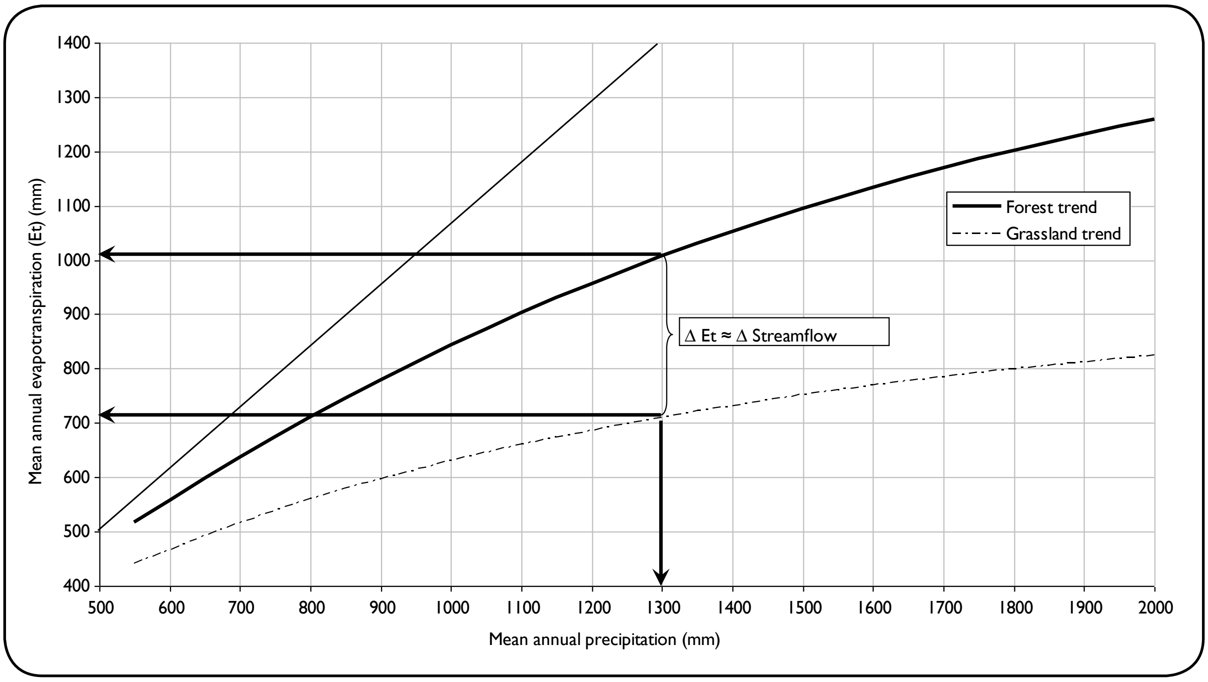


Figure 3.1: **The relationship between (MAP) mean annual precipitation and (MAE) mean annual evapotranspiration (Et) for different vegetation types. Lines indicate the global trends in mean annual evapotranspiration (MAP) from forested and grassland catchments (after Zhang et al. 1999). The effect on streamflow of differences in Et between grassland and forest sites for a given MAP are illustrated.**

a) The extent to which the activity significantly reduces the water availability in the watercourse;
b) The effect of stream flow reduction on the water resource in terms of its class and the Reserve;
c) The probable duration of the activity;
d) Any national water resource strategy;
e) Any catchment management strategy".

Implicit in the above explanation is the need to understand if a proposed activity (e.g. bioenergy plantation) will result in the consumptive use of water over and above what would be used by the "baseline" (natural) vegetation, thereby confirming it to be a streamflow reduction activity. The baseline vegetation represents the naturally occurring vegetation of the area of interest, and is used as reference against which all changes in land-use are assessed in terms of water-use impacts. The decision on whether a replacement land-use will constitute a streamflow reduction activity or not consequently requires knowledge of the water-use (evapotranspiration) of both the natural vegetation and the replacement vegetation. Importantly, the South African government (Dept. of Water Affairs) opposes irrigation of biofuel feedstock due to water and food security concerns, so water-use comparisons between rain-fed baseline vegetation types and replacement bioenergy crops (rain-fed) are valid.

This legal requirement to understand if a potential land-use change constitutes a streamflow reduction activity or not, is uniquely incorporated in South Africa's water law. This law has been lauded and acknowledged internationally for its progressive approach to environmental sustainability and equity, and other countries are increasingly identifying the need for similarly robust mechanisms of assessing the water resource impacts of potential future land-use changes. The methodology developed to meet the requirements of South Africa's water law is similarly of relevance worldwide, as it has the potential to influence future policy and the sustainable management of water in any country faced with water resource management challenges.

3.4 Methodology

Methodologies for assessing the spatial water resource impacts of potential future land-uses (e.g. tree-based bioenergy feedstock) have been developed since the new Water Act of 1998 was passed in South Africa. While approaches may differ slightly based on specific needs or preferences, they all have a fundamentally similar goal, and all require the fulfilment of a number of pre-determined steps. The means of successfully completing each step will vary depending on certain criteria (e.g. choice of plant species, availability of data, preference of model to be used, scale and time-frame), and these aspects are discussed in more detail later. Nevertheless, in terms of a broad overview of the methodology, the following tasks are suggested for a comprehensive assessment:

- Identify the geographical area of interest.
- Select an appropriate hydrological response unit (HRU) to apply the assessment at, within the area of interest.
- Identify the "baseline" vegetation for each HRU across the area of interest.
- Select an appropriate hydrological model to use.
- Gather the necessary model input data for each HRU.
- Determine the length of the simulation period.
- Decide on the most appropriate way to represent changes in vegetation parameters associated with physical plant growth.
- Run the model to simulate streamflow and evapotranspiration under baseline and future land use scenarios.
- Analyse the data to determine potential changes in evapotranspiration (and the resultant impacts on streamflow) associated with the replacement land-use.
- Draw conclusions on the likely water resource impacts of the proposed land-use.

These steps have been graphically represented by Kruger et al. (2000) for a typical South African example (Figure 3.2), and are elaborated upon in the following sections.

3.4.1 Identifying the geographical area of interest

The geographical area of interest may range in scale from farm-level plantations, to regional areas, and up to national scale assessments. For local scale development of limited extent, where an environmental impact assessment is required, the suitability of the site for cultivating the species has usually already been established as part of a business plan. However at larger scales (regional to national), the area of interest may be defined as climatically suitable areas where the proposed bioenergy species may successfully be cultivated. Determining viable production areas requires knowledge of the bio-climatic requirements of the species. These usually take the form of marginal, adequate or optimum requirements in terms of rainfall (amounts and seasonality), temperature, relative humidity, soils, frost days, solar radiation, slope and aspect, amongst others. The availability of adequate (i.e. high temporal and spatial resolution) data on climatic conditions across the potential land area being assessed are thus an important requirement. This enables the bio-climatic requirements of the species to be matched with the actual bio-climatic

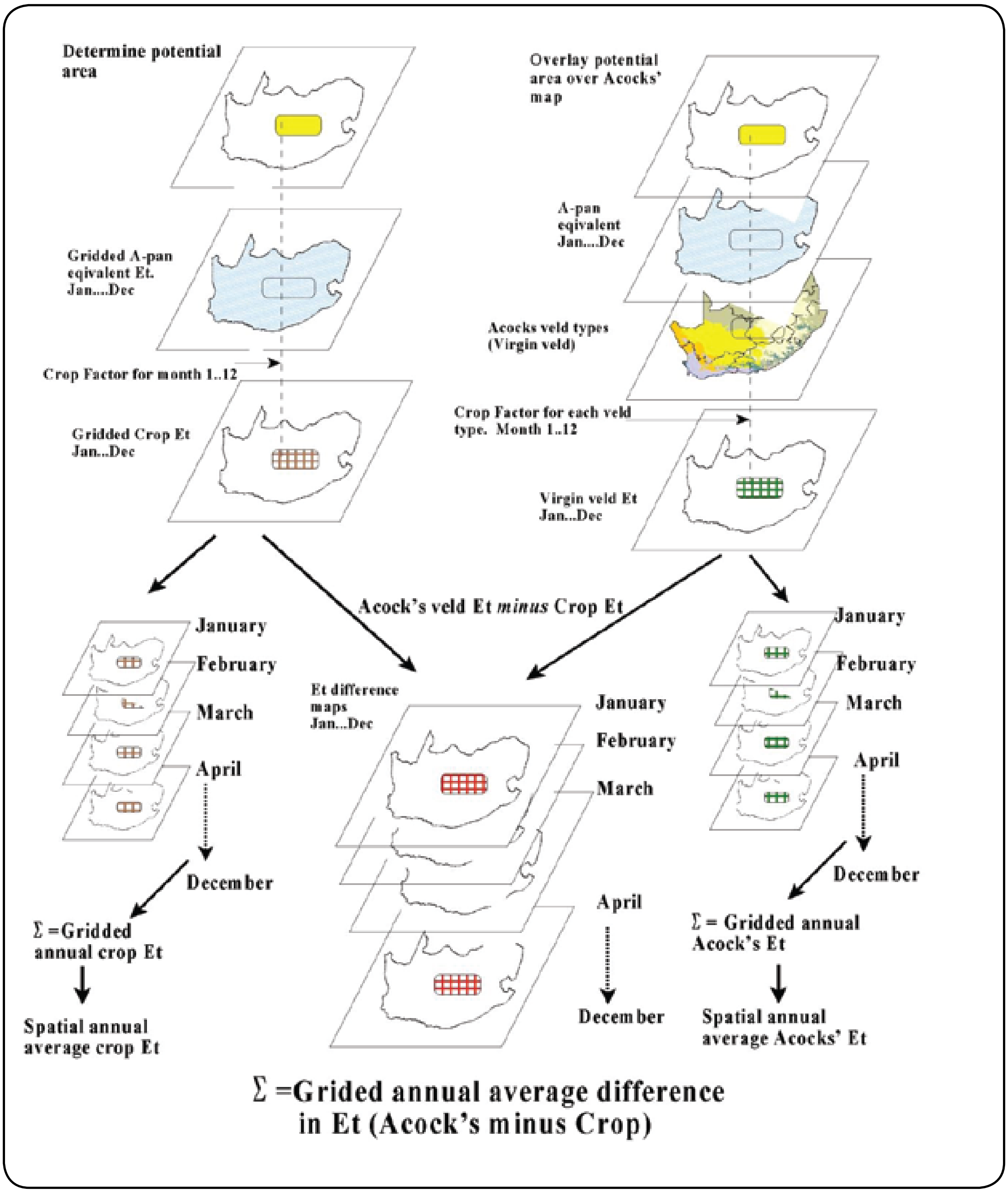


Figure 3.2: **Steps in the assessment of the potential water resource impacts of a proposed land-use by means of changes in evapotranspiration attributed to conversion of the "baseline" vegetation to a given crop across a geographical area of interest (after Kruger et al. 2000).**

conditions across the land, and areas suitable for cultivation may then be mapped. Consequently, the area of interest may initially be for the whole country (to ascertain where the species may successfully be cultivated), but is typically narrowed down to climatically (economically) viable areas only, using pre-determined cut-off values of the above bio-climatic variables. In terms of site quality, the sub-set of selected areas may then be classified as marginal, average or optimal growth areas, which also influence subsequent yield estimates.

3.4.2 Selecting an appropriate hydrological response unit

The scale at which hydrological impacts will be assessed (e.g. small scale / plantation size, or large-scale regional / national size) will determine the choice of an appropriate HRU. The more detailed the catchment and climate data available, the more detailed the water resource assessment that is possible (i.e. potential for using smaller HRUs). However the tradeoff between assessment detail (i.e. HRU scale) and computing / data analysis complexity needs to be borne in mind. Specific applications will have appropriate levels of detail. For national assessments, for example, the use of the Quaternary, and more recently the Quinary Catchment scale has been popular in South Africa, providing an adequate level of detail without undue complexity. Southern Africa has been delineated into 22 so-called Primary catchments (watersheds), and then subdivided into Secondary, Tertiary, Quaternary and now Quinary (Schulze and Horan 2007) sub-catchments. For each of these HRUs representative time-series of climatic variables (e.g. daily rainfall, reference potential evaporation, maximum and minimum temperature data), catchment attributes (e.g. area, mean altitude, MAP, latitude and longitude), soils attributes (e.g. type, texture and quality) and land cover attributes (e.g. vegetation characteristics) exist.

The development of these databases requires long-term investment and considerable research and extrapolation from observed data, but their existence greatly facilitates large-scale hydrological assessments. Southern African hydro-climatic databases have been developed/refined to the extent that wide-ranging and innovative agro-hydrological and water resources studies can now be undertaken (Schulze 2007). More regional or local-scale assessments may apply HRUs of smaller sizes, either relying on the existence of adequate observed data within each HRU or simply deriving the necessary data by means of downscaling from quinary catchment databases. Examples of the assessment of national scale hydrological impacts of commercial afforestation in South Africa are available at Quaternary (Gush et al. 2002) and Quinary (Jewitt et al. 2009) scales.

3.4.3 Identifying the baseline vegetation

The baseline vegetation type associated with each HRU represents the indigenous/ native vegetation that would have occurred in each HRU should the vegetation not have been anthropomorphically altered in any way. The determination of this baseline vegetation is critical for the assessment of streamflow impacts as it provides a platform for assessing any potential future land-use change. A number of aspects need to be considered when determining the baseline vegetation, such as which vegetation classification system is to be applied and whether data on the necessary input variables to represent the associated vegetation types are available. Assigning appropriate model input parameter values to vegetation types linked to a particular classification system is a significant task. Realistically it is only accomplished through a dedicated project, and is likely to be reliant on expert opinion; as observed vegetation parameters for all vegetation types represented in a particular classification system are unlikely to be available. Furthermore, verification studies of the resultant water-use rates are only likely to be available for a limited number of vegetation types. As vegetation classification systems are updated and become more spatially detailed so the challenge of assigning appropriate parameters to all vegetation types increases. The vegetation classification system that has been most extensively utilised in South Africa for hydrological modelling purposes is Acocks (1988), and representative model parameter values exist for all the vegetation types in this system. More recently, an updated and more detailed vegetation classification system for South Africa was produced by Mucina and Rutherford

(2006). However, vegetation characteristics appropriate for hydrological modelling purposes are not available for all the vegetation types in this latest classification system, so the earlier system of Acocks (1988) is generally utilised (Figure 3.3).

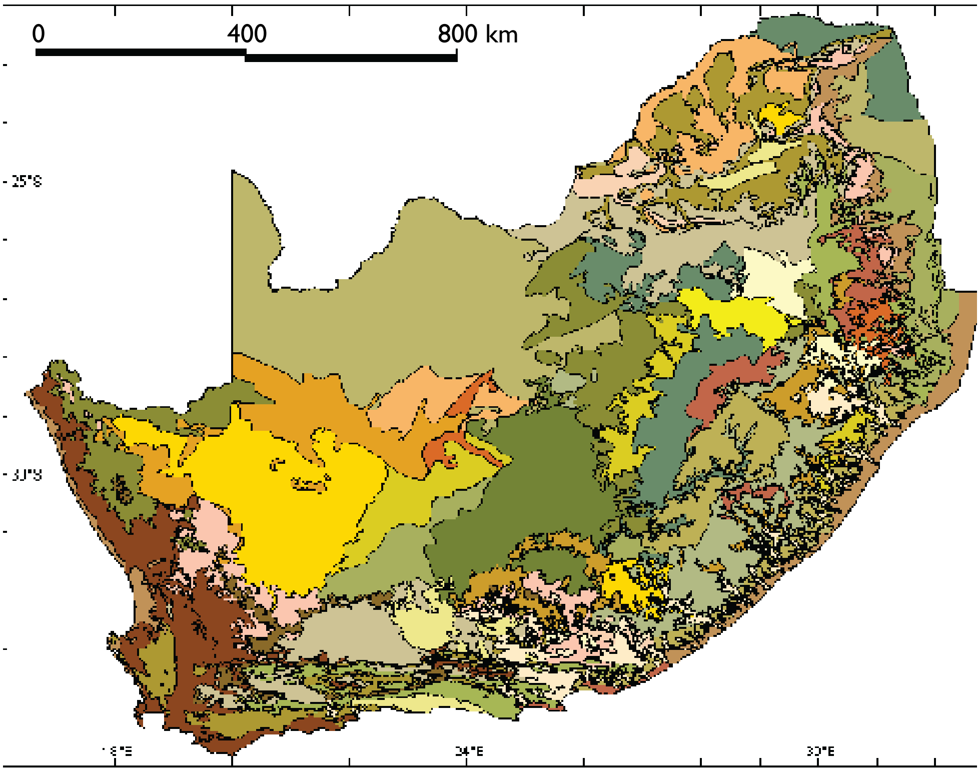
There is usually considerable uncertainty in the representativeness of the baseline vegetation type assigned to a particular HRU. This is a particular challenge when needing to assign a single spatially-representative type to large (e.g. quaternary catchment scale) HRUs. Inevitably, a pragmatic approach to the application of the baseline vegetation concept requires a certain degree of generalisation. An alternative approach, more suited to small scale assessments, is to utilise observed water-use (evapotranspiration) data for the predominant natural vegetation cover in the HRU, where such data is available. Examples of South African projects aimed at improving the prediction of evapotranspiration rates from natural vegetation types include Jarmain et al. (2004) and Dye et al. (2008). Either way, it is important that consensus be reached amongst stakeholders (see Chapter 2 for gaining stakeholder consensus in planning for sustainability) that the chosen vegetation types (and their associated model input data, and resultant water-use) are the best approximation/representation of the naturally occurring vegetation types within the HRU. The water-use of this vegetation is the basis by which the water resource impacts of future land-uses will be assessed.

3.4.4 Choice of model

The choice of an appropriate model to be used for the simulation of evapotranspiration and streamflow under baseline and future land-use scenarios is the next consideration. The choice of a particular model will depend upon a number of factors including: model availability, proven scientific credibility and application in hydrological assessments of vegetative land-use change studies, good documentation, a balance between simplicity and realism, applicability to a wide range of vegetation types, the availability of input data required by the model, the level of spatial representativeness required at the HRU level (e.g. lumped large-scale vs. spatially explicit fine-scale) and the time-scale required to operate at (e.g. daily vs. monthly). The chosen model may be locally or internationally developed, with strengths and weaknesses inherent in both options. A principal advantage of using a locally developed model is that its routines are customised to local conditions and locally available data. There is always a need to parameterise the chosen model for the location where it is being applied, and for locally developed models there is usually a history of aligned projects, such as determining suitably representative input parameter values and routines. This greatly facilitates the data collection exercise. For "off the shelf" internationally developed models, there may be a need to adjust existing local input data, or collect additional input data, in order to parameterise the model.

In South Africa, locally developed models that have been widely used for hydrological assessments include ACRU (Schulze 1995) and the Pitman model (Pitman 1973). There are numerous other hydrological models developed internationally, which have also been applied in South Africa, including SWAT (Arnold et al. 1999), FAO56 (Allen et al. 2004) and WAVES (Dawes and Short 1993). These models all require certain input data, usually comprising climate data, soils information and vegetation descriptors for the site under investigation. Vegetative land-use changes affect hydrological responses through canopy and litter interception, infiltration of rainfall into the soil and the rates of evaporation and transpiration of water from the soil. Consequently, the provision of appropriate input data required

Veld Types of South Africa
by J.P.H. Acocks



Vegetation map of South Africa
Mucina & Rutherford (eds.), 2006

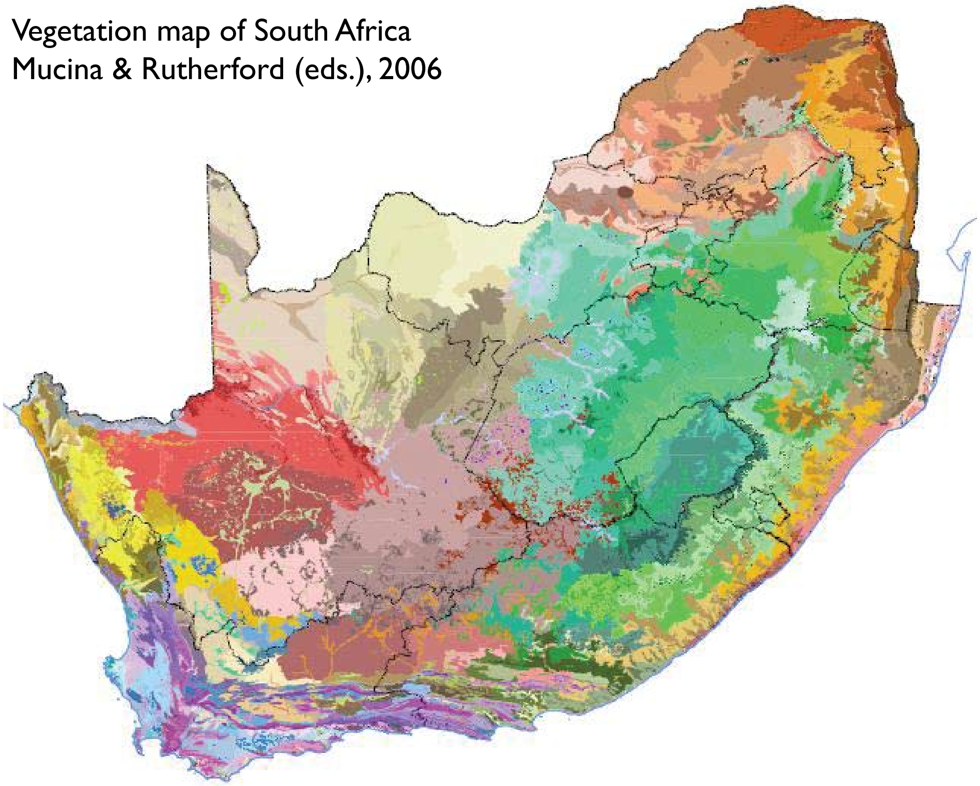


Figure 3.3: **Comparison of the vegetation classification systems of Acocks (1988), top, and Mucina and Rutherford (eds) (2006)**

by the chosen model is critical. Minimum data requirements to represent the spatial and temporal variation in vegetation vary depending upon the model, but usually include some or all of the following: monthly values of leaf area index (LAI), crop factors or coefficients, rainfall interception rates and rooting depths or root colonisation patterns. Verification studies are essential to promote confidence in the ability of the chosen model to replicate observed data. These may take the form of testing certain routines within the model (e.g. evapotranspiration), or may consist of more generalised verification of the primary model output of interest, namely streamflow.

As a local-scale alternative to using complex hydrological models, more easily measured surrogate variables (e.g. plant age or LAI), which are broadly linked to the water-use of plants, may be used to estimate plant transpiration / evapotranspiration. However, this is dependent upon the availability of observed data to verify these simple relationships. Their advantage is that they do provide an indication of changes in water-use over time (Figure 3.4).

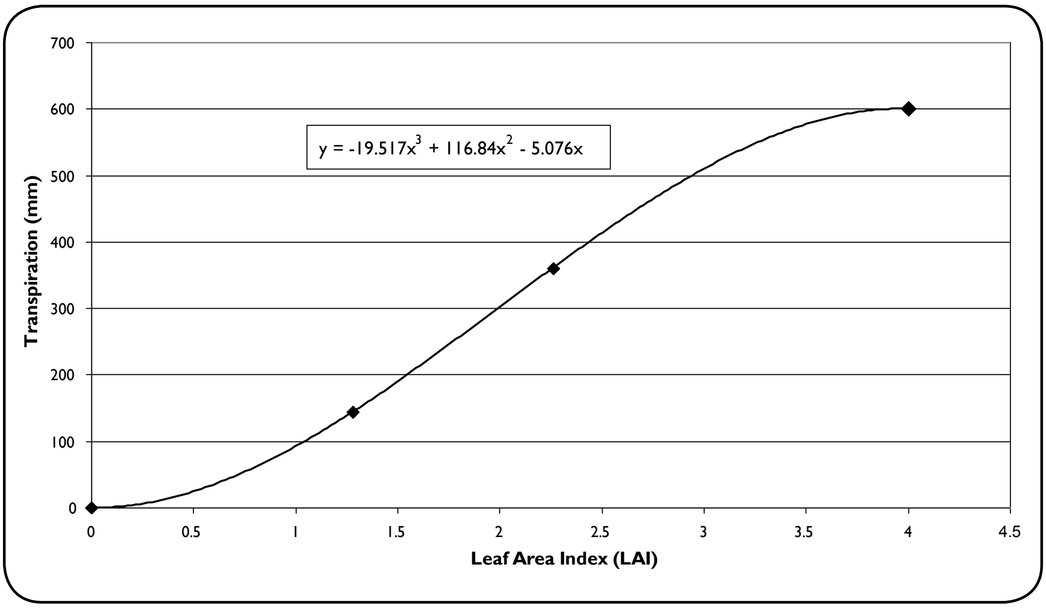


Figure 3.4: **Relationship between annual transpiration totals and maximum (mid-summer) Leaf Area Index values for different sizes of *Jatropha curcas* trees (Gush and Moodley 2007).**

3.4.5 Gathering the necessary data for each HRU

Data required for each HRU represented in the broad area of interest will depend upon the choice of model to be used, and its associated input data requirements. The minimum information required usually includes a daily rainfall record of adequate length (see next section), monthly means of maximum and minimum temperatures, monthly means of reference potential evaporation (e.g. A-Pan or Et_o), HRU physical attributes (e.g. delineated area, size, mean altitude, latitude and longitude), soils attributes (e.g. soil type and texture, horizon thicknesses, soil water contents) and land cover attributes required by the model (i.e. data to describe the vegetation within each HRU).

The importance of existing databases of climate, soils and land-use information can not be over-emphasised and obviously greatly facilitates the model parameterisation process. Ideally, these should be pre-determined, patched, quality-checked and respected databases, relevant to the country of interest. In certain instances, some or all of this data may not be available, or existing data may need to be modified to suit specific model input requirements. The degree to which scientifically credible data (required as input data into the model) is (un)available will affect the confidence that end-users have in the final product. As this is usually the case (i.e. all required model input data is rarely available), there is commonly a need to provide a justifiable method of deriving the input data that is not available. This may take the form of extrapolation of existing data sets to unmeasured areas (e.g. interpolation of climate data), the use of certain assumptions regarding parameter values (e.g. drawing on expert opinion to derive monthly leaf area, root depth and rainfall interception estimates for a broad range of vegetation types) or making allowances for generalisation or averaging of certain variables (e.g. use of the modal soil type or vegetation type in a HRU). These assumptions need to be shown to be necessary and should be backed by scientifically credible approaches to addressing them.

3.4.6 Determining the length of the simulation period

The time-period of the simulation should be a suitably representative period that is likely to incorporate typical climatic variation (dry, wet and average years) in the area of interest. The period selected should be as long as possible but obviously requires adequate input data in terms of the climatic variables required by the chosen model. The most important input variable required by most hydrological models is daily rainfall. Consequently, it is imperative that a continuous and quality-checked daily rainfall record be available for each HRU in the area of interest. The length of this record usually determines the simulation period, as monthly means of temperature and evaporation are generally acceptable to use in conjunction with a detailed daily rainfall record. Apart from being representative of the long-term climate of a particular HRU, the record length is also important in terms of statistical analysis.

3.4.7 Representing changes in plant growth over time

A single representative parameter set for the dominant (e.g. modal) vegetation type in each HRU may be used to represent the "baseline" vegetation for each HRU being assessed in the model. This parameter set needs to account for typical seasonal variation in certain parameters (e.g. by incorporating monthly changes in LAI, rooting depths and rainfall interception rates) thereby influencing the resultant monthly evapotranspiration patterns. The baseline vegetation within each HRU is usually assumed to be in a stable, climax stage of development with little year-to-year variation. However for the proposed replacement vegetation (e.g. monoculture bioenergy plantations) it may be necessary to account for the entire life-cycle or rotation period of the feedstock, with the associated variation in vegetation characteristics over time. For the hydrological assessment of small scale bioenergy developments over the typical life-span of the feedstock it may consequently be necessary to "grow" the species over time, by means of changing vegetation parameter values. This would obviously require data or assumptions on how aspects such as leaf area, rooting depth and rainfall interception rates change over the life-span of the feedstock species. Observed data on these aspects is the ideal source of information. If this data is not available, temporal changes in the species need to be modelled or estimated in some way, accounting for management activities such as pruning and thinning of trees (Figure 3.5).

For the assessment of long-term (i.e. longer than one rotation length), large-scale (e.g. quaternary/quinary catchment scale) bioenergy developments, the need to represent changing vegetation parameters over

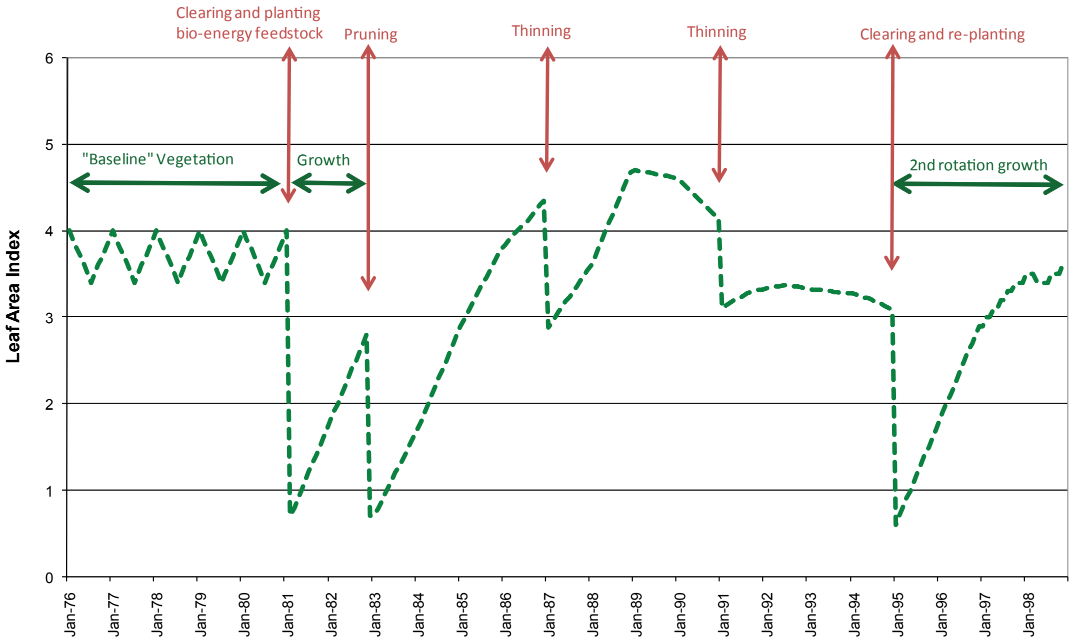


Figure 3.5: **Hypothetical changes over time in leaf area index of natural "baseline" vegetation and replacement bioenergy feedstock. Plantation management interventions and their resultant effects on LAI are illustrated.**

time may not be necessary. In this case it may be acceptable to assume that, while individual trees go through a growth cycle, bioenergy plantations at larger spatial scales would consist of a mosaic of tree ages representing all stages of the feedstock life-span as a result of variable planting dates and life-spans. Consequently, a normalized single representative age of tree may therefore be assumed to, mimic the average situation over the HRU. This representative age of the feedstock species (with its associated model input parameter values) may be utilised for each HRU. Representative parameter values may be determined by utilising age-specific vegetation parameter values to simulate the growth and resultant streamflow reductions for every year in the life-span of the feedstock. The tree age resulting in a streamflow reduction closest to the median streamflow reduction over the entire life-span may then be considered to be representative of the entire life-span of the feedstock. The relevant vegetation parameter values for that age may then be used in the model.

3.4.8 Running the model

Hydrological simulations at the desired time-step (e.g. daily) need to be run for each HRU within the area of interest, over the pre-determined simulation period. Depending upon the number of HRUs to be assessed this may require the model to be operated in 'batch' mode, whereby unique information relevant to each HRU is automatically selected from an input database and read into the model, generating outputs for each HRU respectively. Numerous potential scenarios may be modelled, however for hydrological impact assessments the minimum requirement is for simulations under the baseline vegetation, as well as under the proposed replacement land-use (e.g. bioenergy feedstock). While the climate, soils and physical catchment information remains consistent, unique input parameter values representing the respective vegetation types are utilised in the model to distinguish between the different land cover scenarios. Once the model has been run, time-series of relevant model outputs (e.g. daily streamflow (Q) and evapotranspiration (Et) information) from the respective land-use scenarios are stored for each HRU, and aggregated into time-series of monthly and annual totals for further analysis. Additional statistical outputs that may be generated for relevant variables include maximum, minimum, mean, median, percentile and coefficient of variation values.

3.4.9 Analysing the data

At Quaternary or Quinary Catchment scales, mean monthly, and mean annual, streamflow and evapotranspiration values, for each land-use scenario and each HRU, are the most important outputs with which to assess hydrological impacts of the proposed land-use. Using this information within the simplified water balance equation (streamflow = precipitation minus evapotranspiration), it is possible to calculate mean monthly and mean annual stream-flow reduction estimates for each HRU. Where the natural vegetation uses less water (on average) than the replacement vegetation, its Et will be lower and Q will be higher, indicating that the bioenergy feedstock species will (on average) result in a streamflow reduction. The converse is also possible, where the replacement vegetation may have a lower Et and higher Q than the natural vegetation, thereby resulting in a streamflow increase. The analysis of mean monthly outputs are important in terms of quantifying seasonal impacts on streamflow of the proposed future land-use. For example, water resource impacts during so-called "low flow" periods (dry months) are often more critical than during wet months, and monthly information is required to assess this. Where these kind of results are produced for numerous HRUs within the area of interest, it is possible to display them in the form of tables or maps representing spatial variation in streamflow reduction estimates (Figure 3.6).

The analysis is different for small-scale (plantation size) assessments, where streamflow reduction impacts over the life-cycle of a proposed bioenergy feedstock are to be evaluated. As assessments at this scale generally simulate streamflow changes over the entire rotation, compared to the baseline vegetation, it is better to compare accumulated streamflow under the respective land-use scenarios, over a typical bioenergy feedstock rotation. Divergence in the accumulated streamflow totals reflect differences in Et rates between the two scenarios, and the resultant impacts on streamflow attributable to the replacement land-use may be assessed at any time after planting (Figure 3.7).

3.5 Conclusions

An overview of the tasks required for the hydrological assessment of proposed land-use changes (e.g. tree-based bioenergy feedstock) have been presented in this chapter. It is clear that the approach to conducting such assessments differs depending on the scale of assessment required. However, in all modelling assessments it is important that verification studies are conducted wherever possible, in order to lend credibility to the model results and eventual extrapolation over wider scales. For example, where proposed bioenergy plantations (particularly deep-rooted, evergreen, tree-based feedstock) are to be established in areas dominated by short, seasonally-dormant vegetation (e.g. grassland or shrubland), streamflow reductions as a result of the altered land-use are likely. This has been amply demonstrated in South Africa, where exotic tree plantations established in former grassland areas have

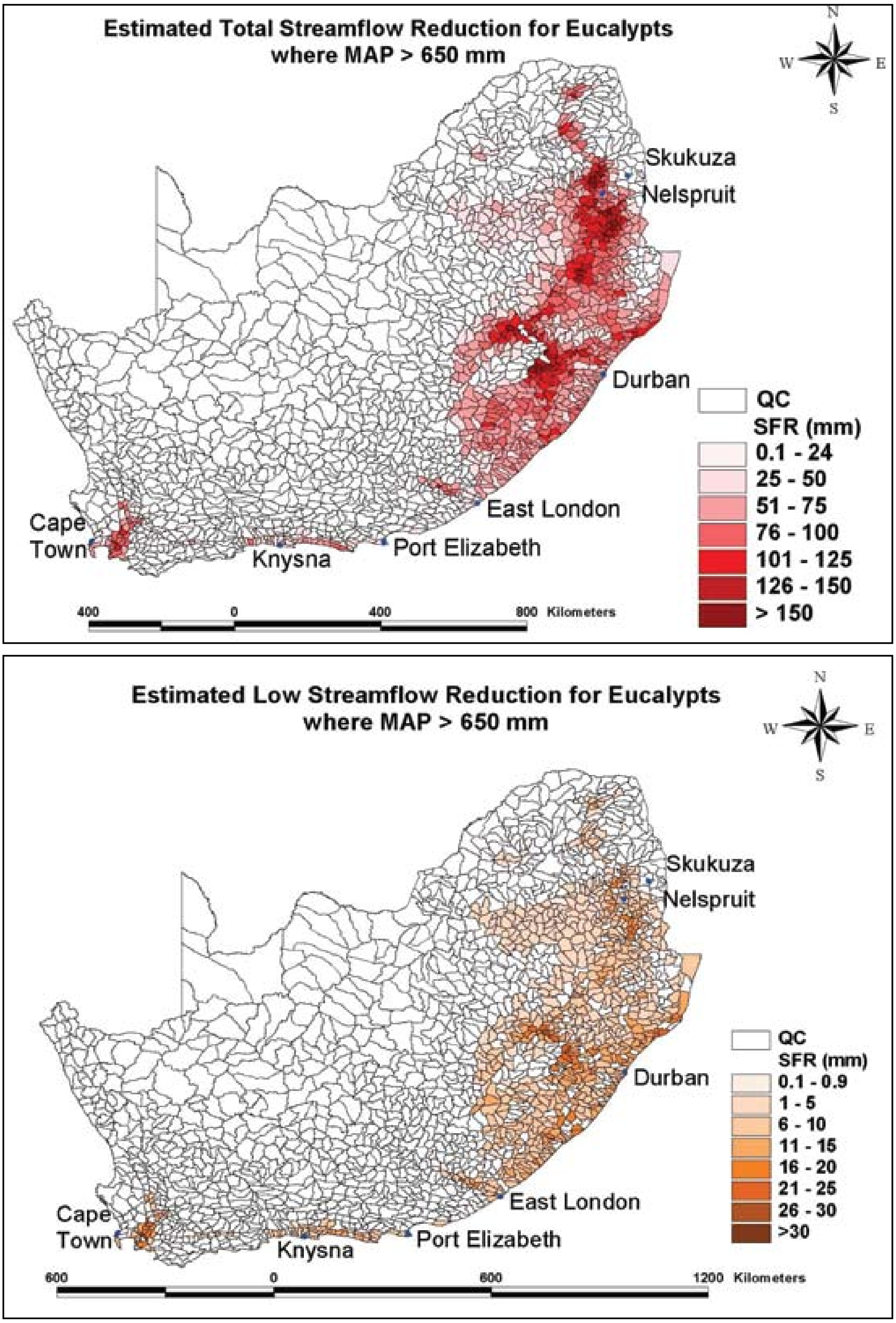


Figure 3.6: **Spatial representation of simulated streamflow reductions caused by eucalyptus plantations (total and low flows), for all South African Quaternary catchments where Mean Annual Precipitation exceeds 650mm (Gush et al. 2002).**

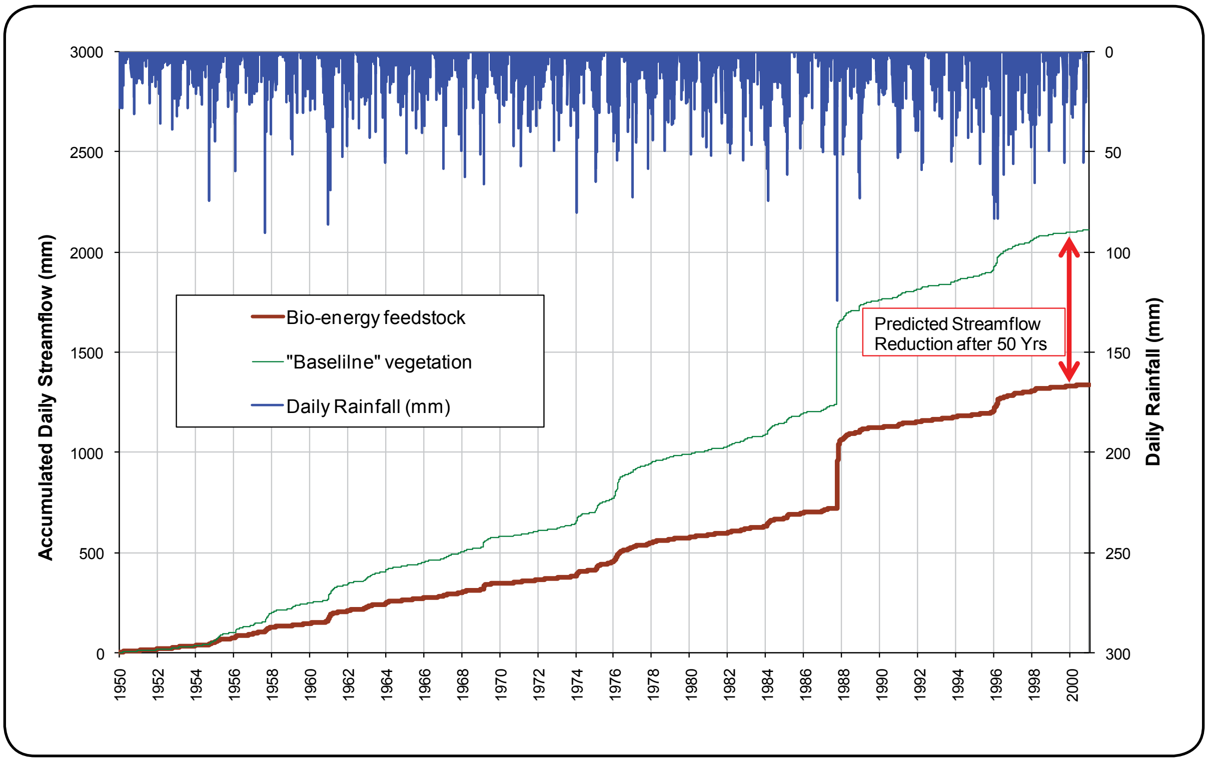


Figure 3.7: **Hypothetical example of accumulated streamflow under different land-use scenarios, simulated using a hydrological model, to predict streamflow reductions associated with potential bioenergy feedstock.**

conclusively been shown to consume more water than the baseline vegetation, reducing streamflow as a result (Bosch and Hewlett 1982; Zhang 1999; Scott et al. 2000; Brown et al. 2005; Calder 2005; Dye and Versfeld 2007; Scott and Prinsloo 2008). The expansion of exotic plantation forestry is now restricted in most areas of South Africa because of the environmental impacts (primarily in terms of water-use) of commercial plantations.

Similarly, it is imperative that bioenergy strategies being developed for any particular country consider water resource impacts together with all the other relevant social, economic and environmental considerations associated with the development of the industry. This is particularly important in those countries where there is increasing competition for water, now virtually a global phenomenon. Appropriate legislative and regulatory mechanisms may then be applied to new land use sectors (such as the bioenergy industry), if they are assessed to be streamflow reduction activities. Results of these kind of assessments therefore have the potential to influence policies governing the establishment and distribution of proposed land-use activities. Regulation, in the interests of sustainable water resource management, needs to be based on results from scientifically defendable work. The inevitable shortcomings and weaknesses associated with any methodology need to be identified and addressed in on-going research programmes.

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Chapter 4

Greenhouse Gas Emissions and Bioenergy

Neil Bird, Francesco Cherubini, Naomi Pena and Giuliana Zanchi

4.1 What Does Renewable Mean? Is Bioenergy Renewable?

4.1.1 The carbon cycle and the effect of human activities

Carbon is an essential element for life on Earth. The exchange of carbon between different reservoirs is represented by a biogeochemical cycle: the carbon cycle. The main reservoirs are: the atmosphere, the biosphere, oceans, soils, sediments (including fossil fuels) and rocks (Wallace and Hobbs 2006). Several biological, chemical and physical processes transfer carbon between carbon reservoirs and its residence time in a certain reservoir varies greatly according to the processes involved.

Carbon is one of the key elements in nutrients and structural compounds of living organisms, i.e. the biosphere. Living organisms extract carbon from other carbon pools or other living organisms to support their own existence. The extracted carbon is stored in the organism and then released at its death through decomposition processes. The main biosphere actors in the carbon cycle are the autotrophs that are capable of fixing carbon from the atmosphere by transforming carbon dioxide (CO_2) into organic compounds through photosynthesis (using energy from light) or chemosynthesis (though inorganic chemical reactions). Most of the autotrophs such as plants, algae and some bacteria use photosynthesis to produce organic compounds. All the other organisms (heterotrophs) depend on autotrophs for energy and other compounds they need.

Human beings and their activities also contribute to the carbon cycle. They produce CO_2 through respiration as other heterotrophs, but in addition humans have been using reservoirs of fossilized carbon to produce energy for their activities and they have been clearing carbon stocks, such as forest land, for agriculture amongst other things. The period after the Industrial Revolution has seen a dramatic increase in the use of fossil fuels. This has released huge amounts of carbon - as CO_2 - that had been stored in stable reservoirs for millennia into the atmosphere.

Carbon dioxide acts as a greenhouse gas in the atmosphere. Together with water vapour and other gases as methane, nitrous oxide and ozone, it absorbs and reflects heat radiated from the Earth's surface, keeping this heat trapped in the atmosphere. Without the "greenhouse effect", the average temperature at Earth's surface would be below the freezing point of water at about -19 °C (Le Treut et al. 2007). The concentration of greenhouse gases (GHG) in the atmosphere has changed several times during geological eras (Figure 4.1). It is estimated that in the past two centuries the concentration of CO_2 in the atmosphere has increased by about 35% (Le Treut et al. 2007). This sharp change of the composition of the atmosphere is attributed to human activities, primarily to the use of fossil fuels for energy. At the same time, long term temperature records show that, since 1900, the surface temperature steadily increased. Many factors influence the climate, but research studies have determined that human activities are most likely the dominant cause of the warming observed over the past 50 years, primarily because of the increase of GHG concentration in the atmosphere (Hegerl et al. 2007).

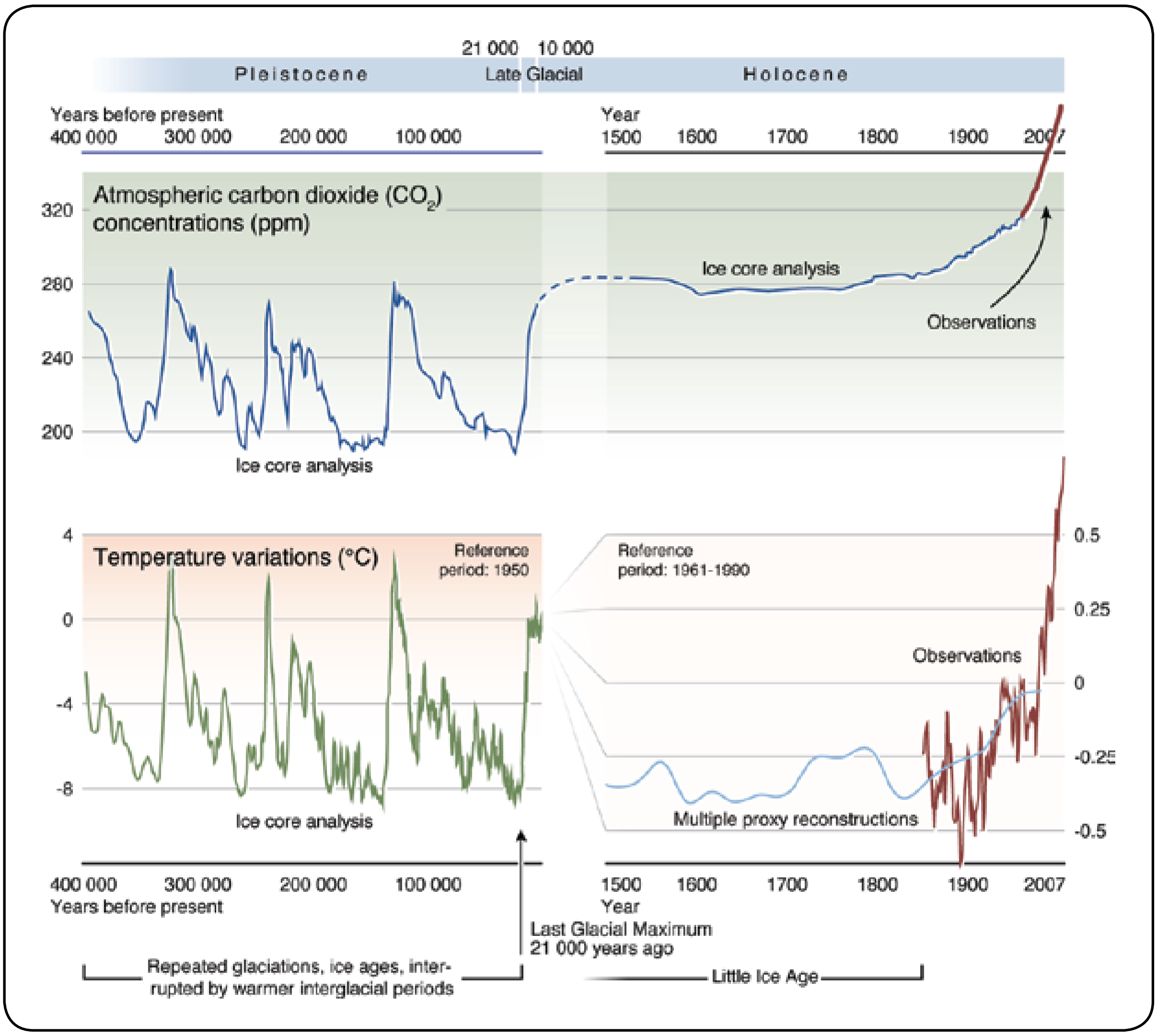

Figure 4.1: **Historical trends in carbon dioxide concentrations and temperature on a geological and recent time scale**[9]

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[9] Source: http://maps.grida.no/go/graphic/historical-trends-in-carbon-dioxide-concentrations-and-temperature-on-a-geological-and-recent-time-scale

The 4th Assessment of the Working Group II of the Intergovernmental Panel on Climate Change (IPCC) concluded that warming will affect natural systems, physical and biological and that the frequency of extreme weather, climate and sea-level events is likely to increase. The climate impacts will most likely increase net annual costs that result from increased catastrophic weather events and with increased temperature (IPCC 2007).

4.1.2 Fixing the carbon imbalance: the role of renewable energy

To counteract the effect of human activities on the global climate and its negative consequences, some countries have committed themselves to limit their GHG emissions into the atmosphere by promoting and ratifying international agreements. The current climate policy framework operates under the principle of differentiated responsibilities according to which industrialized countries, which have emitted the majority of GHG emissions, are the main actors responsible for mitigating climate change.

Due to this principle, industrialized countries committed themselves to adopt policies and to take measures to limit anthropogenic emissions under the United Nations Framework Convention on Climate Change (UNFCCC). These countries, including the European Union (EU), are classified as Annex-I countries. With the ratification of the Kyoto Protocol, some Annex-I countries adopted binding targets to reduce their GHG emissions by a certain percentage in comparison to a reference year (baseline). The EU promoted a series of parallel actions to help comply with its Kyoto Protocol target. The emissions produced by major industries (or, and possibly better, "large industrial sources of GHGs") are regulated through the EU-Emission Trading Scheme (EU-ETS) which established a cap on maximum allowable emissions. Recently, the EU approved a Directive (EU 2009) for the promotion of the use of energy from renewable sources. This Directive established national targets which, together, correspond to "at least a 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020".

The use of renewable energy sources is indeed one of the strategies to reduce future emissions of CO_2 and other GHGs in the atmosphere. Renewable sources are, by definition, sources that can "regenerate" or "restore themselves to the original state". This regeneration capacity prevents contributing to the imbalance in the carbon cycle produced by the use of fossil fuels. In theory, fossil fuels can also regenerate themselves, but the time frame required for organic matter to fossilize and to recover the reservoirs is incompatible with the human consumption of these reservoirs. For this reason, more carbon is released than is removed from the atmosphere by other carbon pools. Therefore, to define an energy source as renewable, it should regenerate in a time frame compatible with the speed of consumption.

Among renewable energy sources there are some - like solar or wind - that are considered renewable, because human use does not alter their magnitude or availability. Plant biomass is also considered a renewable energy source, because it can regenerate itself by regrowth. However, the time of regrowth varies considerably according to the type of biomass used. While crops have a regrowth cycle of one year, forest biomass can require decades to grow back to the previous state. For this reason biomass can produce a temporary carbon increase in the atmosphere that is recaptured in the biosphere only in a certain time frame, depending on the regrowth rate (see section 4.4).

4.2 A Tale of Two Energy Systems

Its like comparing apples and oranges

To understand and estimate if a bioenergy technology actually has a better environmental impact than the fossil energy technology it replaces, one needs to compare them, but this is difficult because they can be as different as "apples and oranges". To make sure that the comparison is being made properly, a formal methodology, Life Cycle Assessment (LCA), has been developed and adopted by the scientific community. The LCA identifies energy and materials used in a process, as well as the greenhouse gas emissions caused during the life time of the process from "cradle to grave" (Larson 2005; Zah et al. 2007). The aim of this methodology is to provide guidelines for homogeneous calculation procedures of GHG balances of bioenergy systems in comparison to reference systems and to summarize the key methodological issues that can influence final outcomes.

4.2.1 What is Life Cycle Assessment?

A Life Cycle Assessment is the investigation and evaluation of the environmental impacts of a given product or service, based on the identification of energy and materials used and emissions released to the environment. LCA includes the estimation of environmental impacts (e.g. GHG emissions) in all stages of the product life cycle.

As shown in Figure 4.2, the term life cycle refers to the major activities in the course of the product's life span, from raw materials acquisition, processing, to recycling and waste management, accounting for all the auxiliary energy and material inputs required along the full chain in the inventory.

As defined in the ISO 14040 standards[10], a typical LCA study is structured in the following steps:

1. **Goal and scope definition:** this phase is used to define and describe the object of the analysis, establish the context in which the assessment is developed, discuss assumptions and data quality, identify system boundaries and environmental effects. The object of study is described in terms of a so-called functional unit. Functional units are either input related (for example: tonnes CO_2 per tonne of biomass or GJ per hectare) or output related (for example: g CO_2 per kWh electricity or g CO_2 per passenger-km)

2. **Life cycle inventory (LCI):** this phase involves data collection and modelling, and compilation of data both about energy and material flows and on emissions to the environment, throughout the life cycle of the case study. Usually life cycle inventories and modelling are carried out using dedicated software packages. The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can be made already at this stage. The results of the inventory is a LCI which provides information about all inputs and outputs in the form of elementary flows to and from the environment in all the unit processes involved in the study.

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[10] http://www.iso-14001.org.uk/iso-14040.htm

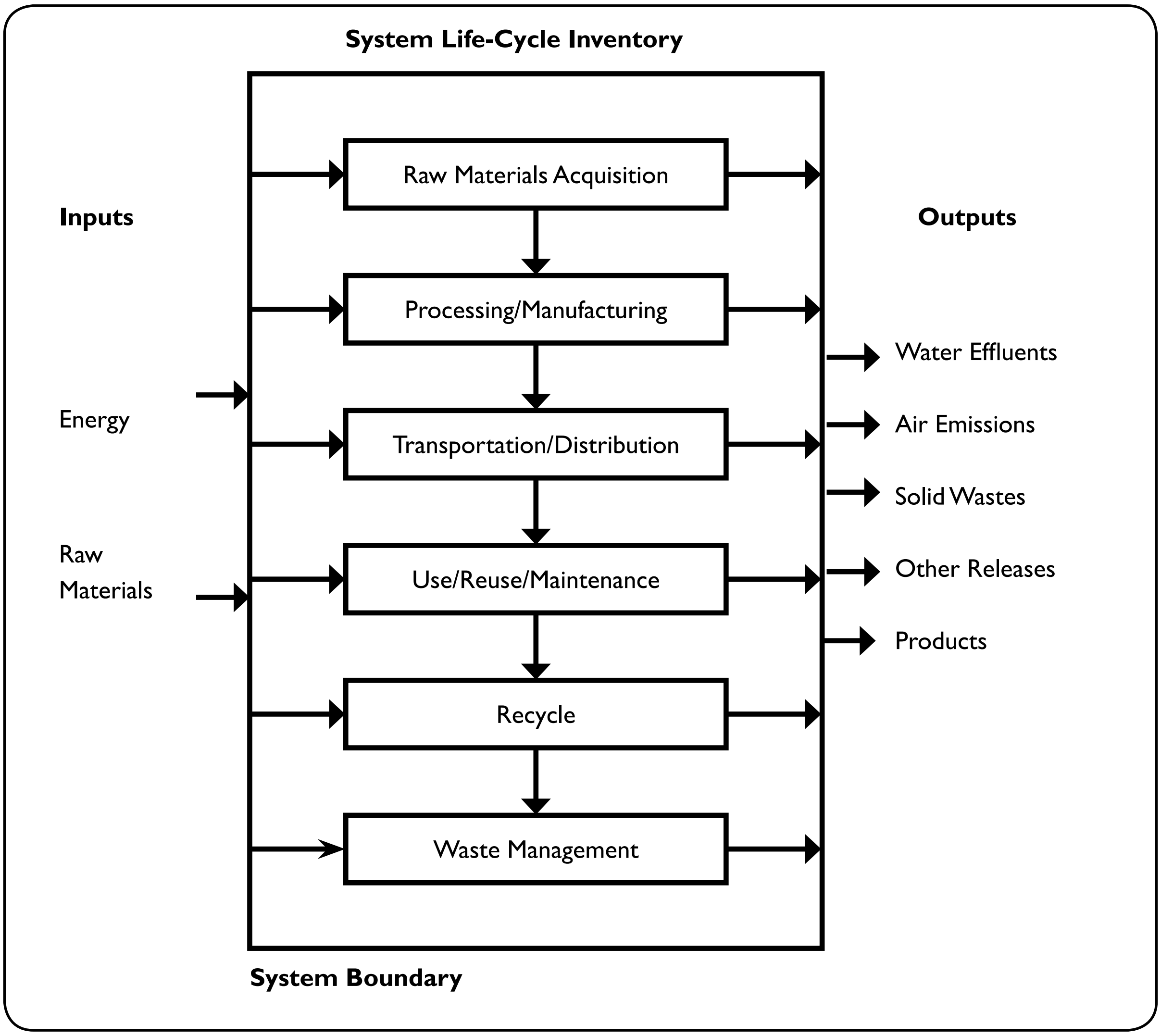


Figure 4.2: **Scheme of the main steps and flows involved in Life Cycle Assessment**

3. **Life cycle impact assessment (LCIA):** assessment of the potential impacts associated with the identified forms of resource use and environmental emissions. This phase aims at evaluating the contribution to impact categories such as global warming, acidification, etc. The first step is termed characterization. Here, impact potentials are calculated based on the LCI results. The next steps are normalization and weighting, but these are both voluntary according to the ISO standard. Normalization provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). Weighting implies assigning a weighting factor to each impact category depending on the relative importance.

4. **Life cycle interpretation:** interpretation of the results from the previous phases of the study in relation to the objectives of the study. All conclusions are drafted during this phase. Sometimes an independent critical review is necessary, especially when comparisons used in the public domain are made.

4.3 Bioenergy versus Fossil Systems

The goal of LCA is to compare the environmental impacts of a certain system to the environmental impacts of a reference system, both providing the same type of product or service. In bioenergy, this means that the selected bioenergy system is compared with a fossil reference system (Schlamadinger et al. 1997). In Figure 4.3, the full fuel chains of a bioenergy (left side) and a fossil (right side) system producing electricity and heat are compared.

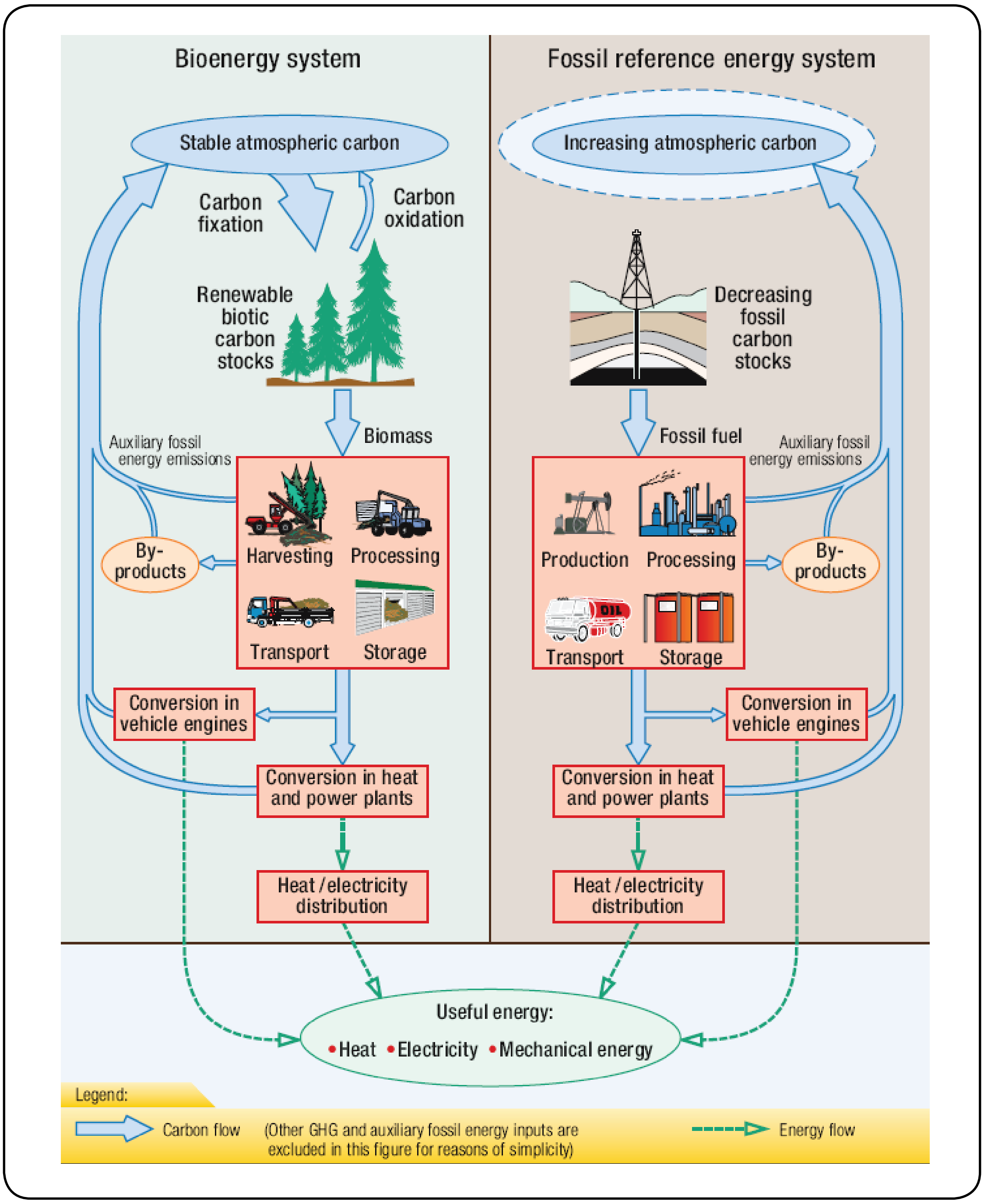


Figure 4.3: **Full energy chains for comparison of bioenergy and fossil energy systems producing electricity and heat.**

The bioenergy chain starts at the top left of Figure 4.3 with possibly a change in land use, after which biomass for energy is produced by carbon fixation from the atmosphere via photosynthesis, or biomass carbon taken as biomass waste from the agricultural or forest product sector. The biomass requires harvesting, transporting to a conversion site, conversion to an energy carrier (the useful form of the biomass), and the energy carrier is distributed to the energy user. At the end of the bioenergy chain a certain amount of useful energy (electricity and heat) is supplied. All energy inputs and GHG emissions occurring along the fuel chain, for planting and harvesting the crops, processing the feedstock into biofuel, transporting and storing of feedstocks, distributing and ultilizing biofuels must be accounted in a life cycle approach. Non-energy utilization of by-products must also be considered; by-products can be used to displace other materials and therefore have GHG and energy implications (i.e. GHG credits).

The fossil fuel energy system is analyzed in a similar way, including all GHG emissions and energy consumption associated with the following life-cycle stages: construction of the extraction facilities, production and transportation of the raw fossil fuel, refining and storage of the fuel, and distribution and combustion. Both the reference and bioenergy systems should include the land used to produce the bioenergy feedstocks. Similarly, when the bioenergy pathway delivers some by-products able to replace existing products (thus possibly saving GHG emissions), the reference substituted products should be defined in the fossil reference system and emissions for their production accounted for in the GHG balance.

The differences between the two systems producing the same product/service are compared. Final savings per year, per hectare of land and per unit of biomass should be given in order to provide a complete picture of the investigated bioenergy system.

When estimating the GHG savings of the bioenergy system, the definition of the fossil reference system is highly relevant. According to the assumptions made, results can widely differ. For instance, fossil-derived electricity can be assumed to be produced from oil, natural gas, coal or other sources, all of which having different GHG emission factors. In the most realistic evaluation, the bioenergy system should be compared to the most likely fossil energy system it would replace. Alternatively, a conservative evaluation of the GHG emission benefits of the bioenergy system may be done by comparing it with the best available fossil technology. For example, electricity in the fossil reference system should be produced from natural gas (the best available fossil technology), since natural gas generated electricity has a GHG emission factor of 120 g CO_2-eq./MJ. On the other hand coal-based electricity generation has a GHG emission factor of 237 g CO_2-eq./MJ (GEMIS 2008). As a consequence, the resulting GHG emission savings of the bioenergy system will be much larger if coal-based electricity is displaced.

4.3.1 Direct land use change

A very important factor in the comparison of the two energy systems is what happens to the land when it is used to produce biomass for energy purposes. This change in land management practices that affects lands within the system boundary is defined as direct land use change (dLUC). The new land management or use may store a different amount of carbon than the original land use when it was not used to produce biomass for energy. The changes in carbon storage occur over time, and after many years the new land use reaches a dynamic equilibrium. During the transition to this new equilibrium carbon level either there will be a net emission of CO_2 if carbon stocks are lower in the new land use, or a net removal of CO_2 from the atmosphere if carbon stocks increase to a higher level under the new land use. One can easily calculate the emissions from dLUC because you know which lands are affected and what change has occurred.

In LCA, the change in carbon stocks is usually spread over the assumed life of the bioenergy system, so that the impact of LUC is shared across each unit of output. This approach underestimates the short-term impact of LUC for a system in which there are significant emissions in the first years of the project, for example due to removal of vegetation during site preparation. Table 4.1 shows carbon stock changes for different land use types.

Table 4.1: **Carbon stock changes for different land use changes (tC/ha)**

	To	Tropical				To	Temperate		
From		**Crop**	**Grass**	**Forest**	**From**		**Crop**	**Grass**	**Forest**
Tropical	Crop		-11 to 22	35 to 351	Temperate	Crop		-11 to 25	34 to 730
	Grass	-22 to -11		14 to 373		Grass	-25 to 11		15 to 755
	Forest	- 351 to – 35	-373 to -14			Forest	-730 to - 34	-755 to -15	

	To	Boreal	
From		**Grass**	**Forest**
Boreal	Grass		11 to 138
	Forest	-138 to -11	

Note: carbon stock changes relate to total CO_2 emissions from a land use change by the ratio of the molecular weight of CO_2 to C (i.e. 44/12 = 3.67). Therefore 1 t C lost equal 3.67 t CO_2 emitted
Source: Bird et al. 2010

4.3.2 Functional unit

Comparing the two systems requires some metric for the comparison. This is called the functional unit and it provides a reference to which the input and output process data are normalized and the basis on which the final results are presented. Typical functional units are: emissions per unit energy produced, emissions per service provided, emissions per unit of biomass input, and emissions per unit of land required. The merits of these functional units are discussed in detail below.

In comparing bioenergy and fossil energy systems, the results should be expressed in terms of the same functional unit, to ensure that the comparison of different systems is based on the delivery of the same service. When assessing the environmental impacts of alternative energy systems, it is common to use measures such as input-output ratios or absolute emissions and primary energy requirements to be compared with conventional fossil fuel systems. Only a few studies on transportation biofuel systems express the results on a per vehicle-km basis in order to make them comparable with conventional diesel and gasoline.

The question of relative land-use efficiency for different biofuel pathways is not so often addressed. Land-use efficiency should, however, be the first parameter to be taken into account when dedicated energy crops compete against food, feed or fibre production under land-availability constraints, in order to optimize the efficiency of scarce land resources (Schlamadinger et al. 2005). Therefore, the results of the energy and GHG balances of bioenergy from dedicated biomass crops should be also expressed on a per hectare basis, since the availability of land is the biggest bottle-neck for the production of biofuels. On the other hand, for biomass residue feedstocks, the results should be expressed either on a per unit output (kWh, km) basis, in order to be independent from the kind of biomass feedstock, or on a per unit input basis (kg, or J of feedstock) in order to be independent from the conversion process (this is usually the most relevant option when comparing the best use for a given residue).

In general, it is recommended to show the results on a per year basis, both for the bioenergy and the fossil reference system, because timing of emissions is important. At a later step, GHG savings per year can be shown, along with other parameters like GHG emissions and savings per unit of biomass, final product (either kWh or km) and dedicated land.

4.3.3 Comparing syems with different products

A big question in LCA is how the total environmental impact is shared among the different products of a system. This concept is extremely important for bioenergy systems where multiple products are delivered. For example, electricity and heat are produced in combined heat and power (CHP) applications, and bioethanol production produces dried distillers grains with solubles (DDGS) which can be used as animal feed as a secondary product. How to allocate environmental impacts to these by-products is still open to discussion. Scientific publications show benefits and disadvantages of several allocation methods in LCA (Curran 2007; Ekval and Finnveden 2001; Frischknecht 2000; Wang et al. 2004).

The ISO standards suggest solving the allocation issue by expanding the system boundaries. This method consists of expanding the boundaries of the analyzed system to include the additional impacts related to the by-products. This procedure (called substitution method or system expansion) does not require allocation.

If the substitution method cannot be applied, input and output data might be allocated between by-products in proportion to their thermodynamic and physic parameters (such as energy or exergy content of outputs) or to their economic value. Allocation methods based on thermodynamic parameters and economic values of the products share the environmental impacts among the different outputs, without identifying a main product.

4.4 Timing of Emissions and Emission Savings

> ***Time is what prevents everything from happening at once.*** *~John Archibald Wheeler*

International, regional and domestic climate change policies, including the Renewable Energy Directive of the European Union (EU-RED) can be strong drivers for an increased use of biomass for energy generation. It is estimated that the deployment of renewable energy sources considered by the European Commission to meet the EU-RED targets will require 173 Mtoe of domestic solid biomass and 22 Mtoe of imported biomass in 2020 (Ragwitz et al. 2009). The sources of biomass will vary a lot, from agricultural residues to additional fellings from forest. Biomass resources, which would not have been used without the new policies, will be used to produce energy. This means that carbon that would have been stored in the biosphere in a "fossil energy" scenario will be released into the atmosphere as CO_2 as soon as the biomass is combusted. If this biomass is used to replace the same amount of carbon in fossil fuel, at the point of combustion the emissions in the atmosphere are the same for bioenergy as for fossil fuels. However, biomass can re-grow and re-capture the emitted carbon.

Under a current common assumption, the time required for the newly cut biomass to re-grow is ignored. In other words, it is assumed that temporary emissions released when biomass is burnt are re-captured in a short time period. This assumption is close to reality for crops that usually require one year to grow. The situation is different for woody plants, such as trees, that need a certain time period to restore lost biomass (Figure 4.4). The time needed to reabsorb the carbon released from woody biomass depends very much on the source of wood and its growth rate.

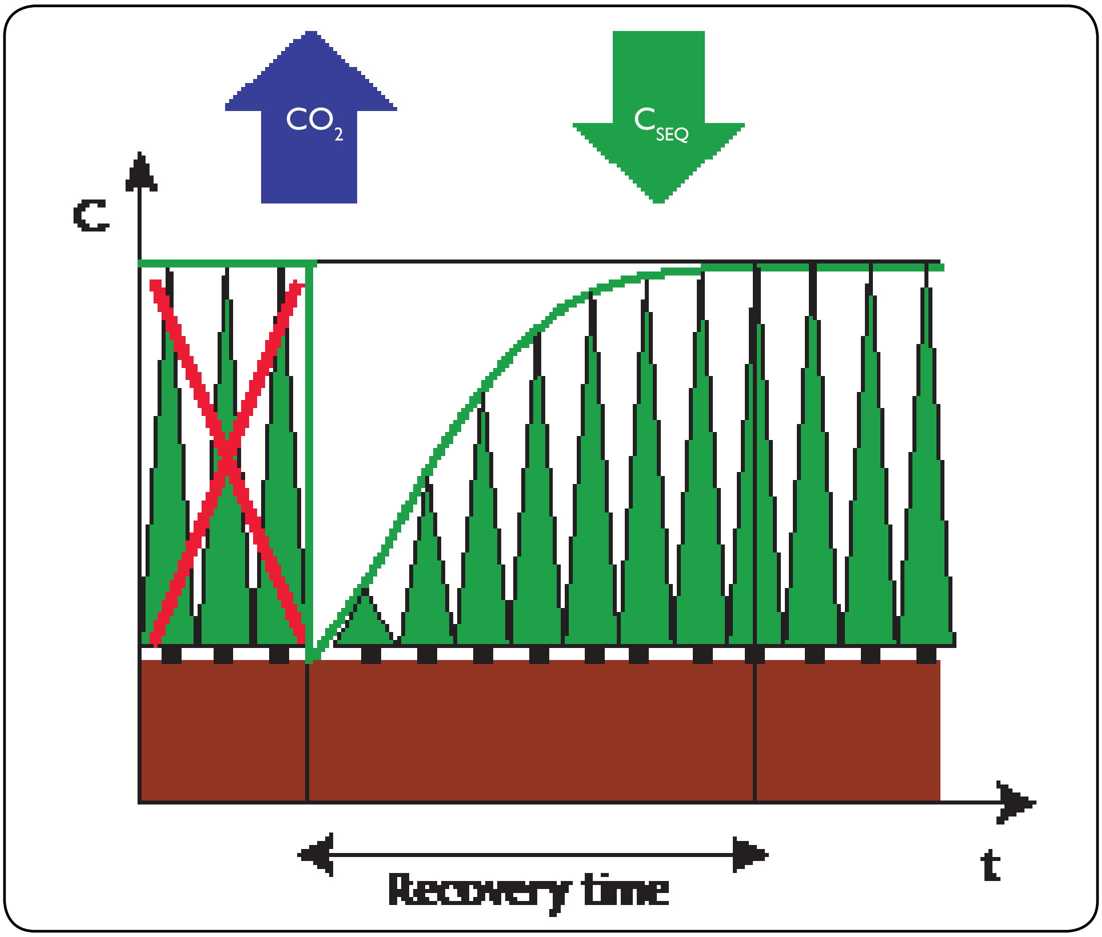


Figure 4.4: **Time delay between loss of carbon stock produced by burning biomass and recapture of carbon by regrowing biomass**

In addition, an increased use of forest biomass to replace fossil fuels can, under some circumstances, result in removals that forest regrowth is not capable of completely compensating. For example, the removal of forest residues results in reduced inputs to litter pools and consequently the litter and the soil carbon pools could decrease. In this case, the level of carbon stock after regrowth will be lower if the biomass is used for bioenergy than if it isn't and these carbon stock losses, i.e. emissions, should be also taken into account (Figure 4.5).

Therefore, the consequences of an increased use of woody biomass could be:

- a temporary carbon stock loss recovered by regrowth; and
- a permanent carbon stock loss due to intensified biomass extraction

In the context of near-term climate policy targets, a short term benefit, in terms of emission reductions, needs to be achieved. For these targets temporary carbon stock losses should be accounted for. For longer term (i.e. > 20 years) climate and energy strategies, the real climate mitigation potential of different biomass sources depends on the time frame needed to recapture the emissions released from the combusted biomass or the time frame in which the biomass would have decayed naturally, in comparison to the time frame considered relevant for climate mitigation, and on losses, if any, not recovered within those time frames.

In a GHG oriented LCA, the advantages or disadvantages, from a GHG perspective, of using bioenergy instead of fossil fuels should include the temporary and permanent carbon losses produced by bioenergy use. For this reason, it would be important to define a "time boundary" in addition to the spatial system boundary that is usually adopted.

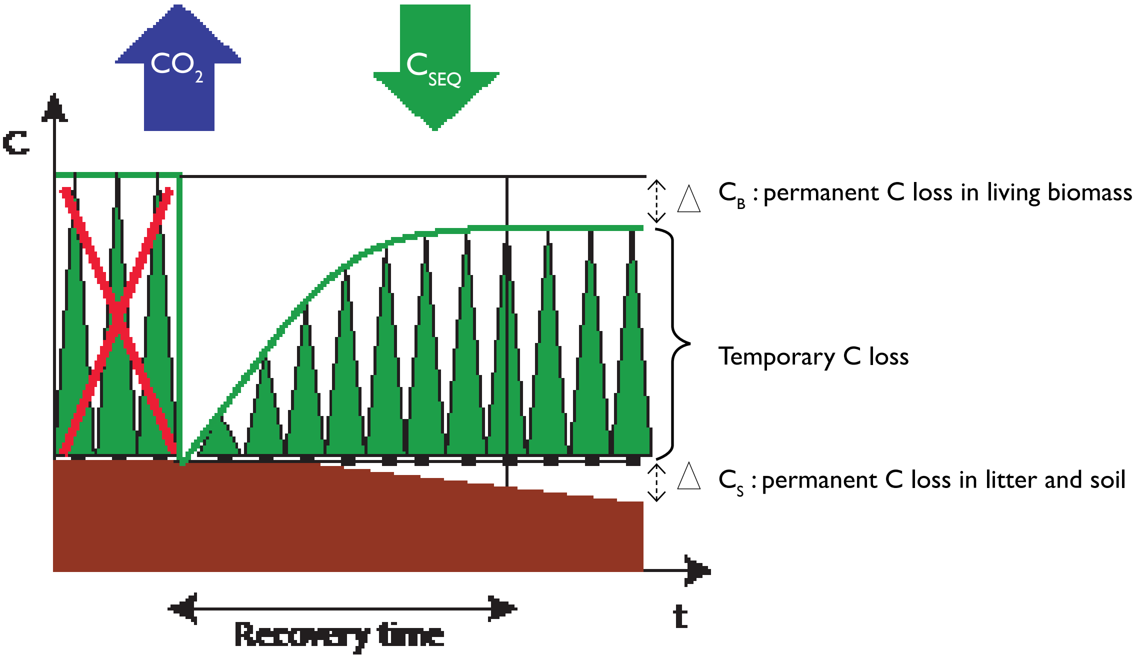


Figure 4.5: **Temporary and permanent carbon stock losses produced by increased biomass use**

4.4.1 How can bioenergy from a net growing forest still produce emissions in the atmosphere?

Global Forest Assessments published by FAO show that global forest resources are decreasing (FAO 2010). However, there are regions in the world, including most of Europe, where forest area and the carbon stock per hectare are steadily increasing. These forests are a net carbon sink in the carbon cycle that partially compensates for the current flux of carbon into the atmosphere.

If this net forest carbon sink would stop functioning and the amount of emitted carbon from other sources would stay the same, the carbon imbalance towards the atmosphere would be even greater than what it is today (Figure 4.6-A). This would happen if annual removals or natural mortality equals forest annual growth, resulting in forests reaching a steady state.

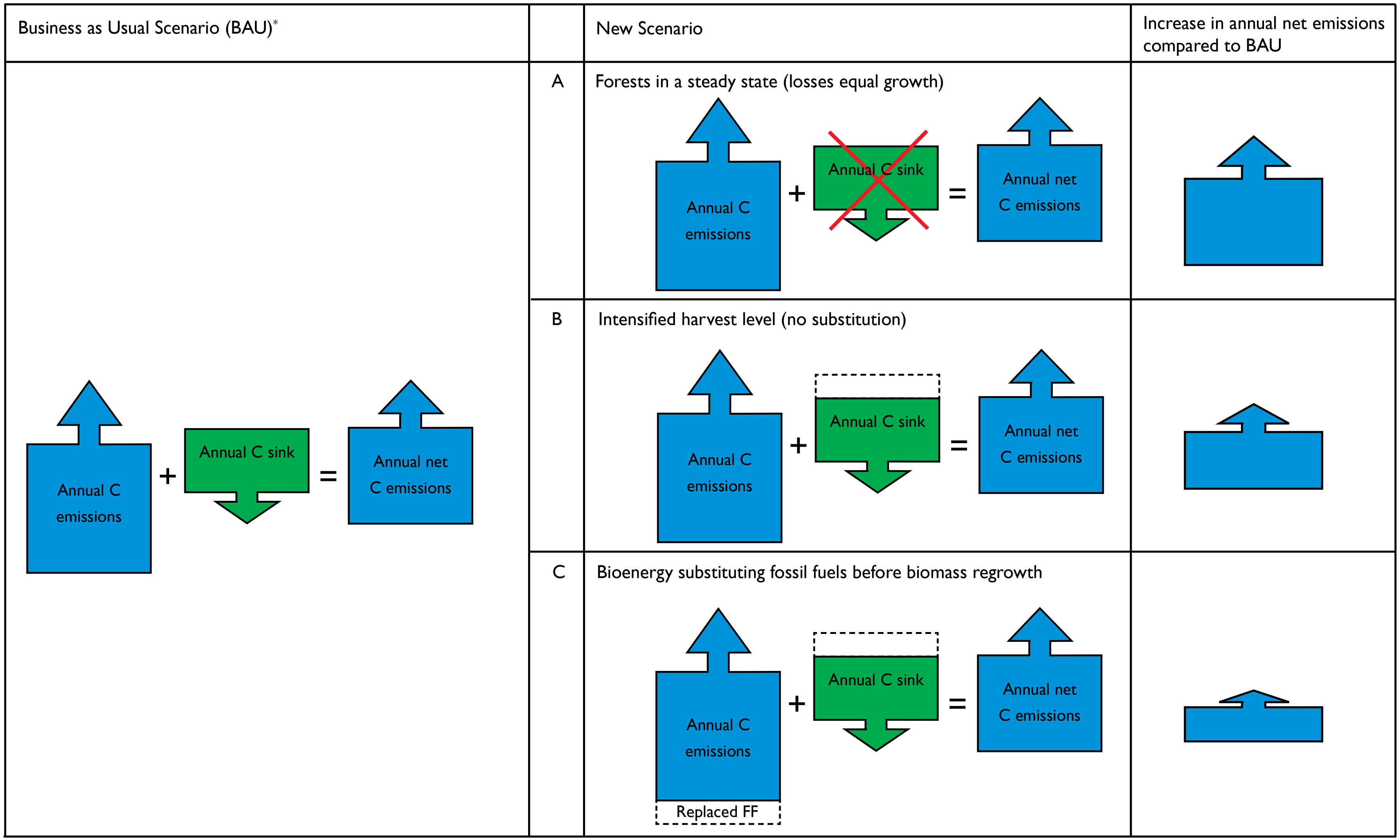
If the amount of forest removals is increased but remains less than the annual forest growth, the annual net carbon sink in the forests is only partially reduced (Figure 4.6-B). When the harvest level is increased, the losses are partially compensated by higher growth rates of younger trees, reduced competition between trees and reduced tree mortality. However, in the short term, the result is a reduced net carbon sink in comparison to the business-as-usual (BAU) or reference scenario, because the increased growth rates can not immediately recover all the losses. The net result is that net annual emissions are higher than under the BAU, but not by as much as if the carbon sink stopped functioning.

When bioenergy drives an increase in harvesting levels, the biomass would most likely replace a certain amount of fossil fuels, reducing the fossil fuel emissions to the atmosphere (Figure 4.6-C). However, the reduction in the carbon stocks is always greater in the beginning than the carbon emissions avoided from fossil fuel because:

- Part of the tree is left in the forest, such as roots and part of the aboveground biomass. All these residues decompose more quickly than wood in a living tree, meaning that more emissions are released in the atmosphere in the short-term
- Fossil energy systems are usually more efficient than bioenergy systems, i.e. more carbon is needed from biomass to produce the same amount of energy.
- Thus, in the near term an increase in net emissions in the atmosphere remains in spite of the reduction in emissions in the non-forest sectors.

With time, the additional losses due to an increase in level of harvest are partially or totally compensated by higher forest growth rates and a new steady state is reached approximating the BAU situation. The amount of fossil fuels replaced by the biomass continues at a constant annual amount with the result that the cumulative avoided fossil fuel emissions becomes greater and greater with time in comparison to the losses in the biosphere (Figure 4.7).

Bioenergy starts to produce a GHG benefit in the atmosphere compared to a "no bioenergy" scenario when the magnitude of the biosphere losses is less than the cumulative avoided fossil fuel emissions (in Figure 4.7 the difference to the BAU would be zero or become a sink). The conclusion is that biomass extracted as additional fellings from managed forests and used for energy produces GHG benefits only after a certain time period. This time period should be compared to the existing policy goals when judging the possible contribution of bioenergy to GHG emission reductions.



*The BAU scenario represents the situation in a country whose forests provide a net sink which is smaller than the combined emissions from the non-forest sectors.

Figure 4.6: **Examples of net annual emissions in the atmosphere and the effect of forest carbon sink and additional harvesting on the overall balance under different scenarios**

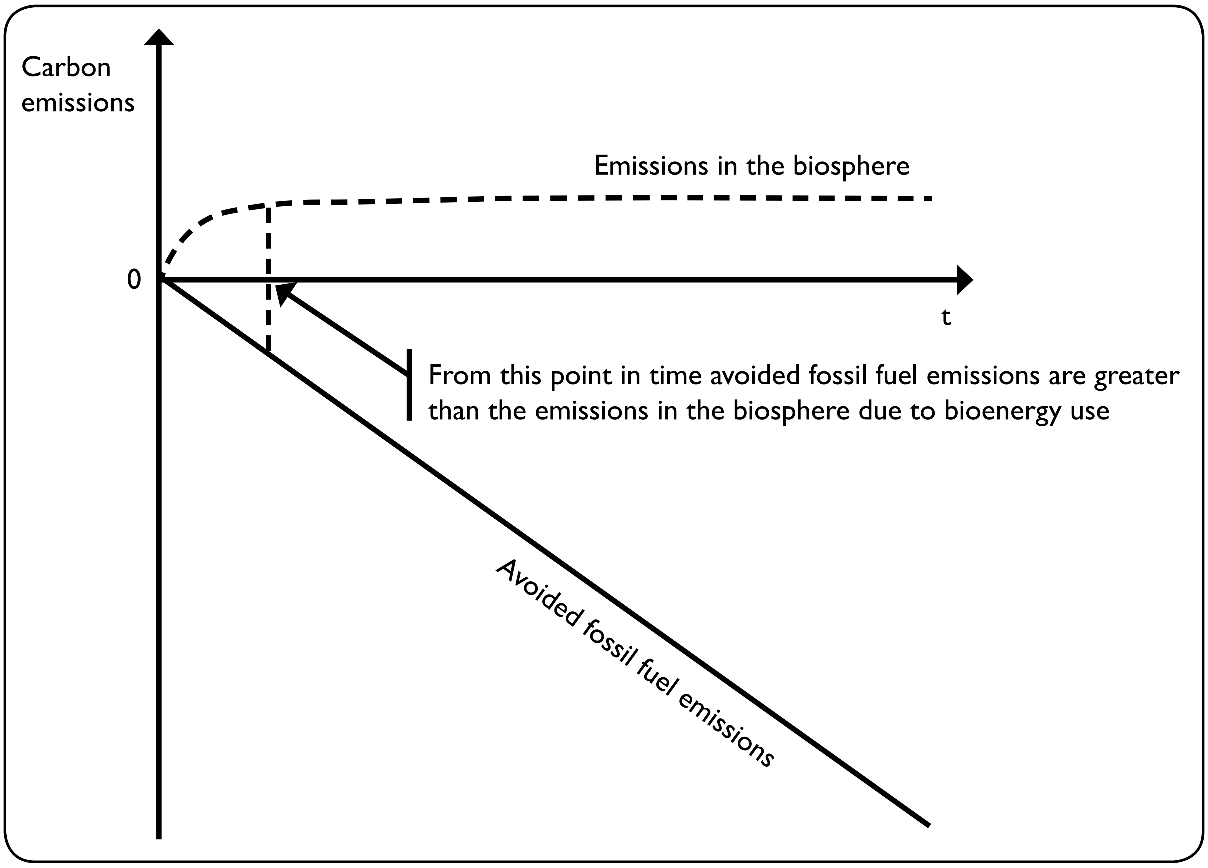


Figure 4.7: **Long-term comparison of avoided fossil fuel emission and emissions in the biosphere due to increased biomass use for energy**

4.5 Indirect Land Use Change

"He's only been talking to NIMBY opponents and his letter reflects that, it is one-sided and inaccurate." Cape Wind spokesman Mark Rodgers[11]

Perhaps, more important than dLUC, is the land-use change that land owners cannot control. Indirect land use change (iLUC) occurs outside the system boundary because of the displacement of services (usually food production) that were previously provided by the land now used for bioenergy. Emissions from iLUC are not as easy to calculate as dLUC because there are many drivers of land use change, so one doesn't know which land use change is a result of the bioenergy system.

Figure 4.8 shows schematically the relationship between dLUC and iLUC. The fossil energy system includes grassland used for livestock grazing. With the introduction of bioenergy, this land is converted to cropland for the production of bioenergy feedstock. This land is under the direct control of the land owner (i.e. within the system boundary), therefore this conversion is a direct land use change.

The loss of food production caused by the direct conversion leads to economic pressures that extend beyond the control of the land owner (i.e. outside the system boundary) and cause other land owners

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[11] http://www.capecodtoday.com/news321.htm

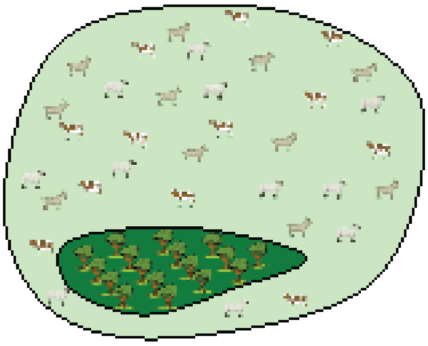
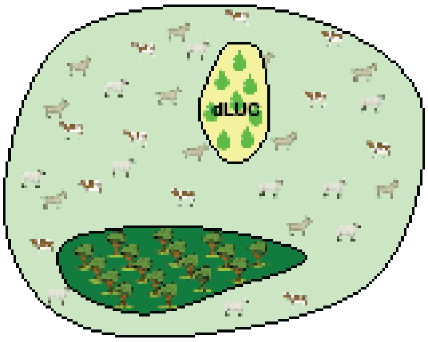
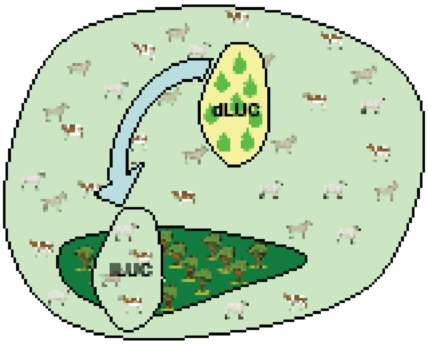
	A. Before introduction of the bioenergy production the land base is a mixture of grazing and forest land
	B. The introduction of the bioenergy production on grazing land is direct land use change (dLUC) and may cause a loss of soil organic carbon (i.e. an emission). If the bioenergy production is introduced on forest land, then the dLUC may be large because there is also a loss of forest biomass (including litter and dead wood). If the production is introduced on existing cropland then the dLUC will be smaller.
	C. Economic, traditional values and other pressures cause an increase in the value of grazing animals (i.e. meat). This creates an incentive for a land owner (not necessarily the owner of the land that was converted to bioenergy production) to convert a portion of the forest land to grazing land. This is indirect land use change (iLUC) and causes a loss of forest carbon stocks (including litter, dead wood and soil) which is an emission. The iLUC may occur instantaneously with the introduction of the bioenergy production or may be delayed by some period of time. If the bioenergy production was introduced on cropland, then both grazing land and forest land may be converted to replace the lost crop production.

Figure 4.8: **Schematic showing the relation between direct land use change (dLUC) and indirect land use change (iLUC)**

to convert an existing forest into grassland (deforestation) to resupply the food products originally produced by the grassland in the reference system.

Emissions from iLUC are potentially large compared to the annual emissions saved by the substitution of bioenergy for fossil based energy. In the worst case iLUC could cause huge losses of terrestrial carbon stock through the conversion of tropical peatland or rain forest to agriculture. This means that it may take decades before the bioenergy system creates enough emissions reductions to compensate for the emissions caused due to iLUC, i.e. to repay the "carbon debt". This has been pointed out by numerous authors (e.g. Fargione et al 2008, Searchinger et al 2008).

The iLUC may occur instantaneously with the introduction of the bioenergy production or may be delayed by some period of time. If the bioenergy production was introduced on cropland, then both grazing land and forest land may be converted to replace the lost crop production.

If an attempt is made to expand the system boundary to include all land use change caused by initial conversion of land to produce the bioenergy, then all emissions would be considered in the LCA and there would be no emissions from indirect land use change. This is not necessarily possible, however, as off-site LUC is not readily detected, and its cause is even harder to determine (if off-site LUC is actually due to urban expansion or increasing global demand for beef, for example, then the associated emission should not be allocated to the bioenergy project).

The pressures causing indirect land use change by bioenergy can be minimized by:

a) lowering bioenergy demand through options such as stringent energy efficiency requirements;
b) using wastes/residues as biomass sources for bioenergy
c) increasing biomass yield per hectare and efficiency of energy conversion technologies
d) increasing intensity of production on land remaining under agricultural use
e) using by-products as animal feed,
f) integrating biomass production with agricultural land uses, such as through agroforestry, and
g) promoting land use and bioenergy policies that support sustainably produced biomass

The first six measures reduce the competition with food production resulting from the introduction of a bioenergy system. Some of these suggestions may themselves cause unsustainable land use practices, or increase the GHG emissions. For example activities c and d may increase nitrous oxide emissions if additional nitrogen fertiliser is applied in order to increase biomass yields.

We have focused on iLUC in agriculture, but it is also an issue with forestry: for example, diversion of biomass from forestry for electricity production may cause iLUC to supply biomass that, in the reference system, was used for pulp and paper. Also, iLUC is not limited to bioenergy. It can also be an issue for other renewables: the flooding of a river valley for a hydro-electricity project will cause iLUC to replace all services that the valley originally produced (agriculture, wood products).

4.6 Bioenergy GHG Impact Evaluation in a Developing World Context

Several differences between developing and developed country circumstances play roles in evaluating the potential for bioenergy initiatives to reduce GHG emissions. In comparison to developed countries, developing countries are often characterized by:

- Greater use of biomass for heat, including cooking;
- Limited access to modern energy services, primarily electricity but also transportation fuels; and
- Conflicting pressures on forests and wetlands: external incentives to preserve them and internal pressures to convert them

The first two circumstances have a strong impact on LCA. They alter the underlying assumptions and render the analysis more complex. Therefore the estimation of the GHG benefits of a proposed bioenergy project becomes more difficult and results are more open to question. The third circumstance forces the issues of land use change and the relative benefits of preserving carbon stocks versus replacing fossil fuels into the foreground. Land use change complicates the assessment of the GHG benefits of biomass-for-energy because it is difficult to estimate which portion of the deforestation which occurs outside the project boundary (i.e., iLUC) can be attributed to the project. The following sections are devoted to further discussion of these issues.

4.6.1 Use of biomass for heat and limited access to modern energy services

Earlier in this chapter it was pointed out that, where undertaken for bioenergy projects, LCA compares a bioenergy system to a fossil energy system that provides the same service, e.g., kWhs of electricity or energy equivalent in transportation fuels. This procedure rests on the assumption, however, that the energy service is either already provided by fossil fuels, or will, in a business-as-usual scenario, be provided by fossil fuels within the planning horizon of the project. Moreover "hidden" within the concept "same service" are the assumptions that the users served, and the purposes to which the energy will be put, are identical whether the energy is based on fossil fuels or biomass. These assumptions do not, in general, apply to many developing country situations.

1. Electricity

In developing countries, electricity is almost always used domestically except in a few cases where one nation has a surplus and exports to a neighbouring country. However, electricity can be used either in the locality where it is produced or transferred to other localities over transmission networks. Biomass-based electricity production is much more amenable to small-scale local production and use in rural areas than coal or natural gas based plants. In some developing countries a substantial segment of rural populations do not have access to electricity. Here, introducing biomass-based electricity is more likely to increase electricity use rather than decrease fossil energy emissions[12].

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[12] In fact, it is well known that increasing energy efficiency does not lead to the energy savings (or GHG savings) expected due to the "rebound effect". Often, people increase consumption because it is cheaper to heat (or cook) than it previously http://en.wikipedia.org/wiki/Rebound_effect_%28conservation%29 for more information.

The first difficulty of estimating GHG reductions from biomass-for-electricity projects in developing countries arises from the limited supply. Due to unmet demand, electricity from a new biomass-to-electricity project will almost certainly increase energy use at least to some extent. For example, the populations without previous access to electricity are likely to increase available hours of light and to initiate small enterprises (Arthur 2010). To the extent that biomass-based electricity increases, rather than replaces energy supply, fossil fuel emissions are neither replaced nor reduced. The fraction that is adding to supply must be determined since the reference system for this fraction is "no emissions" and all emissions due to this fraction will increase total GHG emissions. Some GHG emissions will almost inevitably attend this fraction, e.g., due to biomass harvesting and transport.

A second difficulty of applying LCA arises due to the widespread use of biomass for home cooking and heating. This practice complicates LCA regardless of whether biomass-based electricity replaces pre-existing energy uses or not. The situation can be represented as shown in Figure 4.9.

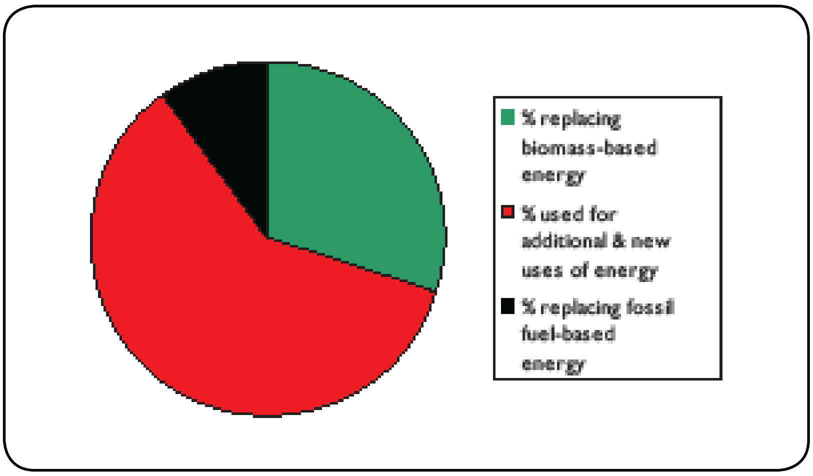

Figure 4.9: **Distribution of use of electricity from proposed biomass-based plant**

Figure 4.9 is intended to convey the reality that, while some portion of electricity from a new biomass-based plant may be used to replace fossil fuel based supply, in addition to the portion used to increase energy, some portion may replace energy currently supplied by biomass. For any given project, the share of each "segment" can range from zero to 100%. However, unlike in developed countries where, in general, one can assume that the entire circle is black (all biomass-based electricity will be used to replace fossil fuel-based electricity); in developing countries the proportion of each must be determined.

Different information and calculations are needed to determine the GHG benefits of each segment. As mentioned above, GHG emissions from "red" use electricity will be additional and will not be compared to any emissions. Both the "black" and "green" segments need to be split into their components. In the case of "black" source emissions, standard LCA approaches can be applied. However, unlike in developed countries where the biomass electricity will most likely replace either coal or natural gas-based electricity, a number of different fossil fuels in different applications will probably be replaced. Biomass-based electricity is likely to replace kerosene-based lighting and small, private diesel-based generation, as well as electricity from a central coal or natural-gas plant. Thus instead of one LCA, three (or more) comparative LCA analyses are likely to be needed, and the fraction of electricity that will be used to replace each fossil fuel use must be estimated.

Calculating GHG emissions for the "green" segment is similarly complex, but for different reasons. Here the electricity will replace existing biomass-based energy services such as heating and cooking. Therefore, the appropriate comparison is between two bioenergy systems, in one of which GHG emissions are due to using some form of biomass to produce electricity. In the other, GHG emissions are due to use of wood, charcoal, farm residues, or animal wastes for heating and cooking. Determining these latter GHG emissions raises difficult issues. In the case of wood, the issue of how much comes from areas where trees will regrow and how much results in deforestation must be addressed. Answering this question is likely to be difficult, as is an analogous question where wastes are used: are soil carbon losses occurring as a result?

To the extent that the wood in a new or existing use comes from areas where regrowth will occur, the issues covered in section 4.3 of this chapter arise. Regrowth rates and time horizons at which to assess GHG benefits need to be agreed on. Under these circumstances it is neither correct to assume that combustion of biomass for electricity has no emissions within time horizons relevant to stakeholders, nor to assume that continued use of wood, charcoal, residues or wastes for heating and cooking would have no emissions in the same time horizons.

2. *Transportation fuel*

Unlike electricity, liquid biofuel projects are frequently targeted for the export market. Production of biofuels is also undertaken for local or national use and to some extent biofuels intended for local use can be produced with simpler technologies. Only in the case of export to nations in which fossil fuel-based transportation fuels are widely available, is it clear that the biofuels would replace fossil fuels. In other cases, particularly biofuels produced for local use, are they likely to increase available supply, as in the case for rural electricity.

The primary difficulty of assessing GHG emissions due to liquid biofuels stems from problems in assessing iLUC associated with production of the biomass. While use of biomass for electricity can also drive iLUC, three interconnected circumstances have centered attention to this issue on biofuels:

- Mandates and incentives driving increased use of liquid biofuels,
- Export of biomass for transportation fuels from developing to developed countries,
- International agricultural price and supply impacts resulting from production of biomass for liquid fuels.

As discussed in section 4.3, land use change is generally divided into direct (dLUC) and indirect (iLUC). As also pointed out, emissions from iLUC in LCA are particularly difficult to estimate due to problems in detecting iLUC and attributing LUC in general to a specific cause. In many developing countries the forest cover is decreasing for a variety of reasons, complicating the attribution of LUC to specific causes. However, even ascertaining the degree to which the emissions from dLUC can be attributed to biofuel (or biomass for bioenergy) production can be problematic. Sugar, corn and palm oil can all be used either for food products or biofuels and their use for one or the other purpose will change depending on market prices. Similarly, wood can be used for bioenergy, pulp, paper or long-lived wood products and its use for each varies depending on market conditions.

Ascertaining iLUC is particularly difficult because, due to the global nature of, and interactions between, food, feed, fibre and bioenergy markets, iLUC can take place anywhere in the world. As a result global economic models must be used to analyze iLUC. Such analyses have only recently been attempted and results vary widely (Sheehan 2009). In addition to using different models, different assumptions are made regarding issues which have significant impacts on results. Such issues include – but are not confined to – which lands will be converted; effects of price increases on production methods and therefore on yields; and the extent, if any, to which replacement of food crops with ethanol by-products occurs (Hertel et al. 2010; Sheehan 2009; Taheripour et al. 2008).

Although one avenue for addressing iLUC is to await better modelling results, an alternative is, as in the case of addressing emissions due to by-products in LCA, to expand system boundaries. In this case the needed expansion is to include a full range of biomass products into accounting systems. It is important to note that what is counted as iLUC from the point of view of bioenergy production may be considered to be dLUC in the recieving system; however the impact of producting displaced goods in the receiving system should be attributed instead to the increased use of biomass for energy.

Incorporation of emissions from all biomass products into accounting systems can be accomplished through consumer-based accounting (CBA). Under CBA, all emissions caused along a products' value chain up to point of use are attributed to the product and considered as emissions "embodied" in the product. Further, consumers of products can be considered responsible for these emissions. This is a very active field of research (Bednar-Friedl 2010; Peters 2008; Peters and Hertwich 2008; Weidmann 2009; Zaks et al. 2009) and several considerations underscore its potential value. International trade is the fastest growing macroeconomic component of global GHG emissions; Annex-I countries are, in general, net importers of embodied emissions (Peters et al. 2009); and developing countries cannot, in general, be expected to agree to GHG limits in the foreseeable future. Under these conditions, a CBA approach can prevent a decrease in the share of total global GHG emissions addressed by developed country action.

A step towards CBA has been taken by the EU RED (EU 2009). The Directive requires that biofuels' GHG emissions up to point of use be determined. Biofuels whose embodied emissions exceed specified amounts can not be used to meet EU Directive targets. This in effect places some responsibility for embodied emissions on EU transportation fuel users. The Directive falls short of a true CBA because, once cleared for use, neither the embodied emissions nor the emissions upon combustion play a role in determinations of whether GHG limit obligations have been met. CBA, if adopted, would add a new dimension to the current accounting approaches in which countries are only responsible for emissions that occur within their borders.

4.6.2 Conflicting pressures on forests and wetlands

Developing and developed nations find themselves in different circumstances with regard to their forests and wetlands. While increased use of land of biomass-for-energy in developed countries may result in food price rises and some conversion of grasslands or forests, existing forests are primarily threatened by suburban growth not needs to meet food demand or supply export income. These circumstances together with the lack of external pressure with regard to the use of domestic land resources reduce level of tension between, and impacts of, alternatives.

In developed nations, forests and wetlands needed for agriculture were converted from their native ecosystems to agriculture in past centuries. Forests are now regrowing on some of this land because productivity on lands best suited to agriculture is sufficiently high to enable abandonment of other areas while meeting sure food security goals and providing commodities for export. In many developing countries, domestic food security has not yet been achieved, productivity per hectare is relatively low, and forests and wetlands are looked on as a resource to be used both for domestic agricultural production and export potential.

At the same time, due partly to climate concerns but also due to interests in protection of natural ecosystems, developed country stakeholders have signalled that they are prepared to offer incentives to preserve natural forests and wetlands in developing countries. The Copenhagen Accord of COP 15 specifically mentions the needs to reduce deforestation and degradation and enhance uptake of CO_2 by forests, and calls for establishment of a mechanism (e.g., REDD+) that would mobilize financial resources for this purpose (UNFCCC 2009). Subsequently Norway provided $1 billion to protect wetlands in Indonesia (Office of the Prime Minister 2010).

As a result, developing countries are likely to have to decide between alternative uses of land, each with its own economic consequences. The GHG and economic benefits of using land to produce biomass to substitute for fossil fuels as well as extend energy services will have to be compared to the GHG and economic benefits of preserving or enhancing forest growth. However, both preservation of forests and production of biomass for energy compete with use of land to produce biomass for food. In circumstances where food supply is insufficient to meet domestic needs and improved living standards are a pressing issue, countries face tough decisions.

The only apparent avenues for developing countries to reduce tensions are:

- Search for opportunities to increase efficiency of land use across all biomass categories: food, feed, biomass-for-energy and biomass for fibre; and
- Clarify domestic goals and priorities among international goals.

Unfortunately, current climate instruments are poorly designed to assist in efficiency issues. While both the CDM and REDD+ could be used for increased efficiency initiatives, in both cases efficiency is, at best, a secondary issue for funders. CDM project developers are searching for the highest return per dollar invested and low management costs, and REDD+ investment is likely to focus on preserving ecosystems of most interest to developing country stakeholders. Many efficiency upgrades, including per hectare productivity, reduced post harvest wastes, and residential cooking, are management intensive as they involve changing practices of many actors. Efficiency concerns are most likely to enter REDD+ when, for example, higher agricultural productivity is seen as vital to preservation of the ecosystem. Given contributors such as insecure land tenure rights and illegal logging, agricultural efficiency is unlikely to be a priority in many instances.

In sum, the evaluation of bioenergy proposals poses a number of challenges in developing countries, well beyond those posed by evaluations in developed nations. Contributions to GHG emission reductions, assessments of potential indirect land use change triggered by projects, and weighing alternative paths to GHG reductions are all challenging.

4.7 An Example – Small Scale Wood Gasification for Electricity Generation in Uganda[13]

Accessibility to electricity in Uganda is one of the lowest in the world. Only 5% of the population has access at the national level. The electrification rate decreases to 1% when only rural areas are considered (Gore 2008). The currently heavily limited reach of the power-grid, high electricity prices, frequent power outages, and high line losses (38% in 2008) pose hurdles to increasing access to electricity over the short to medium term, in particular in rural areas. Previous investigations showed that small-scale wood gasifiers could be an economically and socially feasible energy system to produce electricity in rural areas in Uganda (Buchholz and DaSilva 2010). In addition they could contribute to reduce GHG emissions by substituting tradition fossil fuel based generators.

The GHG impacts of wood gasification are estimated by applying a LCA with the Global Emission Model of Integrated Systems (GEMIS) v.4.5[14]. The LCA compares all processes, which influence emissions, material and energy consumption from cradle to grave. The compared systems are:

- Bioenergy system: production of electricity with a wood gasification system that powers a modified diesel engine running on a dual fuel mode (25% diesel and 75% gas)
- Reference system: production of the electricity with decentralized diesel generators.

The process chains for both systems are shown in Figure 4.10.

The bioenergy system is based on the energy usage of a former Internally Displaced Persons camp in the Amuru district in the Northern part of Uganda. Main electricity users in the camp are a hospital and shops for an annual demand of 30 MWh yr^{-1}. The wood for gasification is supplied by Short Rotation Coppices (SRCs) of Eucalyptus. The productivity of the stands is assumed to range between 5 to 15 oven dry tons per hectare (odt ha^{-1}). In order to exclude indirect land use changes, plantations should be established on areas not used for food production. It is assumed that the SRCs are planted on an area currently covered by grasslands. To guarantee a constant annual supply of wood, a total area of 2.0 to 6.0 ha needs to be converted to Eucalyptus plantations, depending on the productivity of the SRCs.

The full LCA shows that the wood gasification system produces less GHG emissions than the reference fossil fuel, but the improvement depends on the productivity of the stands. When the plantation productivity is low (5 odt ha^{-1} yr^{-1}), the gasification system produces about half of the GHG emissions produced by the fossil fuel system (51%).

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[13] The following example is from Zanchi et al (In Review). Please refer to this publication for the details of the methodology and assumptions.

[14] www.oeko.de/service/gemis

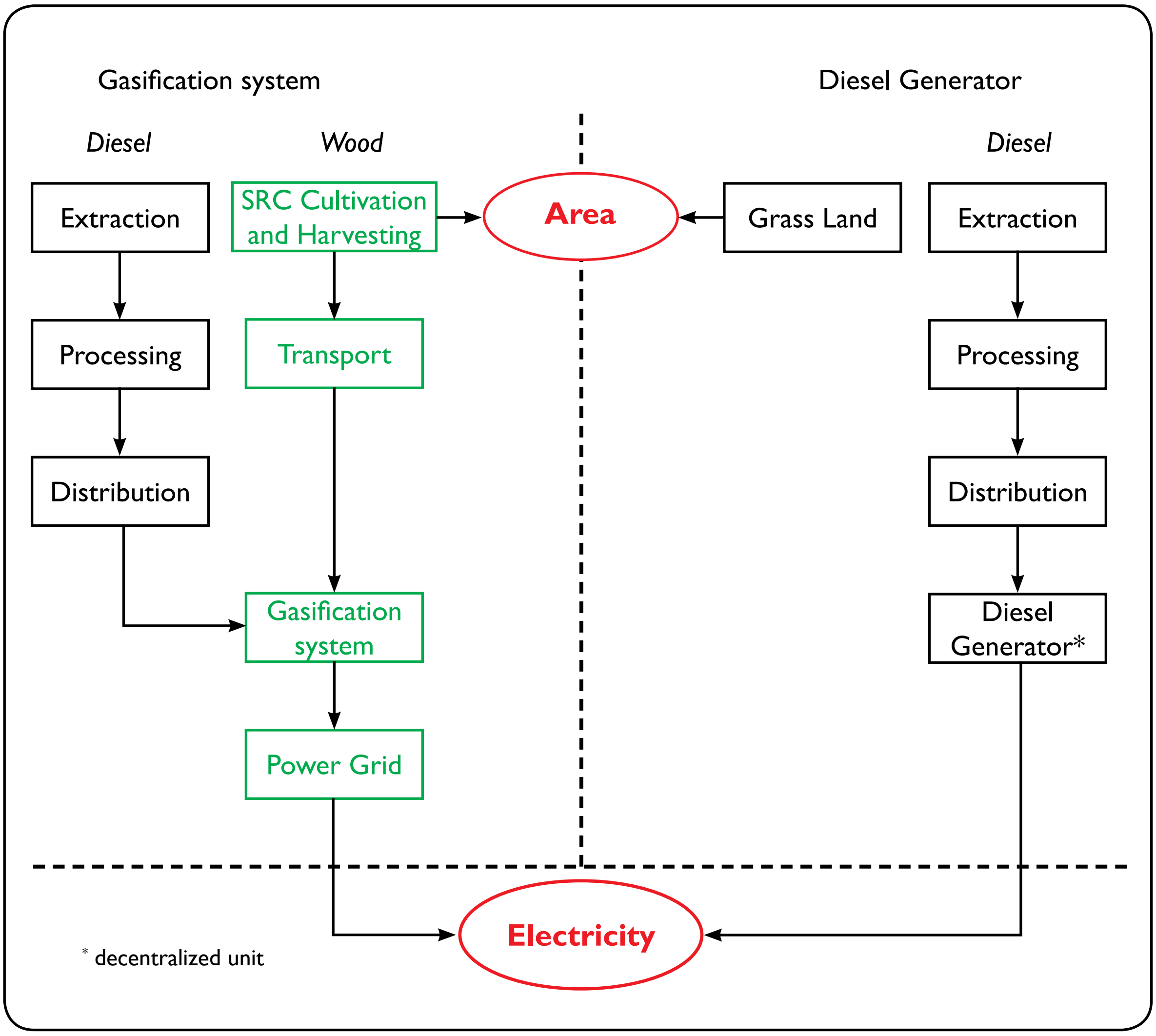

Figure 4.10: **Process chains for the bioenergy system ("gasification") and reference system ("diesel generation")**

The emissions are even lower when the plantation produces 15 odt ha^{-1} yr^{1} of wood. The installation of a gasifier produces about 1/3 of the emissions produced by diesel generators (Figure 4.11).

As shown in Figure 4.12, the overall GHG balance of the gasification system is given by different components. Emissions are produced by the management of plantations (harvesting, fertilization, transport of workers and seeds), the transport of wood, the gasifier (construction material, operation of the system), and the construction and operation of the electricity grid. These emissions are partially offset by carbon sequestration due to conversion from grasslands to Eucalyptus plantations (Land Use Change). The extent to which emissions are offset depends on the productivity of the plantations.

4.8 Conclusions

Bioenergy has a role to play in providing renewable energy while reducing greenhouse gas emissions, but only if the biomass is produced sustainably. This is often not the case in developing countries that rely heavily on wood as an energy source. In these countries, demand for biomass exceeds supply

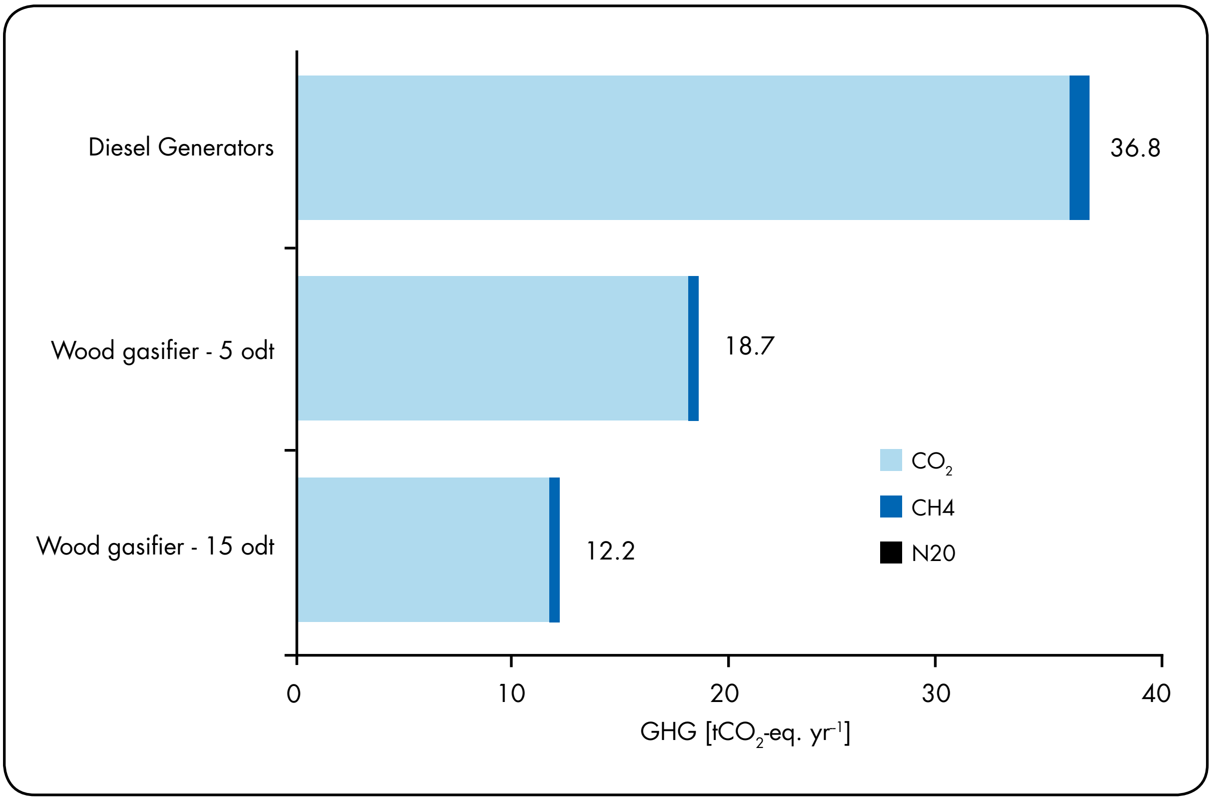

Figure 4.11: **Comparison of GHG emissions produced by diesel generators and the gasifier. The emissions from the gasifier are shown for different levels of productivity of the plantations (5 and 15 odt ha^{-1} yr^{-1}).**

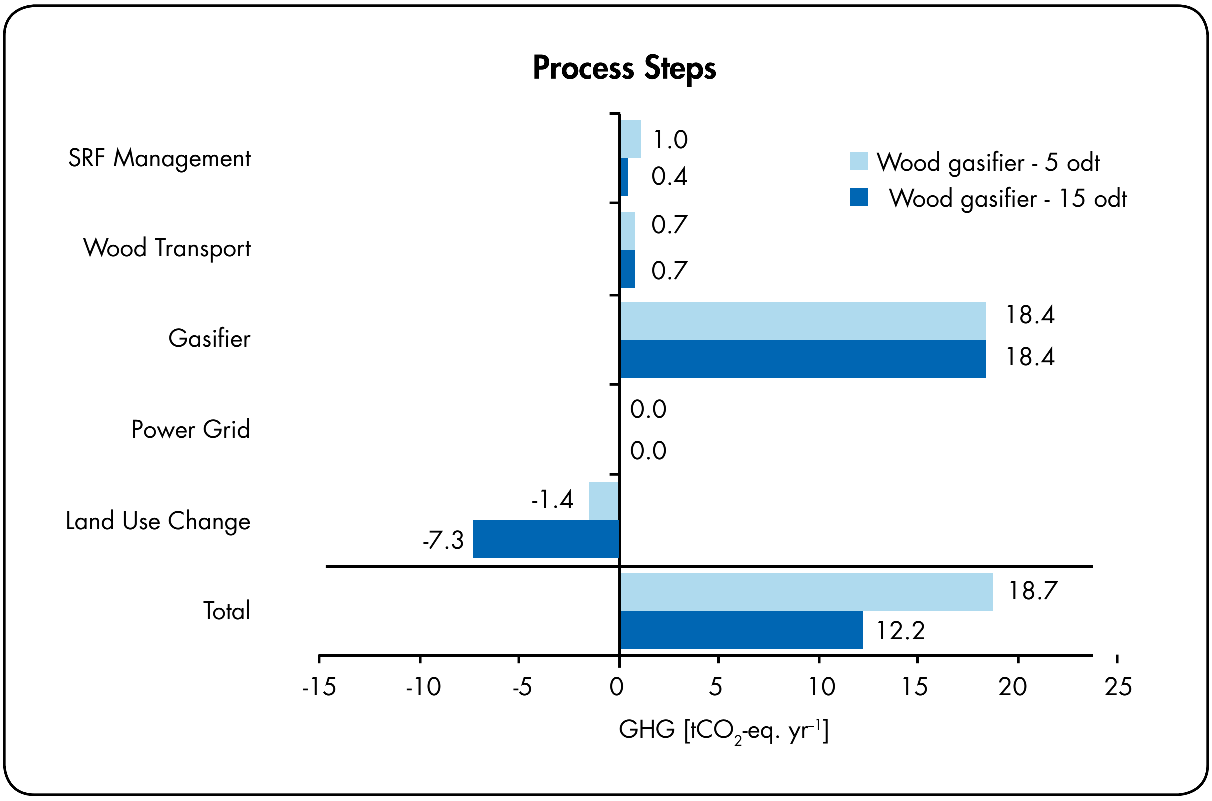

Figure 4.12: **Emission components of the gasification system according to different productivities of the Short Rotation Coppices (5 and 15 odt ha^{-1} yr^{-1}).**

and the emphasis should not be placed on increasing bioenergy use, but rather on decreasing its use by increasing the efficiency of the energy systems used. In addition the supply of biomass could be increased by increasing the forest area.

Life Cycle Assessment is the methodology used to evaluate the amount of greenhouse gas emissions saved by a bioenergy system as compared to a reference fossil system. This methodology calculates the emissions from both systems over their lifetimes along the whole process chain from "cradle to grave" or from "well to wheel". In this evaluation it is very important to include the emissions saved from by-products and emissions from changes in carbon stocks that occur directly due to land use changes cause by the bioenergy and indirectly due to land use changes caused by market effects. However, Life Cycle Assessment generally does not include the timing of emissions and emissions saved. This is especially significant for bioenergy from woody sources, if one has short term greenhouse gas emission targets or goals. These short term goals should be balanced with the long term objective of providing renewable energy.

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Chapter 5
Maintaining Biodiversity during Biofuel Development

Graham von Maltitz, Alecia Nickless and Ryan Blanchard

5.1 Introduction

This chapter focuses on four key issues:

- Understanding the opportunities and threats biofuels pose to biodiversity.
- Understanding how impacts can be predicted and modelled as a component of multi-criteria decisions surrounding strategic decision making on whether to undertake a biofuels programme or not.
- Operational planning at the biofuel plantation level to minimise negative biodiversity impacts.
- Minimising the risk of invasive alien species (IAS) resulting from biofuel production.

Most of this chapter is focussed on the impact of feedstock plantations for liquid biofuels. However, the same techniques can usually be applied to feedstock for other types of bioenergy. This is illustrated in some of the provided examples.

5.2 Why Consider Biodiversity Impacts?

5.2.1 What is biodiversity?

Biological diversity, normally referred to as biodiversity, is defined by the United Nations Convention on Biological Diversity (UNCBD 1973) and the Millennium Ecosystem Assessment (MA 2005) as: *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."* The term is used to cover all forms of life, but for practical purposes is often expressed with reference to specific taxa, e.g. biodiversity of plants, biodiversity of mammals, biodiversity of insects, etc (see section 5.5.2). In most common usage it is the disappearance or decrease in abundance of naturally-occurring (endemic or indigenous) species that is implied when 'loss of biodiversity' is being discussed. When considering biodiversity it is often convenient to subdivide the landscape into units of area which have similar biodiversities such as habitat types or ecosystems[15]. The habitat type is typically defined by eco-regions, biomes or broad vegetation type such as lowland forest, dry deciduous forest, grassland or wetlands when working at a global or national level. More detailed local classifications could be used when working at a smaller scale, such as at a plantation level.

Biodiversity can be expressed at a number of different scales, with the following three scales (or levels) of diversity commonly considered:

1. Genetic diversity is the differences in the genetic composition of individuals of the same species. A sister and brother are of the same species (humans, or more correctly *Homo sapiens*), but have differences in genes that make them different. Unrelated people of different regional origins will have greater differences in genes than closely related people. The same applies to non-human organisms.
2. Species diversity is the variety of different species. For example, buffalo and elephants are different mammals, *Eragrostis curvula* (love grass) and *Eragrostis gummiflua* (Gum grass) two grass species of the genus *Eragrostis*.
3. Ecosystem diversity is diversity between different habitats or ecosystems.

It is useful to think of diversity at this and other levels as having three attributes:

- Diversity in composition (i.e. which ecosystem types are present)
- Diversity in structure (are the patches large or small, tall or short, connected or fragmented?)
- Diversity of function (do they all work the same way and produce the same ecosystem services?).

Depending on the application, ecosystem diversity may compare broad habitat types such as tropical forests to tropical grasslands, or might be measured at a finer scale of different types of forests within tropical forests. The diversity could also be expressed as diversity of different functional types of organisms rather than as difference in species. This is useful due to the fact that very different species may functionally play very similar roles within the ecosystem. For some applications it is the diversity of functions that species play in an ecosystem that may be more important to the ecosystem's integrity than the diversity in species. In this regard, species can be grouped into functional types based on the role they play in the ecosystem or into response types based on the way they respond to different stresses and disturbances. Biologists, when describing or measuring species biodiversity, use the terms alpha (α), beta (β), and gamma (γ) diversity to describe different attributes of the diversity. Alpha (α)-diversity is the biodiversity within a patch of a given size (usually expressed as the number of different species present, or 'species richness'). Beta (β)-diversity is a measure of the degree of change in species composition along a gradient – in other words, if you were to measure another patch near to the first patch, how many shared species would there be? (γ)-diversity refers to the total species richness over a large area or region, and is strongly influenced by how many different patch types there are. This is

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[15] Biome, vegetation type, habitat type and ecosystem can all be used to describe unique assemblages of biodiversity. Key differences relate to the scale of analysis and the basis for the grouping (e.g. based on vegetation or ecological process). Precise definitions are beyond the needs of this text, and the key consideration is that these are used as ways of grouping areas of similar biodiversity for analytical purposes.

best explained by considering the hypothetical species turnover along a hypothetical environmental gradient as illustrated in Figure 5.1. The 10 species in Figures 5.1a and 5.1b are artificially divided into two habitat types. In Figure 5.1a all species are common to both habitat types, but in very different proportions. In Figure 5.1b, habitat type A has three unique species, whilst habitat type B has five unique species and only two species are common in both habitats. As will become important in later sections, this uniqueness of biodiversity within a single habitat has consequences when considering conservation status and impacts of habitat destruction. Totally transforming all of habitat B in Figure 5.1a would not result in the total loss (*extirpation*, or *extinction* if that was the last representative of the species on Earth) of any species, but would result in some common species becoming extremely rare. By contrast, losing the same area in Figure 5.1b would result in the total loss of five species, with a sixth species becoming extremely rare. Figure 5.1a also shows how some species can have very wide habitat tolerances - these are often referred to as generalist species. Species in Figure 5.1b, by contrast, have

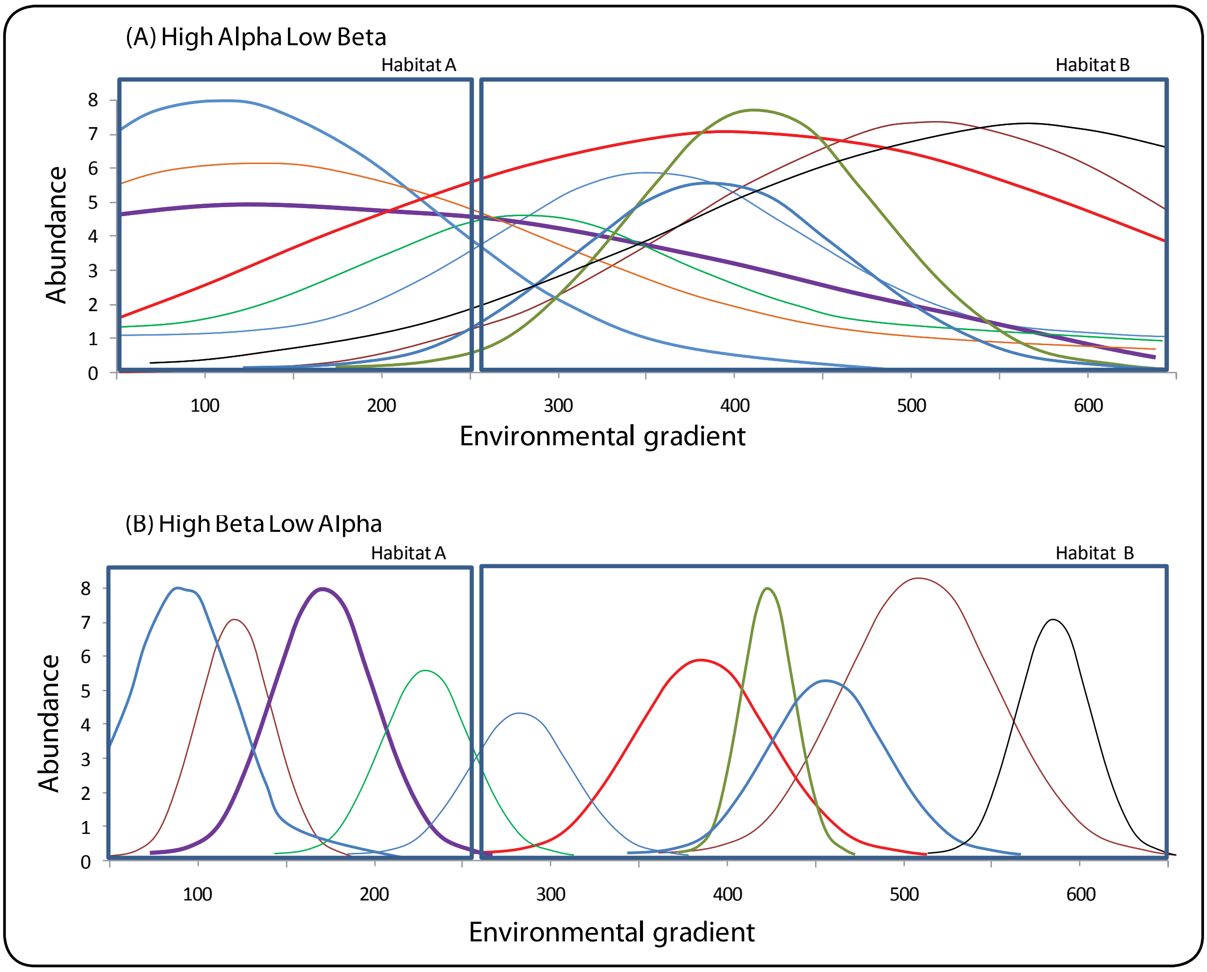


Figure 5.1: **A symbolic illustration of biodiversity changes over an environmental gradient, illustrating the difference between alpha and beta diversity. γ-diversity is the same in both figures as the same 10 species are found in both. Each species is represented by a coloured line, with the height of the line representing abundance (individuals of the species per unit area) at each point on the environmental gradient. The figure also illustrates how species can have wide environmental tolerances (generalists) as in (A) or narrow tolerances (specialist) as is in (B) and how this can lead to habitats with unique species, versus habitats that though different, share all of the same species. In both figures the environmental gradient is split at 250, two artificially defined habitats A and B.**

narrow habitat tolerances and are referred to as specialists. If a species range is naturally restricted to only one area in the world then it is referred to as an *endemic* species (to that area, and an *alien* outside of that area).

Since biodiversity is multi-faceted, quantifying biodiversity and its changes is non-trivial. Clearly, measuring biodiversity comprehensively requires more than simply making a list of the species that are present. Simply listing the species present tends to create a bias toward the well studied and easy to find and identify taxa. A large number of indices on biodiversity have been proposed (see Magurran (2004) for a recent summary). It is beyond the scope of this Chapter to go into details of all the potential biodiversity measures. Nevertheless, it is important to select one or a few indices that meet the needs of the specific task. Many biodiversity indices impose unattainable data needs, focus on a single scale and aspect of the biodiversity hierarchy, or are scale-dependent and thus hard to interpret in a comparative context (Biggs et al. 2004). For the purposes of this chapter we focus on the Biodiversity Intactness Index (BII), for reasons summarised in section 5.5 and expanded in Scholes and Biggs (2005) and Biggs et al. (2006).

Biodiversity is not spread evenly around the globe. In general, species richness increases from the Polar Regions toward the tropics. Developing countries, which are largely within the tropics, therefore tend to have far higher biodiversity than is found in more temperate regions of developed countries. As a general rule tropical regions are historically less transformed than temperate regions, and hence contain more of their original biodiversity. Recent accelerated levels of land transformation in the tropics, including land transformation for biofuels, is placing an increasing threat on tropical biodiversity. As the level of biodiversity is so high in these reasons, so is the potential for large amounts of biodiversity loss (MA 2005).

5.2.2 Why is preserving biodiversity important?

The extinction of species has occurred over the period of historical record (the last few hundred years) at a rate estimated to be one hundred times higher than the long-term average rate calculated from the fossil record (MA 2005). This accelerated rate is attributable almost entirely to anthropogenic (human-induced) causes, principally habitat loss and overharvesting (Sala et al. 2000; Sala et al. 2005). Modelled predictions of extinction rates in the twenty-first century predict a further acceleration (MA 2005; GBO3 2010).

The loss of biodiversity can have direct negative consequences on humankind. Preserving biodiversity is therefore both an ethical and an economic consideration. Biodiversity loss is considered of such global significance that a UN Convention is in place to facilitate the conservation of biodiversity, which has been signed by virtually every country in the world (United Nations Convention on Biological Diversity UNCBD 1973). Understanding the direct importance of biodiversity to humans is best explained though the concept of ecosystem services. Ecosystem services are the benefits people obtain from nature. The Millennium Ecosystem Assessment (MA 2005) distinguishes four key clusters of ecosystem services: provisioning; regulating; cultural and supporting (Figure 5.2). All our food, and much of our fuel and fibre, is derived from living organisms in ecosystems (including highly modified ecosystems, such as croplands and plantations) – these are examples of provisioning services. Though only a small

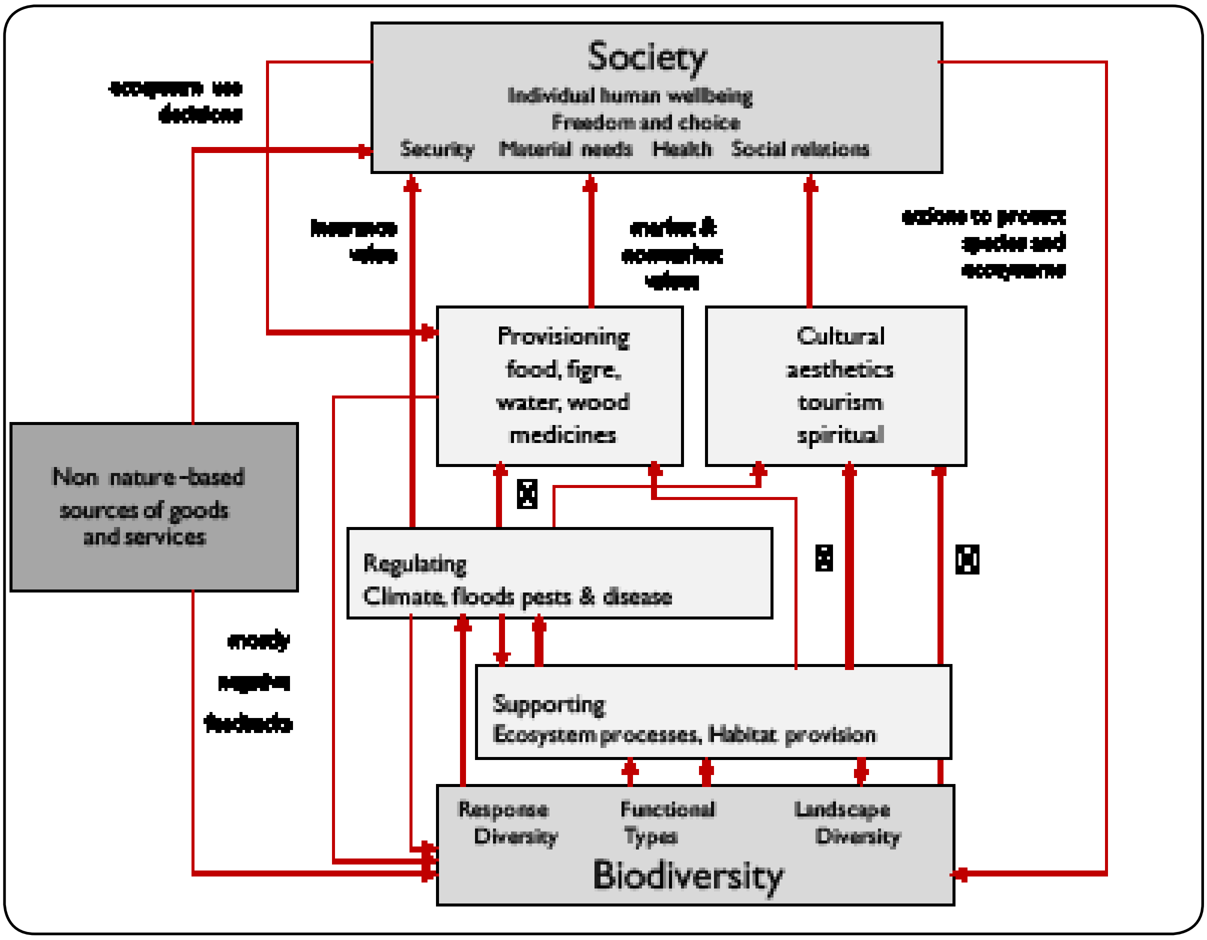


Figure 5.2: **The pathways and processes by which biodiversity influences ecosystem services, and ecosystem services influence human wellbeing. The value of supporting services, most of the value of regulating services and most of the aspects of biodiversity is contained within the value of the directly-used provisioning and cultural services. These underlying elements can influence the direct services through altering the mean magnitude of the service (μ) or its variability in time (σ) or its variability in space (γ).** From Kinzig A., C. Perrings and R.J. Scholes unpublished.

fraction of organisms have been domesticated for human use, the gene pool in wild relatives and in as-yet unused organisms is important in ensuring that we maintain our ability to adapt crops and livestock to changing environmental conditions, and to discover and develop new medicines, compounds and structures. Many widely-used medicines originated from plants or other organisms and it is almost certain that many more useful compounds will be discovered over time.

The deliberate simplification of ecosystems, for instance through mechanised monocultural cropping using high inputs of nutrients, water and pesticides, has been the key mechanism for increased provisioning services such as food, and fuel over the past century. This has generally been at the cost of other services - even of other provisioning services such as water and biodiversity (MA 2005).

Loss of regulatory services can have devastating impacts. An example is the 'dustbowl' in the American Midwest in the 1930s, a consequence of converting diverse, perennial natural grasslands to annual cropland. The loss of ground cover to bind the soils, coupled with drought, gave rise to extensive wind erosion and large dust storms. In other examples, degradation or invasion by alien species has resulted in changes to the hydrological function of a catchment which has in turn led to increased flooding and increased river pollution in one case and decreased river low-flows in the other. The phenomenon of global climate change is to some extent a loss of regulatory services. About a quarter of CO_2 emissions are linked to land use change, including deforestation (IPCC 2007).

Cultural services from the environment are important for both the spiritual, physical and psychological wellbeing of people, as well as having economic significance in aspects such as tourism and recreation.

Supporting services underpin all other environmental services. A breakdown in the supporting services (which include aspects such as soil formation, primary production and nutrient cycling) will reduce the ability of the environment to generate provisioning, regulating and cultural services.

Biodiversity is important in all ecosystem services, directly or indirectly, although the relationship is often quite complex and subtle. There is firm evidence that diverse ecosystems, in general, are both more productive and more resilient to stress than less diverse ecosystems (MA 2005).

In addition to the direct human benefits derived from biodiversity (the so-called ‘utilitarian’ value of biodiversity), there are also ethical reasons as to why humans should maintain biodiversity (sometimes referred to as ‘intrinsic value’ arguments).

5.3 Likely Impacts of Biofuel Production on Biodiversity

Biofuel expansion, if not carefully regulated, has the potential to have very high impacts on biodiversity, especially as a consequence of habitat loss. It is counter-productive to fight one global environmental problem, climate change, and simultaneously exacerbate a second global environmental problem by increasing biodiversity loss. This is, however, a complex tradeoff since climate change is also predicted to have profound impacts on biodiversity (Thomas et al. 2004). Changes in temperature and rainfall regimes will displace habitats. Since temperatures are predicted to rise this will displace the zone of climate preference for most species polewards or to higher altitude. It is likely that a significant fraction of species will totally lose their current habitats and will thus ultimately become extinct unless intervention steps are taken (Hannah et al. 2002; Thomas et al. 2004). Though biofuels can in part mitigate climate change impacts, this positive impact is likely to be very small compared to the high negative land transformation costs. The synergistic impact of both land transformation and climate change will have a double blow to biodiversity with transformed habitats making it much harder for species to adapt to climate change.

5.3.1 Habitat loss

Land cover change (both direct and indirect) is the single biggest biodiversity concern from biofuel feedstock production. To grow biofuels will require land, and since biofuels are grown mostly as monocrops, this will result in the loss of most existing biodiversity from the area planted. When replaced by a biofuel monocrop, the structural, functional and compositional diversity of the original habitat is replaced, with a single functional response, highly reduced structural diversity and very limited species diversity. This impact will be greatest where previously intact natural landscapes are transformed. Land clearing results in habitat loss. In response, some policies encourage biofuels to be grown on so-called degraded land or land formerly used for other monocultural crops, and in this case the additional impact on biodiversity loss is small. But if vast volumes of biofuel are to be produced, as would be required to meet the more than 50 biofuel policies and mandates worldwide (Peterson 2008), then this cumulative demand will require the opening up of new land for biofuel plantations.

5.3.2 Impacts of iLUC

Only locating biofuel plantations on land already used for agriculture or grazing does not automatically reduce the risk of biodiversity loss since there is a very real threat of causing indirect land use change (iLUC). This process is also known as 'leakage' or 'displacement' and is shown in Figure 5.3. Put simply, because current agricultural land is converted to biofuel, new agricultural land needs to be sought to make up for the agricultural shortfall resulting from the reduced agricultural production. iLUC is difficult to quantify because the impacts of iLUC are by definition expressed in spatially separate locations from the biofuel production area itself. These locations could be remote being in other countries, or even on the other side of the world. There is strong circumstantial evidence that biofuel expansion has resulted in iLUC (see Chapter 4 this volume). For example, indirect land use change attributed to biofuels is considered one of the drivers for the current high rates of Amazon deforestation (Morten et al. 2006). Ways to reduce the risk of causing iLUC include:

- Increasing agricultural productivity (reducing the need for increased agricultural area)
- The use of biofuel by-products (biofuels might be able to provide food or feed as well as fuel)
- 'Second generation' biofuels (the so-called second generation biofuels make use of crop residues, allowing fuel and food to be come from the same land)

The biodiversity assessment methods discussed in this chapter relate predominantly to direct land use impacts, but are also applicable to situations where indirect land use impacts can be quantified.

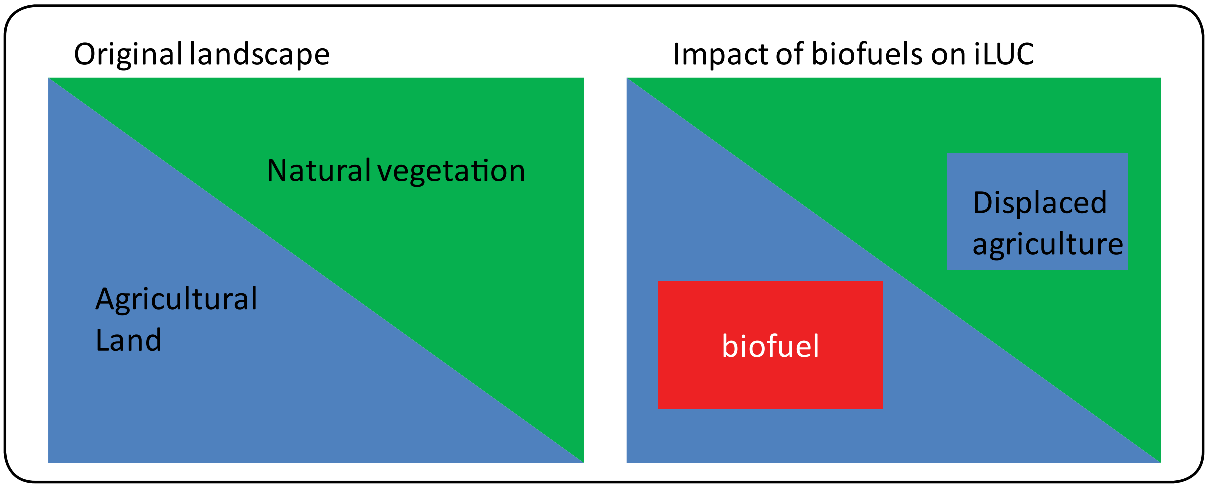


Figure 5.3: **A simple diagrammatic example of iLUC on land transformation of natural vegetation. Though biofuels feedstock growing took place on agricultural land, natural vegetation was converted to make up the agricultural production loss due to biofuel. Note: this displaced agriculture need not occur locally and could be of a different spatial extent due to different productivity levels.**

5.3.3 High diversity importance of developing countries

As stated above, most developing countries are located in the tropics, and hence in intrinsically biodiverse areas. This therefore increases the potential for biodiversity loss from habitat change. In addition some of these tropical habitats have been identified as areas with high levels of threatened species. For instance, the Millennium Ecosystem Assessment found tropical and sub-tropical moist broadleaf forest to be the terrestrial habitat type with by far the highest number of threatened vertebrate species (MA 2005). This habitat type is undergoing rapid transformation to oil palm plantations in SE Asia and to soybean fields in Brazil. Both these crops are potential biofuels, though currently only a small percentage of their oil is used for biofuel with the remainder being used for food or fodder. Tropical and subtropical dry broadleaf forest, and tropical and subtropical grassland, savanna and scrubland all have high levels of threatened vertebrate species (MA 2005). These ecosystems are potential locations for expansion of the oilseed *Jatropha curcas* as well as for numerous other grain and oilseed crops. Sugarcane is also a potential biofuel crop in these habitats, especially where water is available for irrigation. This potential for high biodiversity loss places an added burden on tropical areas when considering potential biofuel expansion.

5.3.4 Impacts from invasive alien species

The introduction of invasive alien species (IAS) is a direct and indirect threat to biodiversity though it has received little attention compared to other sustainability issues associated with biofuel production. Alien species are plant or animal species not native to a specific location. If these species are introduced and can reproduce, establish and expand on their own, then they are considered invasive. That is to say they becoming naturalised and a pest in their new environment (Pheloung 2003). The concern with IAS is that they are able to competitively displace the indigenous species, largely because they lack natural predators in their new environment. They might even alter the habitat by being of a different structure (e.g. tree species in grassland), through impacting on fire regimes (for instance by being highly flammable and tolerant of fire), soil fertility (e.g. through fixing nitrogen), soil hydrology (through sustained high transpiration) or other aspects of the environment. The total economic cost of IAS can be enormous and controlling IAS is costly and difficult. Alien invasive species have, for instance, been estimated to cost the USA agricultural industry $77.8 billion per year, and the cost to restore the Cape Floristic region to its pristine state without aliens is estimated as $2 billion (Pimentel et al. 2005; Turpie and Heydenrych 2000). Despite the fact that very few introduced species become invasive (Pimental et al. 2005; Zaveletta 2001) it is far better to prevent invasion rather than attempt to eradicate or control a species once it has invaded (Lockwood et al. 2001). Biofuels, and especially what are termed second generation biofuels, hold a high risk of becoming IAS, specifically because the very features that make for a good biofuel are the same features that are common in invasive species. These include rapid growth, aggressive colonisation of space, ease of establishment, wide habitat tolerance and resistance to pests and diseases. In addition to potential biofuels feedstocks themselves being invasive, the uncontrolled movement of biofuel products can act as a vector for the transportation of other potential pests and pathogens that might be invasive (IUCN 2009). Section 5.8 of this Chapter will focus on methods for limiting invasion risk.

5.3.5 Additional biodiversity risks

Though of lesser importance than land use change and invasion, there are a number of other mechanisms through which biofuels can impact on biodiversity during both the growing of feedstock and the processing of biofuels. These include:

- Pollution in waterways from fertilisers and pesticides applied to the biofuel fields, sediments washing off of them, and salts draining out of irrigated biofuels. This can impact on downstream waterways and wetlands causing eutrophication and toxin accumulation.
- Reduction in streamflow resulting from growing perennial, deep-rooted biofuel species in formerly seasonal grasslands. This has the further effect of exacerbating the water quality impacts noted above, through loss of dilution potential.
- Impacts of pesticides and herbicides on target and non-target species, as well as impacting on predators of these species.
- Pollutions from processing plants that are discharged into river systems. This includes adding organic matter to rivers which results in high Biological Oxygen Demand (BOD).
- Changes in hydrology leading to drying out of wetland systems.
- Impacts on soil micro-organisms through cultivation and the removal of food sources.
- Habitat fragmentation which impacts on species movement and dispersal.

These additional threats to biodiversity will not be specifically considered in this Chapter, but their potential impact on biodiversity should not be ignored.

5.3.6 Can biofuel plantations provide the same ecosystem services as natural forests?

Biofuel plantations have been proposed as a mechanism for reclaiming degraded land, reforesting deforested areas and as crops for marginal areas. In effect the suggestion is made that biofuel plantations may be a mechanism for increasing the flow of environmental goods and services (or even increasing biodiversity) in these damaged areas (Ghosh et al. 2008). Can biofuel plantation be beneficial to biodiversity? In general the answer would be no, but under specific conditions it is feasible that biofuel plantations may be a more favourable land use option than the prevailing land use from a biodiversity and/or ecosystem service perspective. This would be very situation specific: it depends on the current land use and condition, which biofuel is to be grown and how it will be managed. Research data to back up this claim is relatively limited. In some circumstances biofuel crops may be less environmentally detrimental than other agricultural crops (for instance, where the pesticide or fertiliser inputs are lower or the rotations are longer). But where biofuel crops replace other crops, iLUC impacts are likely. Furthermore, it is wrong to assume that marginal lands are low in biodiversity; low-productivity lands are often extremely biodiverse, especially where the high-productivity lands have already been transformed.

A number of studies have compared aspects of biodiversity in oil palm plantations to natural forest and degraded forest. For most taxa and functional groups the oil palm plantation had far lower diversity of indigenous forest species than the adjacent indigenous forest, though may have higher values that heavily degraded forests such as when transformed to *imperat*a grasslands (Danielsen et al. 2009; Koh and Wilcove 2008; Fitzherbert et al. 2008). Some examples include:

- Oil palm plantations have a 77% reduction in forest bird species and 83% reduction in forest butterfly species compared to adjacent mature forest. In the oil palm plantations these taxa are fewer than in comparable logged forests, or rubber plantations (Koh and Wilcove 2008).
- A mean across a number of studies found only 31% of forest invertebrates and 23% of forest vertebrates in oil palm plantations. Total species numbers in oil palm plantations were 89% and 38% of forest species density for invertebrates and vertebrates respectively (Danielson et al. 2009).
- Palm plantations were found to have few or no forest trees, lianas, epiphytic orchards or indigenous palms, but had a higher diversity of pteridophytes (ferns) than mature forest (Danielsen et al. 2009).
- The diversity that does exist is mostly of non-forest species (Danielsen 2009).
- Biodiversity in oil palm plantations tends to be dominated by a few generalist species and often by exotic invasive species (Danielsen et al. 2009; Koh and Wilcove 2008).
- Palm forests, have more forest species in some taxa than *Imperata cylindrica* (itself an IAS in this circumstance) grasslands (Fitzherbert et al. 2008).

Sugar cane is known to support relatively limited biodiversity (Oliver 2005). There are a few taxa that do well in cane plantations - including rats, snakes, spiders and ants. Due to the vigorous growth of cane, very few other plant species are found in cane plantations. The plant species that do occur are mostly weeds, and quite commonly invasive aliens. Bird diversity in cane plantations is also low (Petit et al. 1999; Martin and Catterall 2001).

Almost no data are available on the biodiversity impacts of Jatropha plantations. One of the selling points of Jatropha for famers is the toxicity of the fruit and leaves to mammals. It is probable that the management practices applied to the Jatropha plantation will have a big impact on the biodiversity. Some Jatropha projects such as GEM Biofuels in Madagascar plant Jatropha directly into degraded savannas or grasslands with relatively limited immediate impacts on current biodiversity. Other projects, such as ESV Bio-Africa Limitada in Mozambique, plough the site before planting, effectively destroying most existing biodiversity. Everson et al. (In Press) have found that fully clearing the herbaceous layer during early years of the plantations greatly increases oil yield, so clearing may well become a common practice. If an indigenous herbaceous layer is maintained in Jatropha plantations and the trees are widely spaced, then the habitat will maintain some characteristics of the original, and will clearly support greater biodiversity than if all indigenous vegetation is cleared and Jatropha is grown as a monoculture.

Biofuel plantations fall short of indigenous forests, savannas, shrublands, wetlands or grasslands in terms of their ability to provide habitat for biodiversity. Oil palm plantations and Jatropha plantations probably maintain more natural biodiversity than sugar cane plantations or annual crops such as soybean. They might in extreme cases also maintain more biodiversity than badly degraded landscapes or alternative annual crops. Other tree crops such as coffee, cocoa, rubber or *Acacia mangium* tend to maintain greater forest diversity than oil palm (Fitzherbert et al. 2008).

Biofuel plantations, though not equivalent to indigenous vegetation, might maintain certain environmental services to a degree, especially in contrast to other alternatives. Services which are partly supported include; soil formation and stabilization, carbon sequestration, stream flow regulation and flood mediation. The degree to which these services are maintained will be dependent on actual management practices employed and will vary between feedstock crops. For instance maintaining an understory of indigenous grass within a Jatropha plantation will support more ecosystem services than if the understory is kept totally clear of vegetation. Mechanical harvesting of sugar, where the toppings are returned to the soil as a mulch maintains greater soil carbon, and reduces erosion when compared to manual harvesting after burning (Noble et al. 2003). In general a perennial crop is likely to maintain more ecosystem services, and more reliably, than annual crops.

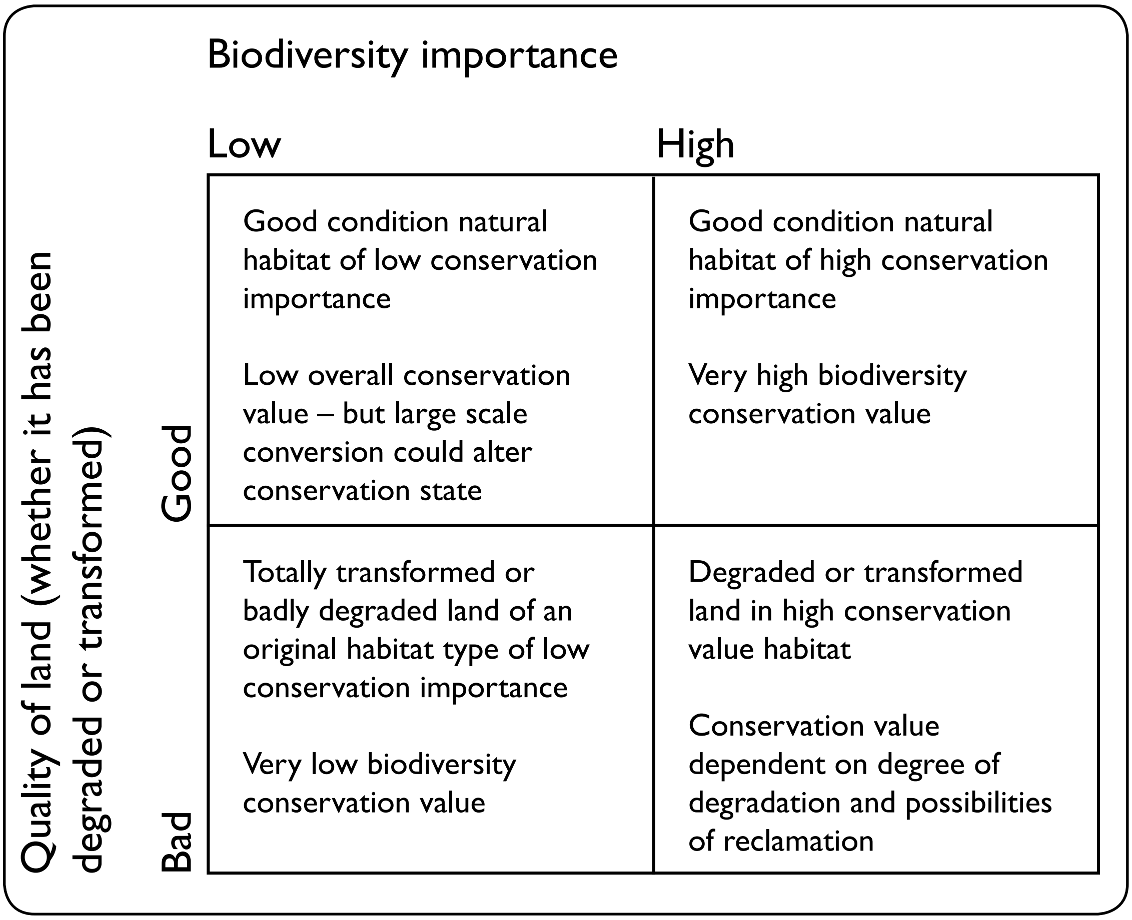
A common feature in biofuel literature is the notion that biofuel feedstock, especially Jatropha, can be grown on degraded, waste, unproductive or marginal land. Even if grown in degraded areas there is limited data to substantiate if this will have positive biodiversity impacts or not; and the reality is that Jatropha will more likely be grown in good areas because this improves the economics of production. While Jatropha can survive in degraded lands, it is at the expense of higher yields that would be obtained with optimum soils, water and nutrient inputs. Unfortunately, definitions of what constitutes these different land categories are seldom given, and the terms are often used interchangeably. From a biodiversity perspective there is a concern that what might be considered as 'marginal' or 'waste land' from an agronomic or livestock grazing perspective, might be a highly biodiverse area from a biodiversity perspective. For example, the Succulent Karroo biome of South Africa is an area of very low rainfall (almost exclusively falling in winter) located along the South African western coast. This area has very limited agricultural value, but has a long evolutionary history and exceptionally high species diversity of endemic flowering plants (Cowling and Hilton-Taylor 1994; 1997), contributing about half of the world's succulent flora.

5.4 How to Identify Areas of Potential Biodiversity Concern for Biofuel Development?

Land transformation to plant biofuels is the single biggest biodiversity concern. This concern is especially relevant to situations where near-intact indigenous habitats are transformed. The degree of biodiversity impacts from the growing of biofuels will differ between different habitats and land use change scenarios. Some habitats are more of a concern in terms of potential habitat transformation and the resulting biodiversity loss than others. In addition, the current status of the land in terms of degradation and transformation is an important determinant of potential biodiversity loss.

Two aspects underpin the severity of biodiversity impacts. One is the importance of the habitat for biodiversity protection, and the other is the degree to which the proposed land is degraded or already transformed. A simple matrix (Figure 5.4) illustrates that it is untransformed areas of high biodiversity importance which are likely to have the greatest biodiversity conservation value. However, determining what constitutes 'important' from a biodiversity protection perspective is non-trivial and may well change over time. The following are some of the features that will indicate that a specific habitat is likely to have a high biodiversity conservation value:

- The area has been identified as a region of global biodiversity importance (Myer et al. 2000)
- The species richness of the habitat. Habitats with high species richness are likely to have high biodiversity conservation importance



Biodiversity importance

Quality of land (whether it has been degraded or transformed)

	Low	High
Good	Good condition natural habitat of low conservation importance Low overall conservation value – but large scale conversion could alter conservation state	Good condition natural habitat of high conservation importance Very high biodiversity conservation value
Bad	Totally transformed or badly degraded land of an original habitat type of low conservation importance Very low biodiversity conservation value	Degraded or transformed land in high conservation value habitat Conservation value dependent on degree of degradation and possibilities of reclamation

Figure 5.4: **Two way matrix illustrating the interplay between land degradation and biodiversity importance when determining conservation importance**

- The degree to which the habitat supports endemic and unique species. Endemics, because of their restricted range, are more likely to be driven to extinction, especially if they are relatively uncommon species
- The number of species present in the target areas that are considered as having a high conservation status due to their rarity or likelihood of being driven to global extinction (IUCN red data species e.g. panda bear or tiger)
- The degree to which the habitat is protected elsewhere. If the habitat is overall well protected, developments in the unprotected areas are less likely to be a biodiversity threat.
- Rate of habitat loss. In habitats where the rate of loss is high, additional drivers of habitat destruction should be discouraged
- Extent of habitat transformation compared to its historic extent. In habitats that are already highly transformed, any additional transformation should be discouraged
- The total spatial extent of the habitat. Transformation in small unique habitats will have disproportionate impacts on biodiversity
- The degree to which the area is a large, natural, undisturbed, unfragmented, fully functioning ecosystem; i.e., does it still maintain a 'wilderness' nature[16]

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[16] The words 'pristine', 'virgin' or 'wilderness' are sometimes inaccurately used to describe such situations. Nowhere in the world is pristine anymore, and a certain low level of disturbance is in fact beneficial for biodiversity. The key issue is whether the ecological processes that allow the habitat to persist and regenerate without external inputs are still in place, and the full suite of functional types are present in more-or-less their natural proportions.

- The extent to which the habitat provides important ecosystem services, especially where they may impact on other habitats (e.g. a wetland provides clean and regulated water to downstream river and estuarine habitats).

Where biofuels are grown on already-transformed agricultural lands, abandoned mine dumps, highly degraded landscapes etc., the biodiversity impacts many be minimal or even positive. However, if agriculture is being displaced by biofuels then there is a very real possibility of indirect land use change (iLUC) and its resultant biodiversity impacts (see Figure 5.4). Growing biofuels on abandoned agricultural lands and other degraded land will have relatively low impacts on biodiversity or possibly even positive impacts.

It is important to remember that not growing biofuel feedstock also has consequences to biodiversity since current and alternative future trends in land use may also have biodiversity consequences which could be either negative or positive. Further, if a biodiversity project is not implemented in a region, this does not automatically imply that the area's biodiversity will be preserved. The opposite could also be true. Current degraded land, if not converted to biofuel, might undergo successional changes back to secondary and eventually mature forest; but it may also continue to degrade, or be used for other agricultural or exploitation purposes that are even more damaging to biodiversity than a biofuel plantation.

5.5 Strategic Assessment of Likely Biodiversity Impacts (the BII Approach)

From a strategic national or regional (provincial[17]) perspective a biodiversity assessment tool is required by policy decision makers to investigate likely impacts from large scale biofuel expansion. The tool needs to be able to investigate likely consequences of different scenarios such as the type of biofuel crop envisaged and where the plantings will take place in terms of habitat types and current land use options. In this regard 'mean species abundance' approaches, such as the Biodiversity Intactness Index (BII) are regarded as an appropriate tool. BII has been widely tested and is well documented (e.g. Scholes and Biggs 2005; Biggs et al. 2006). A simple user manual has been produced by Nickless and Scholes (2009) and is available for download[18]. Extracts from the manual are given below as well as an example of its use to investigate possible impacts from large scale biofuel expansion in the Eastern Cape, South Africa.

In determining consequences of biofuel expansion there are likely to be complex tradeoffs between many different aspects of biofuel impacts. Clearly many of these impacts, such as the biodiversity impact, cannot be accurately and rigorously expressed in monetary value terms. To compare these different types of impacts, expressed in non-commensurate terms, some form of multi-criteria decision analysis is the favoured analytical tool. In this regard the BII is an appropriate method for determining relative biodiversity impacts of a number of competing land use options as an input into multi-criteria decision making.

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[17] The term regional is used throughout to refer to regions within a country such as provinces or states. The BII could also be used for assessments of regions consisting of multiple countries.

[18] http://www.ceg.ncl.ac.uk/reimpact/

The Biodiversity Intactness Index (BII) is a measure of the abundance of individuals, averaged across a wide range of well-known elements of biodiversity, relative to their abundance in a defined reference case (Scholes and Biggs 2005; Biggs et al. 2006). It is an indicator of the average abundance of a specified set of organisms (or functional groups of organisms) in a given geographical area (Scholes and Biggs 2005).

The BII was created as part of the Southern African Millennium Ecosystem Assessment to provide an easy-to-understand overview of the state of biodiversity for policy-makers and the public (Biggs et al. 2006). Specifically, the BII was designed to fulfil the requirements set out by the Convention on Biological Diversity (CBD) which stipulated that an indicator for biodiversity change should be scientifically sound, be sensitive to changes at policy-relevant spatial and temporal scales, allow for comparison with a baseline situation and policy target, be useable in models for future projections, and be amenable to aggregation and disaggregation at ecosystem, national and international levels (CBD 2003a; Scholes and Biggs 2005; Biggs et al. 2006). In addition it requires that the index be easy to understand and use, broadly accepted and measurable with sufficient accuracy at affordable cost (Biggs et al. 2006). The BII is intended to provide a single, integrated measure of biodiversity, for instance in assessing progress towards the CBD goal to "achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level" (CBD 2003b; Mace 2005). The ability to use the index to explore impacts from future land use scenarios makes it of particular importance for assessing potential biodiversity impacts from large biofuels programmes. In this regard, the biodiversity score comparing a landscape with and without biofuel plantations can be easily computed.

The BII is an aggregate index. It is weighted by the area subject to different land use activities, which can range from complete protection to extreme transformation (e.g. in the case of urbanization), and the number of species occurring in the particular area (Scholes and Biggs 2005). Because of the area and species weighting, the BII is essentially scale-independent, and taxonomically unbiased. It can thus be aggregated and disaggregated in many ways. It can be expressed by ecosystem or political unit, or by taxonomic group, functional type, or land use activity. This capability provides the BII with transparency and credibility (Biggs et al. 2006, Scholes and Biggs 2005). The BII can be used to describe the past (Biggs and Scholes 2007) or project into the future (Biggs et al. 2008). The BII also has an associated error bar, allowing the user to monitor the degree of uncertainty (Biggs et al. 2004; Scholes and Biggs 2005, Hui et al. 2008). Critiques of BII, and suggested improvements, can be found in Rouget et al. (2006) and Faith et al. (2008).

BII is not the appropriate tool for examining impacts on rare and endangered species, since the changes in these species will be obscured by the variations in the more abundant species. For this purpose, it is suggested that approaches such as the 'Red List Index' are used, which focus on threatened species (IUCN 2003). As a general principle, it is unlikely that a single indicator will suffice for all purposes. But to avoid a proliferation of indicators, we suggest that a minimalist approach is to have one that reflects changes in the mean state of biodiversity (such as the BII) and one that looks at the fringe of the abundance distribution (i.e. rare and threatened species).

5.5.1 The BII Algorithm

The principles underlying the BII are discussed in Scholes and Biggs (2005) and Biggs (2005). The BII gives the average richness- and area-weighted impact of a set of activities that can be associated with a defined spatial domain on the population of a given group of organisms in an assessment area, which can contain many such activities. The BII is the estimated average population size of a wide range of organisms relative to their baseline populations for a given area (Biggs 2005; Scholes and Biggs 2005). A value >1 would indicate an increase in biodiversity and a value <1 a decrease of biodiversity with reference to the chosen baseline populations. The BII is calculated by:

$$\mathrm{BII} = \frac{\sum_{i}\sum_{j}\sum_{k} R_{ij} A_{jk} I_{ijk}}{\sum_{i}\sum_{j}\sum_{k} R_{ij} A_{jk}}$$

where

R_{ij} = Richness of taxon *i* in ecosystem *j*
A_{jk} = Area of land use *k* in ecosystem *j*
I_{ijk} = (Size of population of taxon *i* under use *k* in ecosystem *j*)
Size of population the reference time
(Biggs 2005; Scholes and Biggs 2005).

'Taxon' means a group of organisms that are expected to react in a similar way to the activities associated with various land uses. Typically, the definition of a taxon for the purposes of BII begins with a traditional high-level taxonomic approach (i.e., mammals, birds, amphibia, reptiles and plants are treated separately), but below this follows a 'functional type' approach rather than a strictly phylogenetic approach (e.g. 'trees' rather than a particular family or genus).

Three basic input factors are needed to calculate the BII: Richness (R_{ij}), area (A_{jk}) and relative population size (I_{ijk}), defined in terms of specific taxa (*i*), ecosystems (*j*) and land uses (*k*) (Biggs 2005). Biggs (2005) discusses the considerations that need to go into the definition of *i*, *j*, and *k* and the determination of R_{ij}, A_{jk} and I_{ijk}. This is summarised below.

5.5.2 Taxa (*i*)

The BII should be calculated across all indigenous species within the broad taxonomic groups that are reasonably well described. This usually includes plants and vertebrate species, such as mammals, birds, reptiles and amphibians. The invertebrates and microbes are typically excluded at regional, national and global scale because, although diverse, they are generally poorly documented at these scales (it is estimated that less than 10% of the probable number of species in these groups have been scientifically described). However, if at a project scale a reasonably stable and complete species list exists for any group it can, and should, be included in the calculation of the BII. The idea is to reduce bias in the estimate by making it as broad-based as possible. Alien species should in general not be included if they were not present at the time of the baseline establishment. An increase in the abundance of aliens is not generally regarded as a 'good thing' for biodiversity. Invasion by a diverse array of aliens could increase the apparent BII, sending the wrong interpretive signal. Where their population is zero in the baseline case, their inclusion can lead to mathematical problems (division by zero). However, in certain circumstances alien species can be regarded as "naturalized". These species can then be included if the baseline population level is not zero and can be viewed as the equilibrium population level. As an example, for long-established agricultural landscapes, organisms that originated elsewhere may be used.

5.5.3 Land uses (k)

Land uses are defined by the major human activities impacting on biodiversity in a particular region. These land uses are expressed in terms of their 'footprint': the area that they affect. The number of classes of land use should generally be limited to ensure that the number of I_{ijk} estimates is manageable: less than ten might be a good guideline. Scholes and Biggs (2005) used six categories of land uses in their application of the BII to the southern African region: protected, moderate use, degraded, cultivated, plantations and urban. The land use classes need to be defined clearly in order that the estimates of impacts on populations can be unambiguously assessed. An example of the land use definitions used in the southern African example (Scholes and Biggs 2005) appears in Table 5.1. A land use map should be created using available information, such as satellite or aerial photo images or ground-derived land-cover maps and land tenure boundaries. Where different data sources lead to an overlap of different land use activities, the highest impact land use class should be assigned.

The resolution of the land use map will affect the estimation of the I_{ijk} and, if the information obtained for land uses is too coarse, it can result in a significant decrease in the accuracy of the BII (Rouget et al. 2006). The impact of habitat fragmentation, as opposed to habitat area loss, can be incorporated in the definition of the land use categories if it occurs at a resolution much smaller than the land parcels under consideration. Or, if it occurs at scales larger than the resolution of the land use classes, it could be incorporated using a species-area curve approach suggested by Faith et al. (2008). If certain impacts are not associated entirely with one class, then multiple classes need to be defined. For example, in the southern African case, the protected areas land use class can be divided into large and small protected areas, thereby accounting for fragmentation. A separate estimate of I_{ijk} would then be obtained for each of these classes. Rouget et al. (2006) recommend carrying out detailed land use surveys in order to ensure that the BII scores calculated are reliable.

Activities that have an impact which can be given an aerial footprint, but are additional to the direct and local effects of the land use (for instance climate change or air pollution) are not dealt with by the standard definition of BII (Biggs and Scholes 2005). Where they are important, they should be applied as a multiplier to the I_{ijk} score due to land use, wherever they apply. Say, for instance, that there is robust information that climate change has caused a 30% reduction in population abundance, then the land-use I_{ijk} for all the affected species, under all land uses within the affected area, would be multiplied by 1- (30/100) = 0.7.

5.5.4 Ecosystems (j)

Broad-scale associations of organisms with particular abiotic environments can be defined as ecosystems, and can typically be arranged into several hierarchical levels. For BII purposes, these ecosystems need

Table 5.1: **Example of land use definitions from Scholes and Biggs (2005)**

Land use class	Description	Examples	Data source
Protected	Minimal recent human impact of structure, composition or function of the ecosystem. Biotic populations inferred to be near their potential.	Large protected areas, national, provincial and private nature reserves, 'wilderness' areas.	World Database on Protected Areas. All designated protected areas of IUCN categories I-V.
Moderate use	Extractive use of populations and associated disturbance, but not enough to cause continuing or irreversible declines in populations. Processes, communities and populations largely intact.	Forest areas used by indigenous people or under sustainable, low-impact forestry; grasslands grazed within their sustainable carrying capacity.	All remaining areas not classified into one of the other five categories.
Degraded	Extractive use at a rate exceeding replenishment and widespread disturbance. Often associated with high human population densities and poverty in rural areas. Productive capacity reduced to approximately 60% of 'natural' state.	Clear-cut logging, areas subject to intense harvesting, hunting, fishing or overgrazing, areas invaded by alien vegetation.	All areas falling below 75% (forest, grassland and savanna) or 50% (shrublands) of expected production as estimated by nonlinear regression (Michaelis-Menten function) of maximum annual NDVI on growth days. Degraded areas not estimated for desert, wetland and fynbos.
Cultivated	Natural land cover replaced by planted crops. Most processes persist, but are significantly disrupted by ploughing and harvesting activities.	Commercial and subsistence crop agriculture, both irrigated and dry land, including planted pastures and fallow, or recently abandoned cultivated areas. Orchards and vineyards.	SADC Landcover Data set, filled with GCL2000 fpr Namibia and Botswana.
Plantation	Natural land cover permanently replaced by dense plantations of tress. Unplanted areas assumed to constitute approximately 20% of class.	Plantation forestry, typically Pinus and Eucalyptus species.	SADC Landcover Data set.
Urban	Land cover replaced by hard surfaces such as roads and buildings. Dense populations of people. Most ecological processes are highly modified. Remnant semi-natural cover assumed to constitute 10% of class.	Dense human settlements, industrial areas, transport infrastructure, mines and quarries.	Urban extents.

to be defined at a spatial level so that the appropriate richness weighting (R_{ij}) can be allocated to each area for the calculation of each I_{ijk}. All three of these classifications (R_{ij}, A_{jk} and I_{ijk}) can be expressed at different hierarchical levels. In the example of calculating BII for all of southern Africa, the WWF Ecoregions (Olson et al. 2001) were used as the basic information on the spatial extent and species richness of ecosystems. These ecoregions (about 30) were aggregated into six high-level biomes for the subcontinental study (forest, savanna, grassland, shrubland, fynbos and wetland), since this led to a manageable number of cases to consider. It was found that if too many ecosystem types were defined, the experts ended up giving them exactly the same impact scores anyway. In this case, R_{ij} and A_{jk} were determined in terms of the disaggregated WWF ecoregion data, while I_{ijk} estimates were determined at the biome level, and then associated with each of the ecoregions.

5.5.5 Richness (R_{ij})

In the calculation of the BII, R_{ij} refers to species richness across the landscape at the reference point in time (normally, prior to the onset of the land transformation process that is under consideration). In general, species richness is available as total species counts for each broad taxonomic group, per ecosystem type, for the 'well-known' biodiversity. Species-by-species distribution data is usually not available for more than a few species for large areas, but it may be available for smaller areas, or places with relatively low biodiversity. Where the potential geographical distributions for individual species are available, these can be used in conjunction with ecosystem-level distributions for other species. There are two approaches for calculating the BII: the raster (pixel) method and the vector (polygon) method. If individual species distribution data is used, the BII should be calculated on a raster basis.

5.5.6 Area (A_{jk})

The area of a particular land use within a specific ecosystem type (A_{ijk}) is determined by overlaying ecosystem and land use maps in a Geographic Information System, after first ensuring they are in the same projection and at the same scale, and correctly geo-referenced.

5.5.7 Relative population size (I_{ijk})

The first step in estimating I_{ijk} (the population size of taxon group *i* under land use activity *k* in ecosystem *j* relative to a baseline population in the same ecosystem) is to define a meaningful and practical reference or baseline population. This reference point will influence the interpretation of the BII. In the southern African context, pre-modern (pre-1700) populations were used as the 'conceptual' baseline, but the practical reference was the current population density in large protected areas, which was assumed to broadly reflect the pre-modern abundances, which are unknown. However, some species have large home ranges, so their levels in large protected areas could conceivably be impacted compared to the conceptual baseline levels. In this case, the effect on the BII of these few species was considered sufficiently small as to be negligible. Parts of the world that were already highly transformed by the start of the modern era can use alternative reference points: for instance a time within record or reliable memory, or even the initiation year of a project. The same baseline should be used when comparing BII between different time points or between different regions.

Field data can be used to estimate I_{ijk} where available, but this will normally only be the case for a few species in a few locations. The value for I_{ijk} calculated from field data is simply some indicator of population density (i.e. some proxy of individuals or biomass per unit area) for an area affected by the land use, divided by the same indicator for the reference area. Since these data are relatively rare and spotty, it is perhaps best to keep them for validation purposes.

Population models can also be used to generate the I_{ijk} matrix where a great deal is known about the underlying drivers of population change. Alternatively, expert judgement can be used to generate this matrix, which can then be validated against field data, as was done in the southern African example.

Where estimates of I_{ijk} are collected using an expert interview process, this can be assisted by subdividing the taxonomic groups into functional types, in consultation with the experts. The same subdivision must be used by all the experts within a taxon. Species in the same functional type should respond in a similar way to the selected land uses. It has been found that body size (or height of the bud, in the case of plants), trophic niche and reproductive strategy are all good criteria for defining functional type. The number of functional types is a practical consideration. In the southern African example about 10 functional types per broad taxonomic group were defined. Classifying plants according to the Raunkier classification (Raunkier 1934) worked well, and the birds and mammals were classified according to size and feeding strategy (i.e. 'herbivore', 'carnivore', and 'omnivore'). Frogs were classified according to breeding strategy as they all were of similar size, and had a similar trophic niche.

Experts specialising in each broad taxonomic group are asked to estimate the impact of each land use activity within the context of each ecosystem type (e.g. biomes) on each functional type in their speciality taxonomic group. In the southern African example, land use (*k*) was considered to be the overriding factor impacting on population abundances, and in this case, the differences in the magnitude of the impact between ecosystem types was small relative to the differences between land use types within an ecosystem. For example, the impact of cultivation in savanna as opposed to cultivation in grassland areas is small compared to the difference in impact between cultivation and urbanisation within a grassland or a savanna. This justified the aggregation of ecosystem types, simplifying the estimation process. Due to the coarseness of the current knowledge regarding I_{ijk}, and the practical constraints of collecting or generating this data, it was in this case sufficient to define I_{ijk} at a relatively broad ecosystem level. Where finer level ecosystem data are available for R_{ij} and A_{jk}, it is recommended that these be used in calculating BII, even if broad-level I_{ijk} estimates are used.

If expert opinion is used in the generation of I_{ijk}, it is important to thoroughly discuss, define and illustrate the land use categories with the experts before beginning the judgement exercise. This ensures that their judgements of the impact of these land uses are accurate and appropriate for each land use category. It is advisable to give the experts examples of each land use category in the area under examination. It is also important that the resolution of these land use classifications is taken into account. For example, if one considers a regional study where the resolution of the land cover and ecosystem maps is 1 × 1 km, and 'cultivated' is a land use category, it needs to be understood that an area mapped as falling into this category is not going to be completely cultivated, but have small inclusions of uncultivated land as well – field edges, contour bunds, riparian strips and set-asides. This needs to be taken into account in the I_{ijk} estimates. In the southern African example, at the 1 x 1 km resolution, areas classified as cultivated were assumed to contain approximately 20% uncultivated land, areas classified as plantations were assumed to contain approximately 25% non-plantation land (in the form of e.g. riparian buffer strips and rocky outcrops), and areas classified as urban were assumed to contain approximately 10% non-built land (e.g. parks with natural vegetation within cities, or undeveloped land such as steep areas, locations within the floodplains of rivers, or rocky outcrops).

Estimates of I_{ijk} were aggregated up from the functional type level to the broad taxonomic level by weighting the estimates for each functional type (*f*) by the number of species in that group in the particular ecosystem type ($I_{ijk} = \sum_{f} \left(I_{fijk} \times \frac{R_{fij}}{R_{ij}} \right)$). Alternatively, if richness (R_{ij}) spatial data can be disaggregated to functional type level, BII can be calculated directly at the functional type level.

It is recommended that at least three experts are interviewed independently for each broad taxonomic group. Experts should not be shown or informed about the magnitude of the estimates provided by others or jointly interviewed to obtain a consensus estimate. Interviews with the experts typically last several hours and result in a few hundred estimates per expert. All estimates should then be entered into the database, and the variability (standard deviation) in expert estimates then enables the determination of the uncertainty around estimates. The range of estimates obtained in this way can then be used to derive a confidence interval for the I_{ijk} estimates (a topic discussed in more detail in Nickless and Scholes 2009) and for the BII as a whole (Hui et al. 2008). For operational applications, this is probably not a necessary step.

5.6 Using the BII to Investigate Provincial Level Impacts of Biofuel Expansion in the Eastern Cape South Africa

The Eastern Cape province (176 377 km^2) of South Africa has been identified as a potential area for canola production for biodiesel. Suggestions have been made that 5 000 km^2 of land be transformed from grassland, savannah or abandoned agricultural fields to canola in an initial project. In addition the Eastern Cape has the potential for forestry expansion with 1 200 km^2 of land being potentially available for this purpose. Though there is no current intent to use this expanded forestry land for bioenergy, it is one potential use of the product.

The Eastern Cape is one of the poorest provinces in South Africa, and has extensive areas under customary land tenure (the ex-homeland areas of the Ciskei and Transkei) as well as extensive areas under private freehold land tenure. The province has relatively high agricultural potential, but in the customary-tenure areas commercial agriculture has almost ceased, and current agriculture is largely small-scale, to supplement household food security. The region therefore has a large area of abandoned agricultural fields, many of which are now reverting to grasslands. Overgrazing means that much of the area is classified as degraded in the land cover maps of the region (NLC 2005) (see Figure 5.5).

The region has areas of high biodiversity value. It includes the Pondoland centre of endemism. The area under consideration for biofuels has three main ecoregions: Drakensburg Montain grassland, woodland and forest (grassland); Maputuland-Pondoland bushland and thicket (bushland) and Kwazulu-Natial coastal forest mosaic (coastal) (Olsen et al. 2001). Though biofuels may not be planted in all three ecoregions due to climatic or social constraints, all are included in the analysis to demonstrate impacts on habitats with limited distribution. The WWF ecoregion classification is used rather than the more recent and detailed classification of Mucina and Rutherford (2006) because it matches the Southern African coverage used by Biggs et al. (2005; 2006) which predated the new biome maps. This enables direct utilisation of the BII scores as derived by Biggs et al. (2006). The Wild Coast region, a strip running along the northern coastline, is an area identified as an area of national conservation priority by the National Biodiversity Conservation Strategy and Action Plan (Driver et al. 2005). Much of the Wild Coast Region coincides with the proposed canola growing region.

The vegetation classes, land use classes and land use biodiversity impact scores of Biggs et al. (2006) are used to investigate scenarios of biofuel expansion in the Eastern Cape province (see Tables 5.2 and 3). A number of alternate scenarios are considered relating to the way in which land is allocated to biofuel.

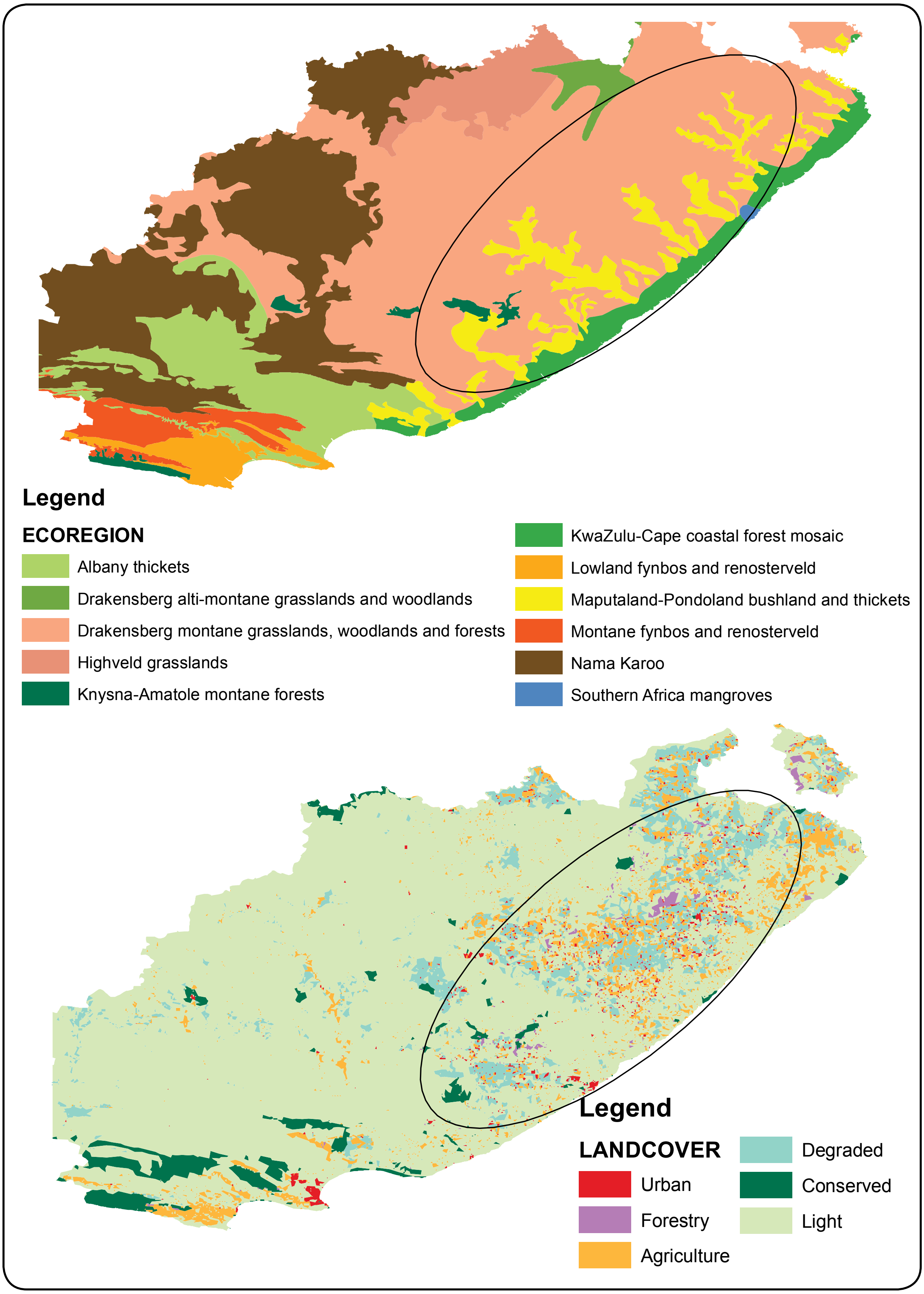


Figure 5.5: **Ecoregions and land cover of the Eastern Cape. The black oval approximates the area being targeted for biofuel expansion.**

Table 5.2: **Species richness of taxa in the Eastern Cape. Note, for the analysis taxa can be further sub-divided into functional groups (from Biggs et al. 2006)**

Ecoregion	Full ecoregion name	Plants	Mammals	Birds	Reptiles	Amphibians
AT0115	Knysna-Amatole montane forests	1000	52	272	36	24
AT0116	KwaZulu-Cape coastal forest mosaic	2000	80	373	88	40
AT1003	Drakensberg alti-montane grasslands and woodlands	800	71	288	29	18
AT1004	Drakensberg montane grasslands, woodlands and forests	3700	152	450	118	47
AT1009	Highveld grasslands	1900	115	397	68	29
AT1012	Maputaland-Pondoland bushland and thickets	2100	92	351	63	38
AT1201	Albany thickets	1200	68	280	55	14
AT1202	Lowland fynbos and renosterveld	3000	75	296	68	27
AT1203	Montane fynbos and renosterveld	6300	88	311	74	31
AT1314	Nama Karoo	1100	106	300	70	11
AT1322	Succulent Karoo	4850	75	225	94	15
AT1405	Southern Africa mangroves	200	26	224	6	2

Table 5.3: **Distribution of area between ecoregions of the Eastern Cape, and the distribution within each ecoregion to different land cover classes (from Biggs et al. 2006). See Table 5.2 for the ecoregion names. The three ecoregions where we simulated biofuel expansion are these with short names. All ecoregions were considered when determining overall BII scores**

Ecoregion	Short name	% Protected	% Light Use	% Degraded	% Cultivated	% Urban	% Plantation	% Total	TOTAL in km^2
AT0115		27.4	52.3	5.5	12.7	1.6	0.4	0.8	1343
AT0116	Coastal	4.1	78.5	3.1	11.9	1.4	1.0	4.3	7302
AT1003		1.0	88.9	7.9	2.0	0.2	0.0	1.5	2542
AT1004	Grassland	1.3	71.5	14.5	9.7	1.7	1.3	46.6	79319
AT1009		0.0	79.1	13.5	6.6	0.8	0.0	4.2	7179
AT1012	Bushlands	1.3	67.7	16.4	11.6	2.5	0.5	5.7	9718
AT1201		5.1	86.0	2.1	5.2	1.6	0.1	8.1	13753
AT1202		2.7	65.0	1.0	28.8	2.0	0.5	2.0	3432
AT1203		47.1	50.2	0.7	1.8	0.0	0.1	3.2	5518
AT1314		1.5	94.0	3.1	1.2	0.1	0.0	23.5	40098
AT1322		12.5	87.5	0.0	0.0	0.0	0.0	0.0	16
AT1405		0.0	91.1	0.0	8.9	0.0	0.0	0.1	157
Total %		**3.43**	**77.68**	**9.52**	**7.46**	**1.23**	**0.68**	**100.0**	
Total		**5842**	**132349**	**16215**	**12717**	**2093**	**1161**		**170377**

- **Scenario 1:** Agricultural land is allocated first, until it is used up, then degraded land is allocated, and finally lightly utilised land (no conservation) land is allocated. This is done per ecoregion, or for all ecoregions at an equal rate proportional to the ecoregion total extent.
- **Scenario 2:** As per scenario 1, but starting with degraded land, then moving to lightly utilised land. No existing agriculture is allocated.
- **Scenario 3:** As per scenario 1, but allocating all biofuel to lightly used land.

The option of using a perennial tree crop instead of an annual agricultural crop as bioenergy feedstock was also investigated. No BII impact is available for Jatropha, but a factor has been derived for plantation forestry based on eucalyptus, pine and wattle (Biggs 2005, Biggs et al 2006). Though there are clearly differences between Jatropha and plantation forestry species, at this provincial scale this provides an initial estimate of possible Jatropha impacts. It is also useful as a scenario generation exercise if forestry is to be considered for bioenergy in the future.

5.6.1 Results

The results give total provincial BII impacts to the Eastern Cape, and given that biofuel was given the equivalent impact factor as crop agriculture, biofuel development has no biodiversity impact when allocated to agricultural land, provided there is no iLUC. Note that, though the overall forestry impact seems to not differ from the agricultural impact, as will be explained below, the impact is different for different taxa, though when combined for all taxa is remarkably similar for the specific ecoregions under consideration. In both the agriculture and forestry scenarios the impact increases as land allocation shifts to degraded, with the highest impacts when allocating to untransformed lightly used land (Figure 5.6). Overall BII impacts for forestry as a feedstock are almost identical to the impacts from crop agriculture on cultivated land.

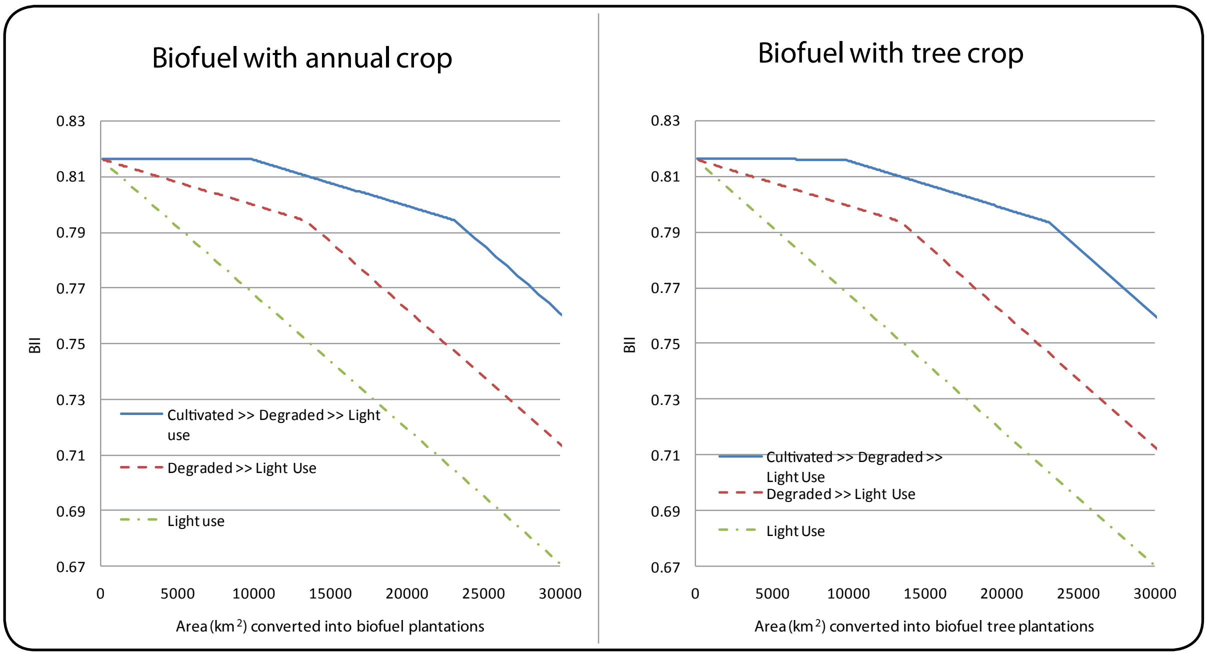


Figure 5.6: The influence of 'type of land allocated to biofuel' on 'the BII impacts', for both annual and tree biofuel crops. The land allocation rules allocate all cultivated land before allocating degraded land, and all degraded land before allocating lightly used land, in the scenarios where this is applicable.

The potential impact of biofuels on biodiversity is considerable, and for 20 000 km^2 (i.e. 12% of the total provincial area) the biodiversity loss ranges from 6 to 14% depending on the land allocation scenario. This is a substantive impact considering that the province has only lost an estimated 19% of its biodiversity over the preceding 300 years. In addition biofuel feedstock plantations are only being allocated to 3 ecoregions in the province and these three ecoregions in total are only 57 % of the total provincial area. This biodiversity loss is not allocated evenly by ecoregion or taxa as is illustrated in Tables 5.4 and 5.5. In this scenario where two million ha of lightly used land is allocated to crop agriculture, both amphibians and plants lose 11% each of their species overall. For plants each ecoregion looses 15% of their plants, whilst for amphibians the loss is far higher in the costal and grassland areas than in the bushlands. Overall, mammals in the grasslands have the lowest BII. This is largely due to a combination of an initially low BII as well as a relatively high estimated future loss. Birds show the highest resilience to loss of species compared to other taxa.

Table 5.4: **Impacts on BII per taxa of converting 20 000 km^2 annual cultivated biofuel (blue) or plantation forestry (red) in total from previously lightly used land to bioenergy for three of the ecoregions in the Eastern Cape. The proportion of area converted per ecoregion was the same for each of the three ecoregions. The number in black is the current BII score**

	AT0115	**Coastal**	**AT1003**	**grass-land**	**AT1009**	**Bush-lands**	**AT1201**	**AT1202**	**AT1203**	**AT1314**	**AT1405**	**Grand Total**
Plants	0.78	0.77	0.88	0.78	0.82	0.78	0.89	0.70	0.95	0.87	0.87	0.80
Cultivation 2 m ha		0.63		0.64		0.64						0.70
Forestry 2 m ha		0.61		0.63		0.63						0.70
Mammals	0.79	0.76	0.66	0.59	0.61	0.65	0.74	0.79	0.95	0.71	0.77	0.64
Cultivation 2 m ha		0.66		0.53		0.60						0.60
Forestry 2 m ha		0.66		0.49		0.59						0.58
Birds	0.92	0.93	0.96	0.90	0.92	0.88	0.97	0.92	0.97	1.07	0.91	0.94
Cultivation 2 m ha		0.79		0.77		0.76						0.86
Forestry 2 m ha		0.85		0.85		0.82						0.91
Reptiles	0.87	0.87	0.89	0.82	0.86	0.83	0.92	0.77	0.96	0.94	0.88	0.85
Cultivation 2 m ha		0.72		0.70		0.71						0.77
Forestry 2 m ha		0.74		0.71		0.72						0.77
Amphibians	0.85	0.86	0.99	0.88	0.93	0.91	0.97	0.79	0.95	0.98	0.92	0.89
Cultivation 2 m ha		0.67		0.70		0.75						0.75
forestry 2 m ha		0.71		0.73		0.86						0.79
Total	**0.81**	**0.79**	**0.89**	**0.79**	**0.83**	**0.79**	**0.90**	**0.72**	**0.95**	**0.90**	**0.89**	**0.82**
Cultivation 2m ha		0.65		0.65		0.66						0.72
Forestry 2 m ha		0.65		0.65		0.66						0.72

Table 5.5: **Percentage biodiversity loss from a scenario of 20 000 km^2 new biofuel plantations in untransformed land in the Eastern Cape, transformed to annual biofuel feedstock production. Current biodiversity minus future biodiversity expressed as a percentage of original biodiversity**

	Costal	Grass	Bush	Total
Plants	15	15	15	11
Mammals	10	10	06	06
Birds	08	05	06	03
Reptiles	12	11	11	08
Amphibians	15	15	05	11
Total	**14**	**14**	**13**	**10**

Table 5.6: **The difference in BII biodiversity loss if the conversion of land is to plantation forestry rather than an annual crop. A negative number indicates plantation forestry has a more negative impact. As an example total grassland bird impact in forestry is 13 versus 5 for agriculture giving - 8**

	Costal	Grass	Bush	Total
Plants	1.4	0.8	1.1	0.6
Mammals	-0.1	3.8	-1.1	2.2
Birds	-5.9	-8.0	-6.2	-5.0
Reptiles	-1.5	-0.8	-0.7	-0.6
Amphibians	-3.5	-3.6	-11.4	-3.4
Total	**0.1**	**-0.1**	**-0.1**	**-0.1**

Though forestry had the same overall BII as crop agriculture, the nature of this impact on different taxa is very different. Plants fare slightly better under forestry than cultivation, as do mammals in grasslands, but all other taxa in all other ecoregions fare substantially worse, with bird biodiversity in particular being disadvantaged by plantation forestry (Table 5.6).

Comparing total provincial biodiversity scores per ecoregion for scenarios where cultivation is restricted to a single ecoregion provides interesting results (Figure 5.7). Providing only existing cultivated and degraded land is used, using land from grasslands has the least impact on provincial level biodiversity. However if lightly used land in the grasslands is transformed then this has the highest impacts. This is despite the fact that grasslands are by far the largest ecoregion, and that there would still be extensive untransformed areas. There is only about 600 000 ha of coastal and 800 000 ha of bushlands in total, excluding a small percentage under conservation. If, as in these scenarios, almost the entire ecoregion were to be transformed to biofuel plantations then there is a very real probability that a number of species get driven to extinction since there are a number of species endemic to the ecoregions that are not found outside the Eastern Cape. As stated previously, the BII algorithm, because it is weighted by area, is relatively insensitive to these losses. The BII is not the appropriate tool to consider this potential loss of what might be rare and endangered species and the analysis would be strengthened by considering this aspect separately.

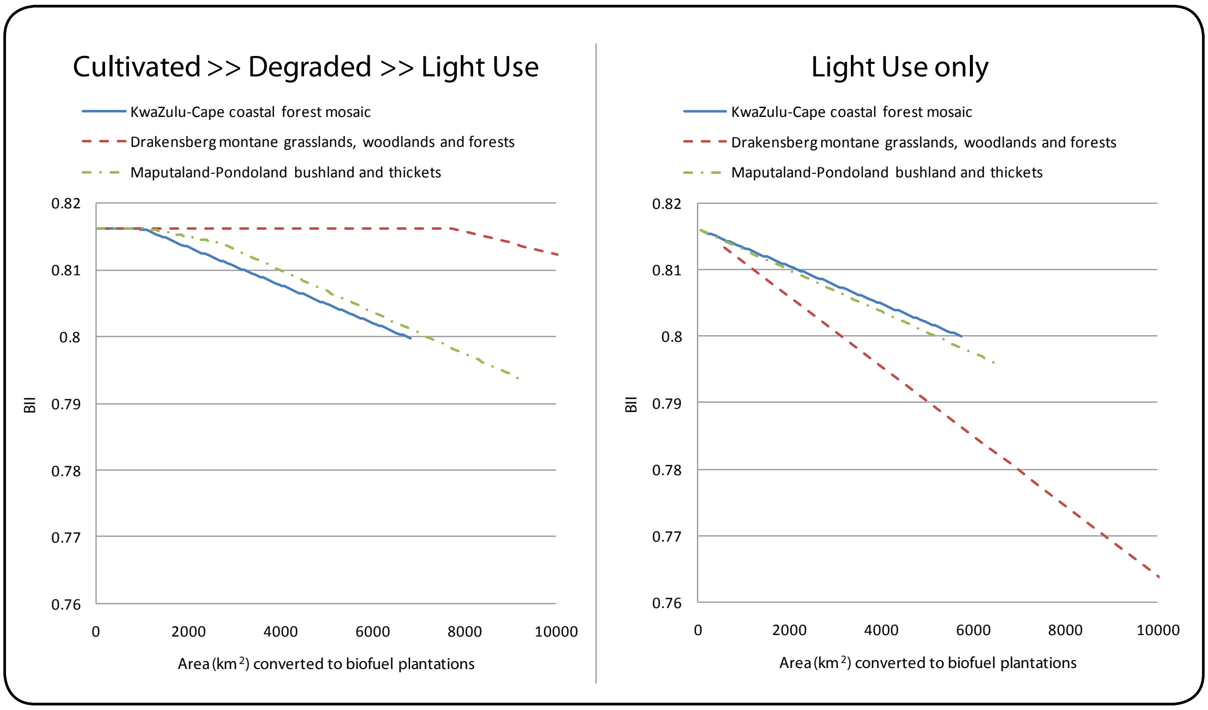


Figure 5.7: Impacts of area converted to agricultural biofuel crops on the Eastern Cape; total BII scores if land transformation is limited to a single ecoregion. Two scenarios are show, one where cultivated then degraded land is used first, and one where only lightly used land is transformed.

The BII analysis highlights a number of important issues. Transforming lightly used land to biofuels will have substantive impacts, especially if it is to take place on what would appear to be relatively abundant grasslands. This confirms the viewpoint that land transformation is a big threat to biodiversity. It is interesting to note that in this situation the use of forestry crops or annual crops would have very similar overall impact, but very different impacts on select taxa. Using currently cropped areas and degraded land has low impacts, however no consideration was made on potential iLUC impacts caused due to the displacing of agriculture.

This analysis demonstrated that, if even relatively coarse BII data is available, the BII approach can be used for rapid scenario generation. Only about 2 to 3 days of analysis time was required to conduct this exercise. However the analysis as presented is very crude and if finer level scenarios were required then the following could improve the results:

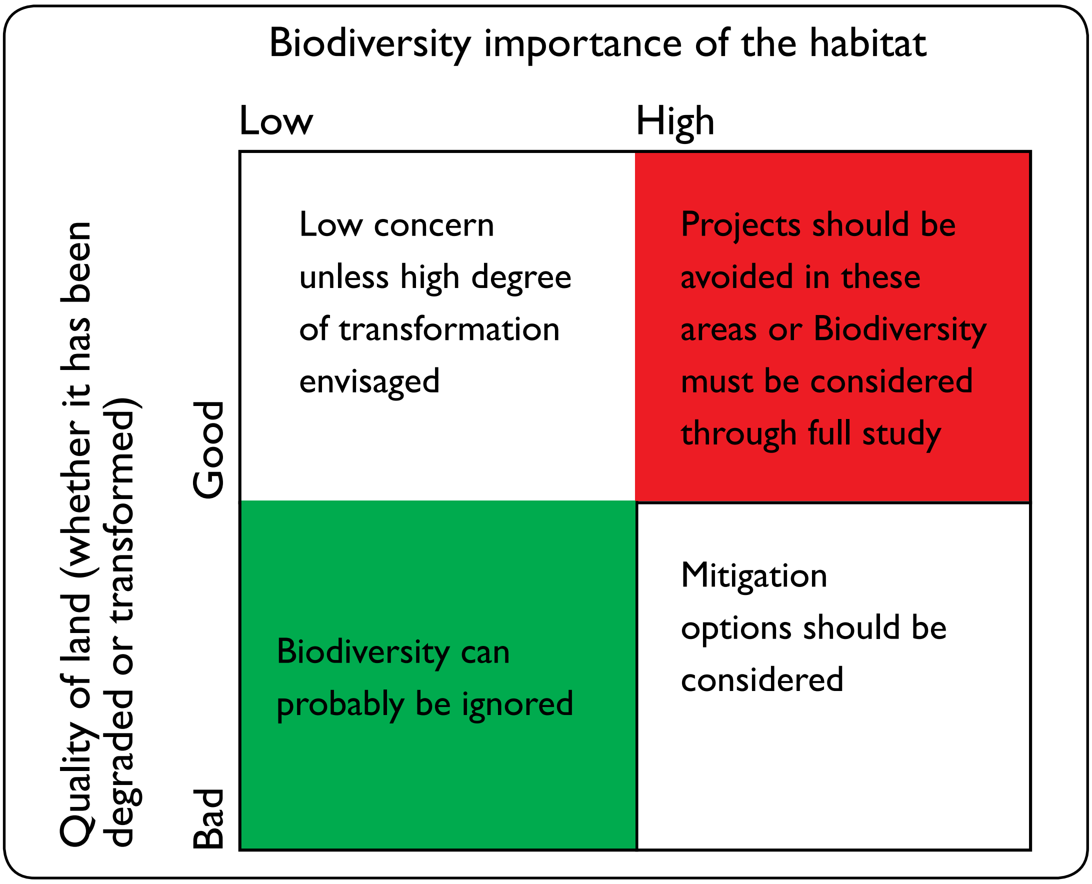
- Developing biofuel crop specific impact factors, but this should only be considered if these are likely to differ substantially from general agriculture or forestry impact factors;
- More detailed ecosystems could be considered (such as the bioregions of Mucina and Rutherford (2006)) for the Eastern Cape example. The use of detailed vegetation types could be used, though experience suggests that specialists are likely to give the same impact factor to all vegetation types in a bioregion, and though detailed species data may be available for some taxa, e.g. trees, it is unlikely to be available at this level of detail for all taxa;
- The process would be strengthened by linking it to a matrix of impacts on rare and endangered species.

5.7 Planning for Biodiversity at the Project Level

At the level of specific project implementation, biodiversity is an important consideration, but methods for planning for biodiversity conservation move away from the strategic conservation planning toward operational issues such as how best to configure plantations in the landscape. Having said this, it is very difficult to implement a rigorous operational biodiversity plan at the plantation level in the absence of a national or regional understanding of biodiversity priorities. In this section we propose a step by step approach to biodiversity assessment with a number of screening techniques and tools, with increasing levels of complexity, for ascertaining if biodiversity issues are likely to be a priority concern during project planning. We also provide links to tools that may assist to minimise biodiversity impacts during the implementation phase of biofuel plantations.

5.7.1 A first cut screening

The two-way matrix in Figure 5.8 is designed as a crude and simple scan to ascertain if biodiversity impacts are likely to be a critical issue. It is not designed to give an exact result, but rather to indicate if further investigation is required. This matrix could be used to assess the entire plantation, but it is probably best to apply it to each and every unique habitat within the proposed plantation footprint. No precise definition is suggested as to what would constitute 'an area of high biodiversity importance'; a list of some of the features likely to indicate high biodiversity interest was provided in section 5.4.



Biodiversity importance of the habitat

Quality of land (whether it has been degraded or transformed)	Low	High
Good	Low concern unless high degree of transformation envisaged	🟥 Projects should be avoided in these areas or Biodiversity must be considered through full study
Bad	🟩 Biodiversity can probably be ignored	Mitigation options should be considered

Figure 5.8: **A rapid screening to identify habitats where biodiversity is likely to be an important concern. Habitats that fall into the red area should be avoided. If they are to be considered then detailed impact assessments should be undertaken.**

Near-intact habitats[19], especially those with high biodiversity importance, should be avoided where possible. If such habitats cannot be avoided, full studies on biodiversity impacts should be undertaken. Where near-intact habitats have a relatively low biodiversity importance currently, it is important to consider if their biodiversity importance may change in the near future due to rapid land transformation as this could potentially change their conservation status. In areas with high conservation status, but that have already been badly degraded, it is possible that biofuel plantations may be able to use mitigation methods that can help overall conservation of the habitat type. One mechanism to achieve this is for the biofuel plantations to set aside some of the habitat and assist in rehabilitating it.

5.7.2 Decision tree approach

A decision tree approach provides a slightly more sophisticated method of screening than a two way matrix. It is based largely on the same logic, but provides more detail on the specific criteria that may be considered as important. The relatively generic model of Figure 5.9 could be improved to represent national conservation priorities.

5.7.3 A simplified BII approach

At the planning phase it is often useful to compare the proposed action (biofuel development) with alternative land use options (doing nothing or using the land for some other type of agricultural crop, forestry etc.). In these circumstances the BII as described in section 5.5 is an appropriate tool, and can be rapidly and cheaply used if appropriate impact factors have been developed for the habitats and land uses under consideration. If calibrations, at the appropriate scale, are not available for specific habitats and land uses then a simplified BII can be used where taxa are rated against a three point (better, no change, worse) subjective scale, or a five point scale (much better, better, no difference, worse, much worse). This would be best done through 'expert judgement': the consensus of a small number (3-5) of biologists with an understanding of the ecology of the area and the taxa involved. Species should be divided into broad taxon groups (e.g. plants, birds, amphibians, rodents, large mammals), and then subdivided into functional groups, if feasible (e.g. trees, shade tolerant grasses, grazing large mammals, large mammal predators, seed eating birds etc). Functional groups should represent organisms that are likely to respond in a similar way to the change in vegetation between the natural vegetation, current land use, bioenergy plantation and any other land use option being compared. Scoring can be done as per Table 5.7. Since most projects are not in complex landscapes, a separate scoring can be conducted for each habitat type that is likely to be impacted.

For example, a proposed biomass-gasification electricity plant in northwest Uganda would require large plantations of fast growing trees. Currently the land is large scale farmland that was previously used for cattle ranching. In the recent past herds of large game including buffalo and elephant used to wander through the farm. At present the area is being re-populated following 20 years of warfare. If this land is not used for biofuel plantations, it is likely that the land will slowly be broken up into small scale allotments for subsistence and commercial farming. Three scenarios are compared against the current

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[19] The words 'pristine', 'virgin' or 'wilderness' are sometimes inaccurately used to describe such situations. Nowhere in the world is pristine anymore, and a certain low level of disturbance is in fact beneficial for biodiversity. The key issue is whether the ecological processes that allow the habitat to persist and regenerate without external inputs are still in place, and the full suite of functional types are present in more-or-less their natural proportions.

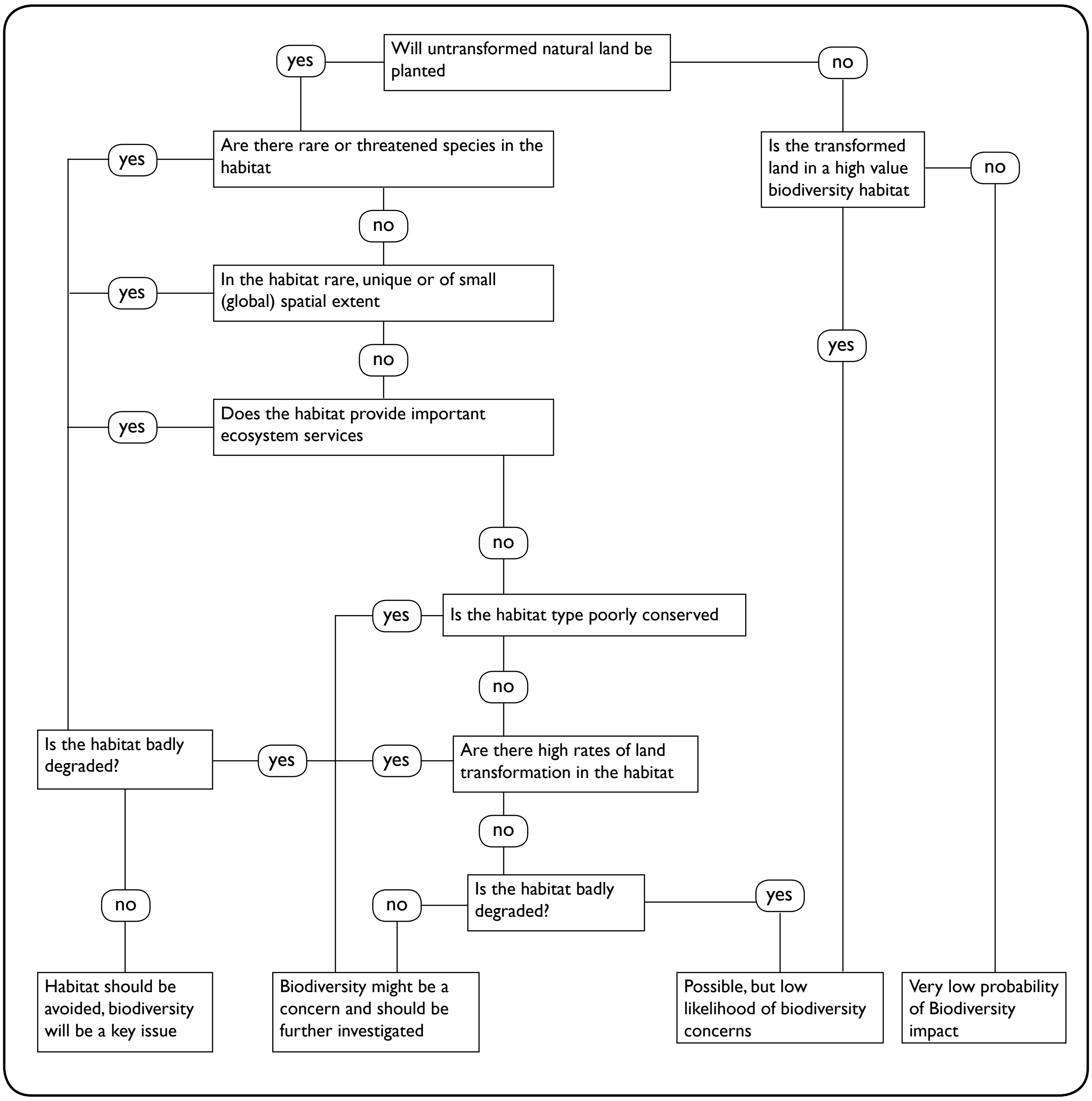

Figure 5.9: **A simple logical tree approach for screening habitats for likely biodiversity impacts.**

baseline: a plantation of fast growing trees; total conversion to small scale subsistence agriculture and gradual transformation to smaller commercial and subsistence allotments (the projected current situation in 10 years).

The results from Table 5.7 suggest that the current land use or a tree plantation would both have negative impacts on biodiversity, but that the impacts would be in very different functional groupings of plants and animals. Both these options have far less biodiversity impacts than the land being fully transformed to small scale cropland. Though a simple summing of impacts gives a trend, data are not normalized and individual functional taxa may carry disproportionately high weightings.

Table 5.7: **A rapid screening of biodiversity impacts per plant and animal functional types for a proposed gasification plant in north western Uganda. – represents a strong negative impact, - a week negative impact, 0 no impact, + a week positive impact and ++ a strong positive impact. (Data for demonstration purposes only and would require further verification from a panel of experts before being finalised).**

Plant or animal functional group	Subsistence agriculture	Current situation in 10 year trend	Fast growing timber plantation
Large mammals	--	-	-
Forest birds	--	-	++
Grain feeding birds	+	+	-
Small mammals (non pest)	-	0	+
Small mammals (pest)	+	0	-
Indigenous trees	--	-	–
Indigenous grass	--	0	-
Total	**-7**	**-2**	**-3**

5.7.4 The HCV approach

For projects wanting a packaged solution for planning around biodiversity, one option is the High Conservation Value Network Approach (HCV). This approach has the advantage that it is backed by methodology manuals, a network of practitioners and it is likely to be directly recognised and accredited by some of the biofuels sustainability standards such as the Round Table on Sustainable Biofuel Production (RSB), Round Table on Responsible Soya (RTRS) and Round Table on Sustainable Palm Oil Production (RSPO).The HCV approach considers conservation value beyond just biodiversity, and incorporates both environmental as well as related socio-economic and cultural issues. In essence, the HCV approach considers 6 aspects of conservation value as given in Table 5.8. Full details of the HCV approach can be obtained from their web site[20]. Unless this approach is backed by good definitions of what constitutes a 'High Conservation Value', it can easily lead to inappropriate planning (Koh et al. 2009). In this regard, the approach is strengthened if there are existing nationally defined biodiversity conservation plans and priorities in place. Preserving only small isolated fragments of areas of high conservation value should be avoided: larger blocks or corridors of indigenous vegetation are preferable. Collaboration with adjacent plantations should be sought to maximise an overall integrated conservation strategy.

5.8 Reducing Risks of Alien Invasion

Due to the vast number of plant species requiring permission to enter a country, the use of a screening tool can help distinguish which species are likely to be actual threats from those which are not. Most countries are signatories to the International Plant Protection Convention of 1952, and the UN Convention on Biological Diversity of 1993 and as such should already have appropriate quarantine and introduction protocols in place, though may be too understaffed and under-resourced to properly fulfil

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[20] http://www.hcvnetwork.org

Table 5.8: **The HCV network uses 6 criteria in determining what constitutes high conservation value areas. Their definitions, though largely based on biodiversity concerns, also include some cultural issues.**

High Conservation Value category		Examples
HCV1	Areas containing globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia).	The presence of several globally threatened bird species within a Kenyan montane forest.
HCV2	Globally, regionally or nationally significant large landscape-level areas where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance.	A large tract of Mesoamerican flooded grasslands and gallery forests with healthy populations of Hyacinth Macaw, Jaguar, Maned Wolf, and Giant Otter, as well as most smaller species.
HCV3	Areas that are in or contain rare, threatened or endangered ecosystems.	Patches of a regionally rare type of freshwater swamp in an Australian coastal district.
HCV4	Areas that provide basic ecosystem services in critical situations (e.g. watershed protection, erosion control).	Forest on steep slopes with avalanche risk above a town in the European Alps.
HCV5	Areas fundamental to meeting basic needs of local communities (e.g. subsistence, health).	Key hunting or foraging areas for communities living at subsistence level in a Cambodian lowland forest mosaic.
HCV6	Areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities).	Sacred burial grounds within a forest management area in Canada.

their mandate. Biofuel practitioners, in their enthusiasm for the rapid establishment of biofuel projects, may well inadvertently or deliberately bypass the formal introduction protocols. This practice needs to be strongly discouraged. Although invasiveness is relatively rare, its consequences are severe, and can completely cancel out any economic or environmental benefits that were intended for the project.

5.8.1 Predicting invasiveness

It has long been a goal of invasion ecologists to identify a specific suit of traits that would identify an invasive plant species. Recently these traits or plant attributes have been summarised based on the correlation of traits with known invasive species, via experimentation and general theory (Pheloung et al. 1999; Pattison and Mack 2008). For example species that share common traits known to increase the risk of invasion include:

- Fast growth and ability to outcompete local vegetation
- Abundant seed production, especially of long-lived and resistant seeds
- Tolerance of a wide range of conditions

While important, the use of traits alone cannot adequately identify new invasive species. A successful invader is the result of a multiple-step process. Before a species can become invasive a series of barriers need to be overcome (Richardson et al. 2000). For example, a necessary condition for plant establishment is habitat compatibility (also known as habitat invisibility) (Rejmanek 2000). A habitat is known to be invasibile when a non indigenous species is able to establish, persist or expand (Burke and Grime 1996).

Current assessment schemes using a combination of approaches have proved most accurate to distinguish between known invasive species and non-invaders. These non-experimental predictions are most accurate when the biological attributes of the species and the climatic variables of both the source and recipient regions are included in the assessment process. In a recent survey, an accuracy level of 80% was considered acceptable (Gordon et al. 2008). Further examples for determining invasiveness include measuring stochastic events such as time since introduction, evaluating specific taxon (e.g. *Pinus*) or experiments (Rejmanek 2000).

5.8.2 Weed risk assessments

Risk assessments follow a non-experimental approach and are based on the biological information of the species, bioclimatic features of the source and recipient regions and the evolutionary history of both (Richardson et al. 1990). The risk assessment phase is intended to be applied at various stages of plant movement. For example, it can be applied to species already present in a country, to determine the risks of increasing the range (Rouget et al. 2002) and whether a species could be moved from one region to another with minimal risk of invasion (Barney and DiTomaso 2008). However in most instances risk assessments are adopted during border control to determine the risks of new species entering a country (Pheloung et al. 1999).

A risk assessment should ideally form part of a decision support system to help determine whether the risk of introducing a non-indigenous species is acceptable (Cousens 2008). An example of its use is described in Figure 5.10 where the risk assessment is part of a three-tiered decision support system adopted by most countries (Pheloung 2003). One of the main aims of the risk assessment process is to find an objective and standardized process for evaluating the risk of introducing an organism to a new environment. This is important as decisions based on expert opinion may be swayed by potential economic opportunities resulting in a subjective bias towards acceptance (Pheloung et al. 1999).

Several methods exist to determine the risk of invasion from plant species (Tucker and Richardson 1995; Reichard and Hamilton 1997; Pheloung et al. 1999). These screening systems either use a decision tree format or a questionnaire coupled with a scoring system to evaluate various sources of information including biogeography, life history, plant traits and specific regional characteristics to draw conclusions about whether to accept, reject or further evaluate a species in question.

One of the challenges regarding the available methods is that they were developed for specific geographical regions, narrow taxa (e.g. pines) or broad taxonomic groups (e.g. woody plants) to facilitate decision making regarding the threat of new species or existing plant species. Therefore, adopting any of these methods as a general screening tool requires slight modifications to the original format before being applied elsewhere (Daehler and Corrino 2000).

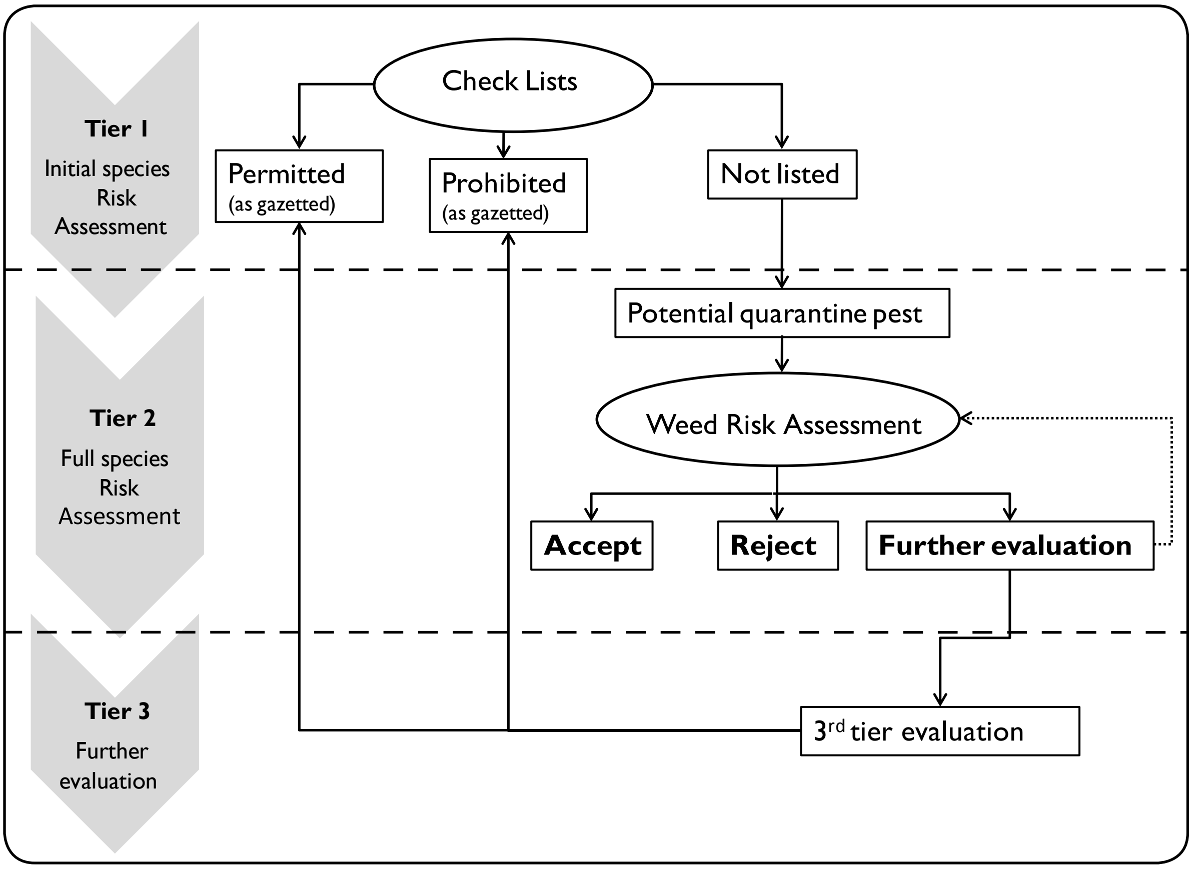

Figure 5.10: **An example of a three-tiered screening system proposed for plant imports to Australia (based on Pheloung 2003).**

The ability of the screening system to adequately identify weeds is a major indicator of the efficacy of such a model. Several recent studies have compared the various methods, for regions other than the region of development, to correctly identify invasive and non-invasive species from predetermined sample of plants from the region including known invaders. Examples of screening systems include (1) Australian weed risk assessment (WRA) scheme (Pheloung et al. 1999); (2) WRA with additional analysis by Daehler et al. (2004); (3) decision tree scheme of Reichard and Hamilton (1997); and (4) altered versions of existing methods (See Jefferson et al. 2004). These comparisons have revealed the WRA to most accurately determine the likelihood of invasive species (Daehler and Corrino 2000; Krivanek and Pysek 2006). For example, an American sample of plants of unknown invasive potential was correctly accepted or rejected over 80% of the time (Gordon et al. 2008). More recent testing of the WRA system sees it as an acceptable tool for assessing weed species beyond the region it was intended for (Crosti et al. 2010; Dawson et al. 2009).

5.8.3 Steps for reducing risks of invasion from biofuel plantation

All species that are to be introduced to an area must be screened for invasiveness if they are a new species to the area. This would apply even to species being moved to new locations within a country[21]. Screening and all appropriate phyto-sanitary requirements as specified by the countries national legislation must be adhered to.

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[21] The term 'indigenous', ie a plant that historically occurs within a given country, is not typically very helpful, since the country boundaries seldom coincide with ecological boundaries. 'Endemic' to a particular habitat is more helpful. It is entirely possible for an indigenous species to be an alien invasive species in its own country, but in a new habitat.

Once approval has been obtained for planting a particular species in a biofuel plantation, a number of options are available to reduce the risk of unintended invasions. The biofuel crop itself might have the potential to invade, and if there is any possibility of this, then strict measures should be undertaken to prevent this happening. Monitoring must be conducted to give early warning of any start of invasion. It is also possible that when moving the biofuel products around that this could facilitate the transfer of other species, including pest species of the biofuel or other crops. IUCN has produced a simple and short manual to help government officials and biofuel plantation managers better understand how to minimise invasive risks (IUCN 2009).

Five key recommendations on reducing invasiveness from IUCN (2010) are:

1. Follow a precautionary approach when choosing feedstocks
2. Work with stakeholders to build capacity
3. Comply with local, national and regional regulations
4. Develop and follow Environmental Management Plans
5. Extend planning, monitoring and assessments beyond the field

This manual is freely available online[22]. Four key areas of intervention are proposed by IUCN as in Table 5.9. The IUCN report gives more detail on the proposed methods of intervention (IUCN 2009).

Table 5.9: **Proposed actions for key areas of intervention to reduce risks of invasion (IUCN 2010)**

Area of intervention	Proposed actions and tools
Planning	Cost benefit analysis Strategic environmental assessments Projects Environmental Impact Assessment Contingency fund
Importation	Quarantine process Phytosanitation regulation and action Comply with regulations Remember the pest associated with biofuel
Production	Follow best practices A contingency plan if an "escape" A contingency fund to pay for eradication, containment, management, or restoration monitoring system that checks for escapes and the presence of pests and pathogens. EMPs should ideally be audited by a neutral third party
Transportation	Reduce distance Process before transportation Monitoring of routes Awareness

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[22] http://cmsdata.iucn.org/downloads/iucn_guidelines_on_biofuels_and_invasive_species_.pdf

5.9 Conclusions

Biofuel expansion carries with it a real risk of resulting in biodiversity loss. This risk is especially high for developing countries in the tropics where there is both a high concentration of biodiversity as well as high levels of threat to the biodiversity due to a multitude of land use pressures.

From a national strategic policy perspective, careful assessment is needed as to whether the biodiversity loss from biofuel is justified relative to the potential gains from biofuel programmes. In this regard strategic multi-criteria assessments are needed in which projected biodiversity impacts are one of the variables. The direct and indirect economic, human wellbeing and ethical consequences of biodiversity loss must not be forgotten. The extent of biodiversity loss can be mitigated to some extent by limiting the size of a proposed biofuel industry and by defining the habitats and land uses in which it is permissible. Impacts of indirect land use change must not be ignored.

Careful planning both at the strategic level and at the plantation level can greatly reduce the level of biodiversity loss. Mitigation measures may also be used to enhance biodiversity overall, so that even if some biodiversity is being lost from specific locations, the overall strategic biodiversity conservation objectives for the region can potentially be increased. Biodiversity impacts from biofuel expansion need to be considered against biodiversity impacts from alternate land use options. In this regard 'doing nothing' also has a biodiversity consequence, which may be greater or less than the consequences from introducing biofuels. Feedbacks between biofuel expansion and other drivers of biodiversity loss need consideration, as biofuel production could potentially reduce or enhance other drivers of biodiversity loss. The way these interactions between sectors are managed could greatly enhance overall biodiversity conservation.

Measuring or monitoring biodiversity and biodiversity impacts is complex and can be extremely costly. For a strategic perspective the BII tool is recommended as an appropriate method to consider overall biodiversity consequences of different biofuel and competing land use scenarios. Because the tool can be based on specialist input rather than raw data, it is relatively inexpensive to undertake a BII assessment, especially in areas of relatively limited data availability. It can, however ultilize more rigorous data sources if available. The BII approach is scalable and results can be disaggregated in a number of different ways. The BII approach is, however, poor at picking up impacts on rare and endangered species and should be run in parallel with a red data approach if impacts of this nature are anticipated.

Numerous techniques are available for local level assessment at the project level. It must, however, be stressed that any local biodiversity plan should be aligned with strategic conservation objectives. Simple screening can give a first cut as to if biodiversity impacts are likely to be an important issue. If biodiversity is likely to be important, then either the development should be abandoned, or more detailed approaches for biodiversity protection should be considered such as the High Conservation Value approach. In many situations, strategic conservation of specific areas within a biofuel estate which have high conservational value can greatly mitigate the overall biodiversity impact.

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Chapter 6

Assessing Social Impacts of Bioenergy Projects

Sunandan Tiwari, Jennifer A. Harrison and Graham von Maltiz

6.1 Introduction

Mitigating and adapting to climate change, effective management of natural resources, adapting to volatile political scenarios, food security, economic development, pledges towards poverty eradication and social wellbeing – all of these have one significant common component, the need for energy security (Goldemberg and Lucon 2010). Conventional sources of energy are no longer as reliable as they were considered to be; not all nations have the primary energy supplies to meet their current and future needs. This is one of the main causes of concern, especially for developing countries, as energy insecurity is a major stumbling block for economic development (Kammen et al. 2002). Therefore there is an increasing global urgency to explore and establish alternative and renewable sources of energy (Heinimö and Junginger 2009). Bioenergy, in the liquid forms of biodiesel and bioethanol, is being considered by many developing countries as one of the potential suitable alternatives; as not only would it bring a level of energy security, but in addition it could boost rural development and help to reduce rural poverty (Domac et al. 2005). Certain bioenergy projects are also considered to be carbon neutral, or even negative, particularly in comparison to fossil fuels (Schlamadinger and Marland 1996; Tilman et al. 2007). Considering the levels of demand for energy, this switch to liquid biofuels would necessitate a major change in land use practices worldwide if a meaningful volume of fuel is to be achieved (Buchholz 2008). The carbon, and other biophysical, implications of such a change need to be accounted for quantitatively (see Chapters 3, 4 and 5), but should also be considered in terms of how they affect people directly, which is discussed in this chapter.

Changes in land use practice and patterns can potentially have three-fold, interrelated positive and/or negative impacts: environmental, economic and social. Bioenergy plantations for the production of liquid biofuels, such as biodiesel, present a significant land use change that several countries are promoting as a means to substitute fast depleting crude oil reserves (Chaturvedi 2004). If negative impacts of this changed land use are foreseen then these need to be better understood so that mitigation plans or alternative approaches, can be incorporated into the design and implementation of the biofuel policies, plans and programmes (Rajagopal and Zilberman 2007). For instance the conversion of by-products of feedstock production into biochar and using this to enhance soil properties could improve both the economic and biophysical aspects of agricultural systems which might mitigate some of the negative consequences from biofuel production (Lehman and Joseph 2009)

Although environmental impacts from development are routinely considered, social impacts have typically not always received the attention they deserve (Becker 2001), and this holds true in the case of bioenergy projects. There is, however, a growing recognition of this shortcoming and attempts are being made to develop an improved understanding of the social impacts of bioenergy projects (Domac et al. 2005). Social Impact Assessment (SIA) is a methodology that has evolved over the past four decades and has been applied to a variety of interventions, most often to meet legal requirements (Esteves and Vanclay 2009). The potential large scale land use change associated with bioenergy projects is certainly an applicable context for SIA, and it is suggested that even small scale projects would benefit from its application.

The methodology proposed in this chapter focuses on examining social impacts, including cumulative ones, and uses as a specific case study the promotion of *Jatropha curcas* seed production for biodiesel models in India. It is accepted that all SIA is shaped in some way by the specific issue or project/ programme context; and therefore by making the approach flexible it is intended to be possible to adapt it to other feedstocks and processing technologies in different socio-economic, or cultural, and policy settings.

6.2 Social Impact Assessment

6.2.1 Social impacts

The Inter-organizational Committee on Guidelines and Principles for Social Assessment defines social impacts as: *"the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organise to meet their needs, and generally cope as members of society"* (Inter-organizational Committee 2003). Put simply, they are considered to be the impacts of developmental interventions on the human environment.

Social impacts cover a much broader range of issues than conventionally assumed. The International Association for Impact Assessment, which is in the process of updating its SIA guidelines, proposes "a convenient way of conceptualising social impacts which involves changes to one or more of the following:

- **people's way of life –** how they live, work, play and interact with one another on a day-to-day basis;
- **their culture –** their shared beliefs, customs, values and language or dialect;
- **their community –** its cohesion, stability, character, services and facilities;

- **their political systems and institutions –** the extent to which people are able to participate in decisions that affect their lives, the level of democratisation that is taking place, and the resources provided for this purpose;
- **their environment –** the quality of the environment in which they live, and their access to and control over resources;
- **their health and wellbeing –** health is a state of complete physical, mental, social and spiritual wellbeing and not merely the absence of disease or infirmity;
- **their personal and property rights –** particularly whether people are economically affected, or experience personal disadvantage which may include a violation of their civil liberties;
- **their fears and aspirations –** their perceptions about their safety, their fears about the future of their community, and their aspirations for their future and the future of their children." (IAIA 2003)

Social impacts or effects can be categorised as: direct effects that are related directly to the proposed action; indirect effects that occur as a result of the proposed action and the changes brought on by the direct effect; and cumulative effects that occur over time as changes build up from the proposed action and all other knock-on consequences (Becker 2001). Whilst undertaking SIA, efforts need to be made to cover all three categories of effects. In practise predicting indirect and cumulative impacts by SIA is difficult and it is possible to gain a sense of false security from an assessment, particularly where the assessment was allowed insufficient time or resources.

6.2.2 An introduction to SIA

Social Impact Assessment methodologies were developed in the early 1970s with the aim of identifying and managing social consequences of developmental initiatives (Vanclay 2005). Since then the approach has evolved considerably. Typically, SIA has been embedded within the longer established Environmental Impact Assessment (EIA) process and has not often been undertaken as a stand-alone exercise. This practice has fuelled the misunderstanding that assessing social impacts is only necessary when they result from environmental impacts (du Pisani and Sandham 2006). More recently, however, there has been a change in perception and SIA is now increasingly being considered as a separate, specialised, and important exercise that needs to be undertaken for an improved and holistic understanding of the various interconnected impacts of different developmental activities (Barrow 2000). It is important to note here that these impact assessments help in identifying the likely positive (synergies) as well as negative (tradeoffs) impacts of proposed policy actions, and thus facilitates informed decision making (CGG 2006).

The basic approach to SIA has evolved since its inception. This can be gauged by the changes that its definition has undergone. The Inter-organizational Committee on Guidelines and Principles for Social Impact Assessment stated in 1994:

"*We define social impact assessment in terms of efforts to assess or estimate, in advance, the social consequences that are likely to follow from specific policy actions (including programmes and the adoption of new policies), and specific government actions (including buildings, large projects and leasing large tracts of land for resource extraction), particularly in the context of the U.S. National Environmental Policy Act of 1969.*" (Inter-organizational Committee 1994, p. 108).

This reflects the 'technocratic' type of approach which was followed until the 1990s. Vanclay (2005) considered this to be inherently limiting as it was regulatory in nature and did not recognise the role for the management, mitigation, and monitoring of impacts or the contribution of other stakeholders towards the redesigning and participation in decision-making about what constitutes an appropriate project. It was felt, therefore, that this approach to SIA was not conducive to engaging communities, achieving sustainable development, or even ensuring good project design; because impacted people might not be outwardly indicating change, but may learn and react differently in future as a result of the intervention.

As the SIA discipline continued to develop it began to move away from this traditional and technocratic understanding towards a more inclusive or 'participatory' definition. In 2003, the International Association for Impact Assessment (IAIA) offered a revised definition as part of the development of International Principles for Social Impact Assessment:

"*Social Impact Assessment includes the processes of analysing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programmes, plans, projects) and any social change processes invoked by those interventions. Its primary purpose is to bring about a more sustainable and equitable biophysical and human environment*" (IAIA 2003, p. 2).

Beyond involving the local communities that could be affected by the change, this revised statement defines SIA as a tool that offers assistance in the evaluation, management and understanding of the process of social change, which is one of its main advantages. It ensures that development interventions are: (i) informed and take into account the key relevant social issues; and (ii) incorporate a participation strategy for involving a wide range of stakeholders. Since 2005 there is increasing demand for SIA to be 'integrative' and more broadly focused, as has also been the case with EIA since the 1980s hence the inclusion of SIA and even Strategic Environmental Assessment (SEA, as discussed in Chapters 1 and 2). It has even been suggested that SIA can be used to identify natural resource conflicts before they occur (Barrow 2006).

It is important to stress that SIA is a primarily qualitative technique which cannot be 100% predictive or accurate, essentially because it relies on the objectivity of the assessor and the knowledge or honesty of the stakeholders involved. Social impacts, particularly indirect and cumulative ones, are complex to predict because, for example, people often respond in different ways to those which might be expected or how others in the same situation might react. In addition it relies on perception and expectations of the future, though in many situations respondents have imperfect information on the actual outcomes that may be achieved. For instance, in the case of Jatropha there is limited data on the yields that will be achieved, the production costs and labour that will be incurred or the market price for the seeds which will make it difficult for stakeholders to formulate a clear perception of likely consequences.

6.2.3 Types of SIA

Becker (2001) identifies three types of SIAs: micro, meso, and macro. Type 1, micro-SIA, focuses on individuals and their behaviour; Type 2, meso-SIA, focuses on organisations and social networks (including communities); and Type 3, macro-SIA, focuses on national and international social systems.

The three types can be found in different settings, sometimes exclusively focused on social impacts, while at other times they can be integrated with other forms of impact assessment (Becker 2001). Identifying the scale at which planning, decision making and assessment or monitoring is made is crucial for understanding the impacts that an intervention might have on communities. In this case, the proposed SIA methodology for assessing bioenergy feedstock production projects, such as *Jatropha curcas* seeds for biodiesel in India which will be considered here, falls largely within the Type 1 and 2 categories but does touch upon Type 3 as well.

6.2.4 Social Impact Assessment as a component of Sustainability Assessment

Whilst in most countries social impact assessments are conducted under the established legislation and procedures of EIA, there is a growing awareness regarding the need for conducting a comprehensive SIA as a separate process in several situations (Barrow 2006). This involves assessing a wider range of social parameters with a focus on social issues of justice, poverty and sustainable development alongside environmental concerns.

It is important to remember that SIA is focused predominately on just one of the three components (social, environmental and economic) that contribute towards the sustainability of any project under consideration – in this case bioenergy feedstock plantations. Therefore, ideally, it needs to be embedded within an overarching sustainability planning framework that is specific to that particular intervention and includes techniques to consider the other aspects (see Chapter 1). SIA is particularly beneficial in planning for sustainable development as it provides a robust mechanism by which stakeholders are involved and can decide on the sustainable future towards which development is directed.

Achieving sustainability is a core challenge for most development programmes. Sustainability can be achieved only if, at the planning and implementation stage, there is as clear an understanding as possible of the expected and potential impacts of the intervention – both positive and negative (Bell and Morse 2008). For this several tools have been developed and tested; one of which is Sustainability Assessment (SA) (see Chapter 2).

6.2.5 Undertaking SIA

The importance of undertaking Social Impact Assessments of interventions is highlighted by du Pisani and Sandham (2006) who, referring to Baines et al. (2003), state that one of the most important contributions to SIA is to "*move the focus of the policy debate away from the notion of a technical problem to be solved to a social issue to be managed*". Therefore SIA is recognised as a planning tool for mitigating adverse social impacts, as well as one that would facilitate the management and monitoring of interventions. This as a result calls for a shift in the manner in which projects are designed, executed and assessed; and to 'put people first'.

While undertaking SIA it is important to recognise that there are many issues to consider and that little can be taken for granted. The regulatory context varies, the cultural or religious context varies, and social and economic priorities for development vary (IAIA 2003). Therefore, there is not a universal blueprint for undertaking SIA, even in a specific area such as biofuel plantations. There are guiding principles, approaches and tools, but in each case these would need to be appropriately adapted to the specific context and location that is being assessed.

6.3 The Need to Consider Social Impacts of Biofuel Projects

As discussed above, SIA has been conventionally considered as one of the components of the EIA process. In general, EIAs have not been undertaken for all developmental interventions that require a significant change in land use, particularly if the land is already under some form of agriculture (e.g. as is the case with many bioenergy plantations), but only for large initiatives, e.g. construction of dams, highways, ports, or large scale deforestation (Hacking and Guthrie 2008). Gradually, over the last decade or two, many more countries are revising their impact assessment procedures. These revisions are largely taking place in developed countries as, whilst in developing countries where there is an opportunity to undertake development 'differently', these procedures are yet to be revised. This can be gauged by taking bioenergy projects as an example.

Biofuels Programmes were initially and mainly developed in response to climate change, concerns around fuel security and oil price crises. The United States is using food-based crops (maize and soybean) for the development of biofuels, and in Europe the focus so far has been on biodiesel production from oilseed rape and sunflower (Fischer et al. 2007). In developing countries such as India, and some others in Asia and Africa, efforts are being made towards developing biofuel feedstocks using different species, institutional models and approaches. However, 'red flags' are beginning to be raised regarding the impacts that these plantations are having, especially on social issues such as food security, water availability, poverty levels, and the rights of local communities (Bailey 2008), in addition to environmental issues such as biodiversity impacts (Fisher and Treg 2007).

In early 2008, the EU Environment Commissioner announced that it may be better for the EU to miss its target of reaching 10% renewable content in road fuels by 2020 than to compromise the environment and human wellbeing (Vermeulen et al. 2008). The Science Council of the Consultative Group on International Agricultural Research (CGIAR) developed a policy statement on the challenges related to the global community's renewed interest in and attention to biofuels, and what the likely implications of this development were for the poor and the environment. This report found that "*within developing countries, there are still trade-offs and distributional effects that must be considered, between rural and urban, and between well endowed and poorly endowed groups. Whether a reasonable share of the benefits from biofuels development can accrue to small-scale actors in the biofuel production system chain is still a question.*" (CGIAR 2008 pg. 19). A report by Oxfam (Bailey 2008) found that, whilst biofuels may offer some 'genuine' opportunities for development in poor countries, "*the potential economic, social and environmental costs are severe and decision makers should proceed with caution*" (pg. 4). The report also stated that thirty percent of the recent increases in food prices was attributable to biofuels, jeopardising the livelihoods of nearly 100 million worldwide and dragging 30 million into poverty (Bailey 2008). The contribution of biofuels to food price increases is, however, contentious with alternate studies refuting these impacts, and pointing out that long term impacts may well differ from short term impacts (Pfuderer et al. 2010). In the case of developing countries, Biofuels Programmes are anticipated to provide a significant rural employment opportunity, which is professed to be one of their major benefits (Domac et al. 2005). This is true on the whole as levels of mechanisation are low and most of the work needs to be undertaken manually. However, an Indonesian analysis concluded that existing smallholder agriculture in West Kalimantan supported almost 260-times as many livelihoods as plantations that could be used for biofuel production (Renner and McKeown 2010, pg. 8); soybean in

Brazil displaces many ranching livelihoods for each biofuel job created (BWC 2008); numerous locals who engaged in the palm oil production industry in Indonesia have ended up indebted and in poverty, with their land tied to monoculture by contract (Glastra et al. 2002); and the profitability of Jatropha to farmers is questioned (Borman et al. In Submission). Therefore, there are several questions regarding the development of biofuels that need to be further investigated and an improved understanding of impacts developed, but one thing that is certain is that there are social tradeoffs involved in their production and use as alternatives to fossil fuels (Vermeulen et al. 2008; Glastra et al. 2002).

Some examples of developing country social concerns that are being raised, regarding the expansion of Biofuels Programmes across the world, have been given. What this highlights is the need for Social Impact Assessments to inform policy and developers in promoting and executing biofuels projects so as to ensure the sustainability of these projects in the long term. There have been concerted efforts at the international level towards achieving this. For example, the Responsible Cultivation Area (RCA) initiative is a private sector initiative coordinated by ECOFYS in collaboration with Non-Governmental Organizations (NGOs), such as the World Wide Fund for Nature (WWF) and Conservation International, and industrial parties such as Shell and Neste Oil. The initiative started in 2008 with the overarching goal to: "*...identify areas and/or production models that can be used for environmentally and socially responsible energy crop cultivation, without causing unwanted displacement effects*." The initiative provides a set of criteria that together define the requirements for RCAs, and a methodology for identifying RCAs (Cornelissen and Dehue 2009, pg. 42).

Similarly, the Sustainable Energy and Climate Change Initiative (SECCI) and the Structured and Corporate Finance Department (SCF) of the Inter-American Development Bank (IDB) created the IDB Biofuels Sustainability Scorecard based on the sustainability criteria of the Roundtable on Sustainable Biofuels (RSB). The main objective of the Scorecard is to encourage higher levels of sustainability in biofuel projects, by providing a tool to think through the range of complex issues associated with biofuel production from the field to the tank. The Scorecard includes general environmental and social criteria. It starts with background information then proceeds to more specific, and covers cultivation, production, and distribution stages of biofuel projects. This scorecard was first launched in 2008 and was revised a year later in 2009. It is viewed as 'work-in-progress' and is to be continually updated and revised as necessary. Despite being designed specifically for the private sector, the scorecard can be used as a conceptual tool for the assessment of biofuel projects (Ismail and Rossi 2010).

These are examples of initiatives at the international level that seek to facilitate the process of building parameters of sustainability into biofuel projects and programmes, with social aspects as one of the key components. It is clear that biofuel projects have social impacts; some of which are adverse in nature, while others are positive. It is also important to recognise that different sectors of society are impacted differentially, and whilst some individuals might clearly benefit, this might be at the expense of others living in the vicinity who might lose out as a consequence of the development. Therefore, not only net benefit, but also equity and fairness in benefit distributions, needs consideration. It is important to identify these impacts, particularly the negative ones and those adversely affected, and to devise mitigative strategies where necessary.

Under the RE-Impact project (see Chapter 1), efforts were made to develop and test a methodology for assessing the social impacts of bioenergy projects which could be used to support a planning for sustainability approach or even for compiling the RSB Scorecard. However, since in the Indian case the Biofuels Programme had already been initiated and a draft Biofuels Policy developed by the Indian government (before the RE-Impact project was started) this exercise might not be considered as a Social Impact Assessment but rather as a social analysis of biofuel projects in the country. Nonetheless, it provides important insights into the kind of social impacts of these projects and its results can be used towards improving their design and implementation, as well as informing the SIA process for future applications.

The following sections present a case study of social impact analysis of the use of *Jatropha curcas* as a biofuels feedstock in India, with a focus on biodiesel production. Jatropha is a shrub which bears seeds of varying oil content. It is described as being hardy and well adapted to dry climates, and has become increasingly popular for biodiesel production as a mechanism to achieve rural development. This is primarily due to suggestions that it will grow on marginal land and even help to rehabilitate such areas.

6.4 Social Impact Assessment Methodology for Biofuel Projects

Biofuel development must be viewed within the context of the existing socio-economic conditions and prevalent resource management systems i.e. the economic, social and environmental conditions and their interrelationships. This methodology draws on the SIA approaches suggested by Becker (2001) and the Centre for Good Governance (2006). In order to adapt it for bioenergy interventions, initial learning from extensive scoping work across seven States in India and one-to-one interactions with relevant national level government officials and key research institutes have been incorporated into this methodology.

The proposed approach has been designed in a broad manner to ensure its cross country applicability so that it can be applied at different scales and situations. Further, it is intended to be simple yet rigorous so that it can be adapted by different actors under a variety of contexts.

There are several approaches to SIA but by and large they are based on five social variables (CGG 2006, pg. 21):

1. **Population Characteristics** mean present population and expected change, ethnic and racial diversity, and influxes and outflows of temporary residents as well as the arrival of seasonal or leisure residents.
2. **Community and Institutional Structures** mean the size, structure, and level of organisation of local government including linkages to the larger political systems. They also include historical and present patterns of employment and industrial diversification, the size and level of activity of voluntary associations, religious organisations and interests groups, and finally, how these institutions relate to each other.

3. **Political and Social Resources** refer to the distribution of power authority, the interested and affected publics, and the leadership capability and capacity within the community or region.
4. **Individual and Family Changes** refer to factors which influence the daily life of the individuals and families, including attitudes, perceptions, family characteristics and friendship networks (commonly labelled as social capital). These changes range from attitudes toward the policy to an alteration in family and friendship networks to perceptions of risk, health, and safety.
5. **Community Resources** include patterns of natural resource and land use; the availability of housing and community services to include health, police and fire protection and sanitation facilities. Key to the continuity and survival of human communities are their historical and cultural resources. Under this collection of variables we also consider possible changes for indigenous people and religious sub-cultures.

These five variables guide the SIA process but need to be adapted to the specific situation being considered. Depending on the case, some of these variables may be more affected by the intervention than others, and would therefore need to be emphasised accordingly. For biofuel plantations, 'population characteristics' would be an important variable only if there was direct displacement of local populations on the plantation site, or if the intervention involved the hiring of labour from outside the area. The other four variables would be affected in one way or another as the establishment and management of biofuel plantations would influence local institutional structures, as well as social, individual and community resources.

Presented below are the steps and corresponding tools that can be used in assessing the social impacts of bioenergy plantations. Though the sequence of the steps is important, there would be overlaps between them and it is possible that certain steps may need to be revisited again. Therefore this process is intended to be adaptive and flexible to incorporate learning as it progresses. Each step has been applied to the cultivation of Jatropha seeds for liquid biofuel production in the Indian context, which will be presented in the following sections.

6.5 Step One: Situation Analysis

The first step is to analyse the programme / project context from the macro to the micro scale. This is very similar to the scoping stage of a traditional SIA, and it allows the practitioner to get a preliminary understanding of the environment within which the intervention is proposed, including the internal (e.g. major drivers and strategies) and external (e.g. global economy and other forces) factors that do or could influence its outcomes. Most importantly, perhaps, this is the first stage in identifying the stakeholders involved. This step helps to identify expected impacts – social, environmental and economic – on each of these stakeholders, who should be extensively drawn from all groups and societal levels, and include, for example, farmers, indigenous groups, landless, labourers.

In order to achieve this, the following sub-steps are required:

- **Sub-step 1:** A desk-based review of all relevant documents (policies, programme/project documents) pertaining to the proposed bioenergy intervention, which broadly covered the following points:

a. An analysis of the broader context (e.g. national / regional) within which the proposed bioenergy project is planned – what led to its development and how it developed? Rationale, justification and goal of the intervention – what are the major issues it proposes to address?
b. What are the major drivers? (e.g. reduced dependence on fossil fuels; economic security)
c. What are the proposed strategies? (i.e. how it proposes to achieve the goals that have been established)
d. What are the planned targets? (i.e. measurable milestones on the way to meeting its goals)
e. Focussed analysis of the specific context within which the bioenergy intervention is to be implemented – existing policies / plans / programmes and projects; resources available / relevant data.
f. Preliminary identification of relevant stakeholders – from policy makers to practitioners and local communities
g. Other issues, concerns and suggestions (e.g. raised by civil society organisations / research institutions with regards to the proposed bioenergy intervention)
h. Any lessons from interventions of similar nature undertaken in the past (e.g. community plantations)?
i. What are the data needs and gaps?

- **Sub-step 2:** The following step aims to identify stakeholders from the national to community level and involves completion of a stakeholder analysis using the matrix presented in Table 6.1. This follows from the desk-based review, as part of which a preliminary identification of stakeholders was made. In the matrix provided in Table 6.1 stakeholders were categorised according to level at which they operate i.e. national; state/province; community. The categories presented under the stakeholder column in Table 6.1 are only indicative and should be customised according to the specific context within which the SIA is being undertaken.

In order to complete the stakeholder analysis information, the desk-based review exercise should be substantiated with semi-structured interviews with each of the identified stakeholders using the matrix provided in Table 6.1 as the basis for the interview. This is crucial as a desk-based study, no matter how thorough, is unlikely to provide sufficient detail to provide a genuine level of understanding of the stakeholders and relationships between them.

6.6 Results and Discussion of the Situation Analysis

6.6.1 A brief introduction to the Jatropha Biodiesel Programme in India

The Indian Biofuels Programme began over 60 years ago but has gained significant momentum only in the past decade, and especially in the past 5 years. Whilst the major focus, until early 2000, was on ethanol as a blending additive to gasoline, in 2003 the National Biodiesel Mission was established by the Planning Commission. The Mission identified *Jatropha curcas* as the most suitable tree-borne oilseed (TBO) for the production of biodiesel and expected fossil diesel to be substituted up to 20% by 2011-12, and degraded land rehabilitated by subsequent improvements to water retention capacity (Planning Commission, Government of India 2003). Since then this target has been revised with the ratification of a national policy on biofuels and indicative target of 20% biofuel blending by 2017 has been proposed (Ministry of New and Renewable Energy, Government of India 2009).

The Government of India's focus is to use waste and degraded forest lands for undertaking bioenergy plantations and to promote rural development. At the time of writing, plantation activities are undertaken under different central government schemes such as the National Rural Employment Guarantee Scheme (NREGS). A few pro-active states such as Chhattisgarh, Karnataka and Uttarakhand have set-up Biofuels Boards and have announced policies to promote biofuels in their respective states and a minimum support price (MSP) for oil seeds has been declared to provide a fair price to the farmers. The responsibility of storage, distribution and marketing of biofuels presently rest with publicly owned Oil Marketing Companies (OMC).

In brief, the work carried out up to 2010 in biodiesel development consists of developing high yielding varieties of Jatropha and other TBOs (by organisations such as National Oilseeds and Vegetable Oils Development (NOVOD) Board, Department of Biotechnology (DBT) research institutes, and private companies), plantation of Jatropha by government-sponsored agencies, setting up of pilot plants on transisterification, and running tests with locomotives and road vehicles using 5% biodiesel blends.

The Ministry of New and Renewable Energy (MNRE), Government of India is the nodal agency for the implementation of the national Biofuels Programme with support from other ministries and autonomous bodies of the government. The major drivers for the Indian national policy on biofuels are reported to be (Ministry of New and Renewable Energy 2009):

- Generating rural employment opportunities
- Saving foreign exchange in purchasing fossil fuels
- Promoting energy security in the country
- Promoting environmental security in terms of rehabilitating wastelands
- Meeting climate change commitments through carbon sequestration and avoided use of fossil fuels
- Promoting renewable energy sources

There are concerns regarding the suitability for Jatropha, a crop which has been around in India for many decades but only recently harvested on an industrial scale for its oil, to provide these benefits (Burley and Griffiths 2009). However, despite being in consultation for almost three years, the draft Biofuels Policy was unchanged when it was mandated in December 2009. Currently there are three approaches for the production of biodiesel from *Jatropha curcas* in India (i) government-centred cultivation: which includes initiatives of various State governments individually or as a joint venture with OMCs on government owned land, (ii) farmer-centred cultivation: Jatropha plantations undertaken by individual farmers of their own accord or with facilitation by civil society organisations on generally private and at times on common lands, and (iii) corporate-centred cultivation: on private lands through contract farming (Altenburg et al. 2008).

6.6.2 Issues and concerns

Civil society organisations have raised a number of issues and concerns regarding the implementation of the Biofuels Programme. Some of the issues raised are:

- There are no 'real' wastelands in the country and that most land with any productive capacity is in use, especially by the very poor who are dependent on these lands.

- Further, there are concerns regarding the negative impacts that monocultures of biofuel plantations could have on biodiversity and correspondingly on the livelihoods of the poor
- In order to achieve economical rates of production of TBO seeds high external inputs (fertilisers, irrigation) would be necessary which could lead to the diversion of good agricultural lands for biofuel production
- Unreliability of existing plant material and the long lag period in Jatropha seed production
- Lack of adequate market support leading to Jatropha and other TBO cultivators incurring major losses
- Concern that biofuel plantations on government land will be used as a mechanism for preventing community members from expanding their tenure into marginal areas.

The steps taken by the Government of India and the issues and concerns raised by civil society organisations are both valid. The drivers for the Indian Biofuels Programme are concerns of national interest whilst the cautionary responses by civil societies highlight local level interests. Without an acceptable degree of harmony between the impacts at both these levels – national and local – there looms the chance of partial success and/or a number of undesired consequences. Further, since the Biofuels Programme cuts across sectors (*viz.* energy, natural resources, rural development) at various scales, it is all the more important to ensure that one does not develop at the cost of the other. What is therefore needed, as in any other developmental intervention, is a Biofuels Programme which incorporates economic, social and environmental concerns that interface within a sustainability framework in its planning and implementation. It is also important to retain a degree of flexibility, accepting that future technologies and species may prove more successful and provide overall more sustainable outcomes.

6.6.3 Social Impact Assessment in India

In the Indian scenario, EIA is most widely used for large development programmes such as river basin planning, highways, thermal power plants, and mining. It is not administered in the case of other land use change interventions such as large scale plantation activities e.g. Jatropha plantations. Ultimately, there is no legislation in place that makes it mandatory to undertake an Environmental or Social Impact Assessment of biofuels projects.

A common critique of EIAs undertaken in India is that they are largely focused on technical aspects (and therefore most often beyond the comprehension of the lay person) with minimal regard to social components. They are also, typically, undertaken in a non-participatory manner. In addition, EIAs are snapshots that capture only part of the picture and not the whole (effects over time) which have a bearing on the sustainability of the proposed intervention. SIA is a component of the EIA process and is most often not given the importance it deserves, even for large development projects.

Doubt around the yield and profitability of Jatropha, as well as the true short and long term costs of production, leads to a larger degree of uncertainty around the potential social impacts than would be expected, and even in extreme cases could affect whether the impact will be positive or negative. Using unsubstantiated assumptions on the agronomics and economics of the crop's production can therefore affect, to some extent, the outcome of the SIA. In this situation the flexibility in the process becomes ever more important and, until the research and development around the long term performance of

Jatropha is more advanced, the full range of agronomic and economic scenarios must be considered. This should therefore be considered as a first level of social impact analysis, given the existing lack of validated information on key determinants such as yield and profitability.

6.6.4 Stakeholder Analysis of Biofuel Initiatives in India

Table 6.1 presents the results of the stakeholder analysis exercise. This is not an exhaustive list but represents the key stakeholders and their stakes in the Biofuels Programme. This matrix enabled the identification of the principal stakeholders in the biofuels chain from the national to community level and for each of the listed stakeholders, (i) their role or potential role in the project; (ii) the expected impacts from the project for each of the stakeholders (was not restricted to social impacts alone at this stage as the idea was to map the range of intended impacts); and (iii) what are the assumptions, if any, on which these expected impacts are based.

6.6.5 Outcomes of the situational analysis

What this situation analysis shows is that there are numerous actors involved in the biofuels production chain, as well as numerous directly or indirectly related groups such as charcoal producers and kerosene sellers, each with their own interests and stakes. This implies that there needs to be a high degree of coordination and cooperation among them since, broadly at least, they are working towards the same overall goal. This therefore presents a significant institutional challenge as collective action is required. Efficient institutions, which can be fundamental in solving collective action problems, can reduce the uncertainty in the behaviour of individuals and create incentives towards greater levels of coordination and cooperation (Bravo 2002). However, achieving this level of coordination and cooperation is not a simple task. Bravo refers to Bates (1988), who points out that creating institutions to overcome a collective action problem is itself a collective action problem of a higher scale (ibid). Therefore the challenge at hand is a significant one. Beyond providing background information for undertaking a social impact analysis, this first step also enables the identification of cases that could be investigated.

As the various approaches to the cultivation of Jatropha based biodiesel in India can be categorised under three broad value chains, namely government-centred, farmer-centred, and corporate-centred, one example of each of these were taken up for further investigation and piloting of the proposed methodology. These examples are:

1. **Government-centred:** the Joint Venture between the Chhattisgarh Renewable Energy Development Authority (CREDA) and the Indian Oil Corporation (IOC), an OMC, in the central Indian State of Chhattisgarh. Indian Oil CREDA Biofuels Ltd. (referred to henceforth as IOC-CREDA) was formed to enable IOC to straddle the complete biofuel value chain. In this joint venture IOC has an equity holding of 74% and CREDA has 26%. IOC-CREDA has been formed for carrying out farming, cultivating, manufacturing, production and sale of biomass, biofuels and allied products and services; they initiated the establishment of Jatropha plantations in selected districts of Chhattisgarh in 2009.
2. **Farmer-centred:** Reliance Life Sciences (RLS), as part of its Biofuels Programme, has been working with NGOs and farmers to promote the cultivation of biofuel crops on marginal lands. It aims to promote a multi-culture agronomy by standardising agronomic practices of Jatropha, *Pongamia pinnata* and other TBOs along with intercrops such as mango, vegetable

Table 6.1: **Stakeholder Analysis for the Biofuels Programme in India**

Stakeholder	(Potential) Role in the project	Expected impacts from the project	Assumptions
National Level			
Ministry of New and Renewable Energy	• National biofuels policy development • National nodal agency for implementing the Biofuels Programme	• Promoting renewable energy sources	• Biofuel is a viable renewable energy option
Ministry of Rural Development	• Member of the National Biofuels Coordination Committee and the Biofuels Steering Committee	• Rural employment generation • Productive use of wastelands • Rehabilitating wastelands	• Effective targeting of beneficiaries • Appropriate identification and acquisition of wastelands • Wastelands not under significant productive use
Ministry of Petroleum and Natural Gas & its Oil Marketing Companies	• Production of feedstock, refining, distribution and marketing of biofuels • Establishing purchase price for biofuels	• Saving foreign exchange • Promoting energy security in the country	• Adequate and regular supply of bioenergy feedstock available
Planning Commission	• National Mission on Biodiesel to demonstrate effectiveness of this alternative approach • Fund allocation to Ministries • Planning and policy inputs	• Rural employment generation • Productive use of wastelands • Rehabilitating wastelands • Promoting energy security in the country	• National and State Governments implement the Biofuels Programme effectively
National Oilseed and Vegetable Oil Development Board	• Identification and development of superior planting material • Developing improved post harvest technologies • R&D inputs to the Biofuels Programme	• Superior bioenergy germplasm available across the nation (seeds with higher oil content) • Improved post harvest and processing technologies of oil seeds	• Improved germplasm and available technologies would facilitate the upscaling of the of the Biofuels Programme
State Level			
Biofuels development authorities	• Production of biodiesel feedstock and biodiesel	• Bioenergy feedstock available • Local communities benefit from employment opportunities provided by the Biofuels Programme • Energy security • Environmental security • CDM benefits	• Wastelands / marginal lands are available for bio-energy plantations • Yields of bioenergy plants under wasteland conditions would be sufficient to support a commercially viable biodiesel enterprise
Forest Department	• Using degraded forestlands for bioenergy plantations	• Promoting environmental security • Meeting climate change commitments	• Bioenergy plantations are a viable option for the rehabilitation of degraded forestlands • No impact on biodiversity

Cont...

Table 6.1 Cont...

Stakeholder	**(Potential) Role in the project**	**Expected impacts from the project**	**Assumptions**
Civil society organisations	• Social watchdogs – protecting the rights of local communities and the marginalised • Demonstrate innovative methods of involving local communities in developing bio-energy plantations	• Should benefit rural communities, especially the poor in a tangible manner • Effectively contributes towards rural development • Environmental security maintained	• Ulterior motives of the government / implementing agency • Monocultures would affect local biodiversity • Tenurial rights, especially informal ones, of local communities would be adversely affected • Bioenergy plantations are a potential livelihood option for local communities
Private corporations	• Production of bioenergy feedstock, refining and sale to OMCs or for export (only extracted oils)	• Feedstock generation • Profits • Rural development (in some cases)	• Bioenergy plantations are a viable business proposition • Predicted yields would be realised under field conditions • Farmers / local communities willing to enter into a formal or informal joint ventures
Community Level			
Individual farmers	• Voluntarily provide their private, unproductive / low productivity lands for bio-energy plantations	• Enhanced financial returns from earlier unproductive / low productivity lands	• Food crops not displaced • Risks to farmer are minimal • Access to relevant information and technical inputs are available to the farmers
Poor / landless / resource users	• Participate in plantation establishment and management	• Income generation though locally available labour	• Specifically involving the poor and landless is part of the bioenergy intervention strategy

crops and medicinal plants in different agro-climatic conditions and under rain-fed and irrigated conditions. In the Bastar District of Chhattisgarh State, RLS has promoted Jatropha plantations on the marginal lands of farmers. Although RLS is a corporate entity, the approach of its Biofuels Programme has been farmer-centred. RLS assures a buy-back of the biofuel feedstock but it does not enter into a formal contract with the farmers.

3. **Corporate-centred:** Mission Biofuels India Private Limited (MBIPL), a subsidiary of Mission NewEnergy Limited, was established in 2007 for the upstream *Jatropha curcas* Feedstock Business and wind energy projects. MBIPL is involved in large scale Jatropha cultivation, nurseries and procurement centres in several States. In its operational areas MBIPL, through its extensive network, identifies suitable farmers and enters into a 30 year contract with them. These farmers are given a buy-back guarantee, technical and financial assistance; the latter on a loan basis where MBIPL facilitates the process of farmers gaining a loan from the corporate banking sector, failing which, it extends a loan to them directly.

These three models were selected for further investigation in the ensuing steps.

6.7 Step Two: System Analysis

This step provides further insights into the functioning, interactions, and varying social impacts on stakeholders within the system of the biofuels intervention.

There are four stages of the biofuel production chain, namely, (i) production of biomass feedstock through cultivation; (ii) conversion of the feedstock to fuel (or electricity); (iii) distribution and retailing of finished fuels; and (iv) bioenergy consumption. The system analysis carried out for Indian biofuels focused on the first stage i.e. production of biomass feedstock through cultivation, as it is at this level that biophysical (e.g. land use changes) and institutional (e.g. tenurial rights) changes could potentially have the most significant social impacts. This is depicted in Figure 6.1, which highlights the need for

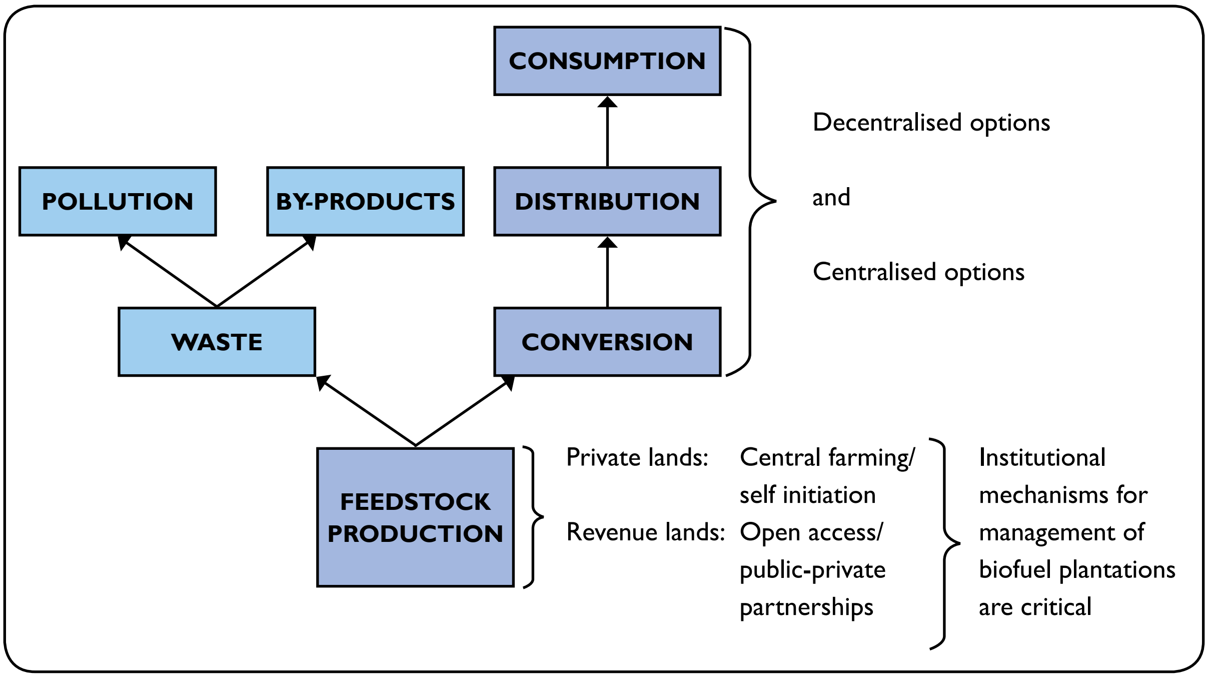

Figure 6.1: **Stages of the biofuels production chain**

effective institutional mechanisms for the management of biofuel plantations, without which the remainder of the production chain collapse.

This exercise comprises of two sub-steps:

- **Sub-step 1:** In the first sub-step the degree of influence of the proposed biofuel intervention across specific components of each of the five social variables was assessed using the matrix provided in Table 6.2. The purpose of this exercise was to rank and map out, in terms of the degree of influence (i.e. high / medium / low / none), the social impacts that the proposed biofuel intervention could have or is having on the targeted populations. For example, if the intervention, as a strategy, proposed to use only locally available labour for the establishment and management of the biofuel plantations, then the impact in terms of 'influx of labour from outside the area' would be 'none', and it would be 'low' if the implementing agency agreed to hire external labour only if and when the local labour potential has been saturated. Each of the listed impacts were categorised as 'positive' or 'negative' and a score ranging from + (plus) 3 to +1 was accorded to positive impacts depending on their degree of influence, i.e. a 'high' degree of influence was given a +3 score, 'medium' +2, and a +1 score to 'low'. Similarly, negative impacts were scored from – (minus) 3 for high degrees of influence to -1 for low impacts. Where there were no impacts, a score of zero was accorded. The scores were totalled separately for each of the five social variables, as well as cumulatively to assess the overall social impact. Across the five social variables each of the scores were given equal weighting. The completed matrix indicated areas where actual or potential social impacts would be higher for that particular intervention.

  Semi-structured interviews were undertaken with key stakeholders involved in the implementation of the bioenergy project i.e. in the designing, planning and operationalising processes, using the points of enquiry listed out in the matrix presented in Table 6.2. Further, focus group discussions with local communities were also conducted using the same matrix.

- **Sub-step 2:** having broadly categorised the potential social impacts, both positive and negative, in the previous sub-step, the following exercise focused on clearly identifying these social impacts (again both positive and negative). The matrix presented in Tables 6.3 and 6.4 facilitated this process. A set of questions which need to be answered for biofuel plantations planned on different land ownership types (i.e. government lands; communal lands; private lands) have been listed. The social impacts were assessed in terms of expected 'direct', 'indirect' and also anticipated 'cumulative' impacts.

  Again, semi-structured interviews and focus group discussions based on this matrix (Table 6.3) were used for interacting with relevant stakeholders and gathering the necessary information.

6.8 Results and Discussion of the System Analysis

6.8.1 Assessing degree of infuence of the biofuel intervention across social variables

As can be seen in Table 6.2, all three models have an overall positive social impact. Based on this framework the ideal score to achieve would be 39. The farmer-centred model scores the highest at 22, followed by the corporate-centred one (16), and the government-centred one, which gets the

Table 6.2: **Assessing the degree of influence of the biofuel interventions across social variables**

Social Variables	Type of Impact	IOC-CREDA Joint Venture					Reliance Life Sciences					MBIPL				
		Degree of Influence				Score	Degree of Influence				Score	Degree of Influence				Score
		High	Medium	Low	None		High	Medium	Low	None		High	Medium	Low	None	
Population change																
Relocation of people (e.g. from encroachments)	Negative		✓			-2				✓	0				✓	0
Influx of labour from outside the area – seasonal or permanent	Negative	✓				-3				✓	0				✓	0
Migration (outflow – seasonal / permanent)	Negative				✓	0				✓	0				✓	0
Sub-total						-5					0					0
Community and institutional structures																
Voluntary associations	Positive				✓	0	✓				3	✓				3
Employment / income opportunities	Positive			✓		1		✓			2		✓			2
Employment equity of disadvantaged groups	Positive			✓		1			✓		1			✓		1
Local-Regional-National linkages	Positive			✓		1		✓			2			✓		1
Industrial / commercial diversity	Positive	✓				3	✓				3		✓			2
Sub-total						6					11					9
Political and social resources																
Distribution of power and authority	Positive				✓	0		✓			2			✓		1
Varying stakeholder interests and concerns accounted for	Positive			✓		1	✓				3		✓			2
Local leadership development	Positive				✓	0	✓				3		✓			2
Inter-organisational cooperation	Positive		✓			2		✓			2			✓		1
Sub-total						3					10					6

Cont...

Table 6.2 Cont...

Social Variables	Type of Impact	IOC-CREDA Joint Venture					Reliance Life Sciences					MBIPL				
		Degree of Influence				Score	Degree of Influence				Score	Degree of Influence				Score
		High	Medium	Low	None		High	Medium	Low	None		High	Medium	Low	None	
Community and family changes																
Perceptions of risk (e.g. poor yields / loss of food crop / debt)	Negative		✓			-2		✓			-2		✓			-2
Trust in the political and implementing institution	Positive		✓			2		✓			2		✓			2
Positive attitudes toward proposed action	Positive			✓		1		✓			2		✓			2
Concerns about social well-being	Positive		✓			2		✓			2			✓		1
Sub-total						3					4					3
Community resources																
Change in community infrastructure (common lands for grazing / fuelwood collection)	Negative	✓				-3		✓			-2				✓	0
Optimal utilisation of land resources	Positive		✓			2		✓			2		✓			2
Labour displacement within the community	Negative			✓		-1			✓		-1			✓		-1
Displacement of food crops	Negative				✓	0		✓			-2	✓				-3
Sub-total						-2					-3					-2
GRAND TOTAL						**5**					**22**					**16**
Source: Adapted from Inter-organisational Committee 2003																

lowest score of 5. Whilst the first two have no impact in terms of the 'population change' variable, as they engage with individual farmers, the government-centred model undertakes plantations on barren lands that were used by local communities for a variety of purposes such as grazing, usufructs, and at times agriculture (although legally these were encroachments). Further, labour from outside the area is also brought in to work on the biofuel plantations, thereby reducing employment opportunities of the resident population. Due to these factors the government-centred model has a negative score (-5) for the population change social variable.

In terms of the following three social variables *viz.* 'community and institutional structures', 'political and social resources', and 'community and family changes' all three models have a positive score. The farmer-centred model performs best, recording a percentage score (of the ideal score) of 73%, 83% and 44% respectively. The corresponding figures for the government-centred model are 40%, 25% and 33%; and those of the corporate-centred model are 60%, 50% and 33%. The main reason for the disparity between the farmer-centred and corporate-centred models is the difference in the 'purpose of engagement' with the local farmers and encouraging a high level of their participation in decision making processes. Whilst the corporate approach has a fixed agenda and activities, the farmer-centred approach is more flexible and attempts to respond to local needs and to balance these with its own, meaning its social impacts are less severe.

With regards to the 'community resources' variable, all three models have negative scores. This is because they each have an impact in terms of displacement of labour or food crops. It is now well established that managing Jatropha plantations is labour intensive and would therefore necessitate a displacement of labour or human capital that could have been directed towards food crops. Further, even marginal lands are used for cultivating low value food crops such as pulses which either provide a source of income or supplement household diets, in some cases providing the main source of protein. Figure 6.2 depicts the performance of the three models across the five social variables and how each compares to the ideal score.

The scorecard in Table 6.2 clearly indicates that all the three models have scope for improvement in terms of social parameters. It also provides information on specific social parameters that would need to be strengthened in each of the three models of biofuel feedstock production.

6.8.2 Assessment of potential direct, indirect and cumulative social impacts

The analysis provided in Table 6.2 can be further substantiated by assessing what the potential direct, indirect and cumulative social impacts of each these models may be. The consideration of cumulative impacts is particularly important and has not always been considered in great depth previously. Tables 6.3 and 6.4 show how this has been completed for the Indian Jatropha production models. Table 6.3 examines the impacts of the IOC-CREDA Joint Venture. Since Reliance Life Sciences is also a corporate agency it has been combined with Mission Biofuels India Private Limited in Table 6.4, however, impacts specifically attributable to either one of these agencies has been duly indicated with RL and MB respectively.

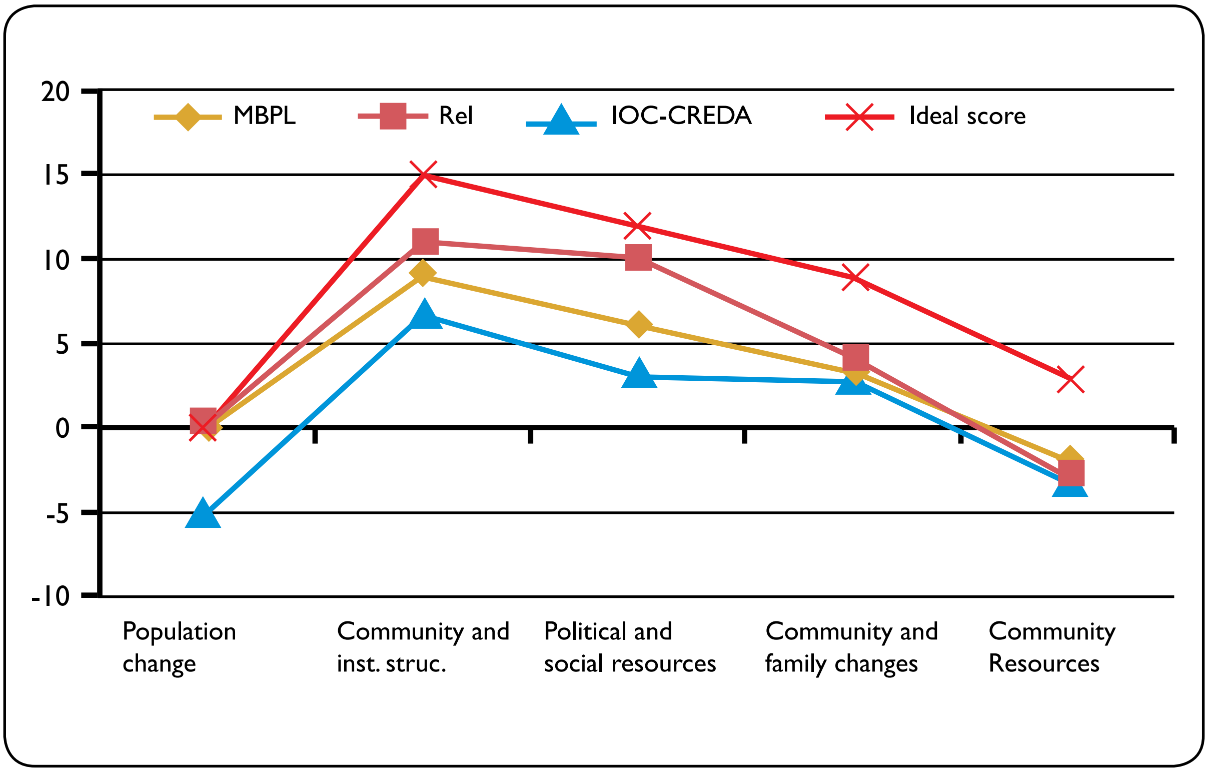

Figure 6.2: **Assessment of the biofuel initiatives across social variables**

The two tables indicate that there are both positive and negative impacts which could be anticipated. In the case of IOC-CREDA, local communities are directly divested of informal rights that they have on the lands that have been brought under biofuel plantations, but the intervention also provides potential employment opportunities. Further, in this case the direct risks to farmers in financial terms are nil and local communities will not be affected if the expected yields are not realised. However, since they will be denied access to lands that were earlier used for open grazing and usufructs these practices will be transferred to other areas surrounding the villages e.g. forestlands or common lands of neighbouring villages which could increase the chances of conflicts between villages as well as with the forest department. Further, this would have indirect and cumulative impacts in terms of indirect land use change (iLUC) which could be adverse for these communities as well as the environment. Infrastructure such as tube-wells that this initiative expects to develop in order to irrigate the biofuels plantations could directly benefit local agriculture and enhance productivity; however, local communities have no active role in decision making in the production of biofuel feedstock even though they are being directly affected by the intervention.

Similarly, in the case of private ventures, farmers are provided with buy-back guarantees but in the case of MBIPL they are locked into a thirty year contract which removes their right to change the land use within that time. Further, there is a breaking down of free market principles by a monopolisation of produce at a set price. Biofuel plantations provide an alternative and potentially long term source of income for individual farmers, but these are also diverting under-utilised indigenous food crops which, though largely ignored during good years, are important buffers, particularly during drought conditions, in terms of food and livelihood security. In view of the predicted climate change scenarios

Table 6.3: **IOC-CREDA Joint Venture: Assessment of potential direct, indirect and cumulative social impacts**

Issues	Land ownership type (govt. / communal)	Potential Social Impacts		
		Direct	Indirect	Cumulative
Who owns the land?	Leased to private companies by Government	• Loss of informal rights	• Privatisation of common lands	• Potential inter and intra village conflicts
What was the previous land use?	Common – used for grazing, collection of NTFPs, typically degraded wasteland, low productivity	• Access to grazing lands, source of fuelwood other usufructs denied • Land productivity enhanced • Land quality improved • Alternative source of income created	• Existing livelihoods especially of marginal communities affected negatively • Encroachment elsewhere – e.g. forestlands (indirect land use change)	• Degradation of forestlands – increased demands • Vulnerability of marginalised groups enhanced • Reduction of wastelands
Who funds establishment?	National / State Government / IOC	• Infrastructure developed (e.g. tubewells for irrigation of plantations) • No financial burden on local communities	• Agricultural practices and productivity enhanced – technical inputs and water availability	• Improved agri-infrastructure
Who makes plantation management decisions?	Agency selected by IOC	• Communities not involved in decision making	• Communities lose control over previously self managed lands	• Improved wasteland management • Reduced role of communities in management of waste/ common lands
Who manages the crops?	Agency selected by IOC			
Who funds management activities?	IOC	• Enhanced viability of successful implementation • Recurrent livelihood option created • Increased local job opportunities	• Labour displacement from existing livelihood options	• Potentially expected yields realised making this a long term livelihood option for local communities
Who has feedstock harvesting rights?	Hired agency for IOC	• Community rights divested • Communities not affected by losses in case of low yields • No real role for communities in the bioenergy value chain	• Monopoly of common lands and of products from them	• In case of crop failure, livelihood option lost
Who has rights to purchase the produce?	Hired agency for IOC	• Established market • Monopolisation of produce	• Food crop lands brought under bioenergy plantation	• Privatisation of benefits from common lands

Cont…

Table 6.3 Cont...

Issues	Land ownership type (govt. / communal)	Potential Social Impacts		
		Direct	Indirect	Cumulative
Who gets access to by-products?	Seed cake would belong to IOC, any others could be accessed by community	• Pruned branches and dried leaves available for fuel and manure use by communities	• Reduction of drudgery in collection of leaf litter and fuelwood • Possible availability of cheap fertiliser equivalent (seedcake)	• Resource removal leading to slower revival of wastelands
Who sets the purchase price?	IOC – CREDA	• (None, as communities not actively involved in the biofuel value chain)		• Breaking down free market principle
What livelihood benefits are available to poor/landless?	Employment opportunities	• Locally available job opportunities • Minimum wage as defined by local government is potentially assured • Potential exploitation of poor / landless by hired agencies to maximise their own savings • Hired agencies contract cheap external labour, denying resident communities job opportunities	• Labour hired from outside the area • Change in population characteristics in the area • Labour diverted away from agriculture	• Income of poor / landless enhanced and secured to a greater degree • Increase in migration by local communities
Who carries the risk if projected yields are not realised?	Hired agency & IOC	• Low risk livelihood opportunity for local communities		• Loss of livelihood option for local communities in case projected yields not realised and activities discontinued
Is there possibility for vertical integration?	Currently none	• Benefits for local communities limited to labour opportunities		
What ecosystem services are gained or lost?	Lost: grazing / fuelwood & usufruct collection. Gained: groundwater tapped / soil condition & water infiltration improved / reduced runoff Unknown: impact on water supply/ biodiversity	• Access to water resources for agriculture • Over exploitation of groundwater if usage not regulated	• Enhanced agriculture yields • Chemical agriculture intensification & corresponding pollution of water and soil resources	• Increased income from agriculture • Soil and water quality degraded • Potential of loss of biodiversity

Table 6.4: **Private Ventures: Assessment of potential direct, indirect and cumulative social impacts**

Issues	Land ownership type (govt. / communal)	Potential Social Impacts		
		Direct	Indirect	Cumulative
Who owns the land?	Individual farmers	In case of contract farming, land locked for a period of 30 years If no contract, then farmer free to change land use	Alternative land use options restricted (MB) Markets for other crops e.g. vegetables / NTFPs available (RL)	Regular source of income for farmer
What was the previous land use?	Under-utilised farm lands (MB & RL) Barren lands (RL)	Food crops diverted especially indigenous crops Access to grazing lands, source of fuelwood other usufructs denied Land productivity enhanced Land quality improved Alternative source of income created	Potential of nutritional deficiency due to reduced availability of indigenous crops Encroachment elsewhere – e.g. forestlands	Greater dependence on cash crops and associated implications on food security in the face of climate change Degradation of forestlands – increased demands Vulnerability of marginalised groups enhanced Reduction of wastelands
Who funds establishment?	Farmer's own equity Banks / company loan schemes Govt programmes tapped	Working capital available to farmer Loan burden on farmer	Opportunities to diversify income sources available to farmers Debt risk	Credit-worthiness of farmers enhanced Loss of assets in case unable to repay loan
Who makes plantation management decisions?	Farmer with technical support from associated company (RL & MB)	Capacity building of farmer Improved land and crop management practices Potentially higher yields realised Income from inter-cropping during lag period	Increased income from agriculture	Improved wasteland management Reduced role of communities in management of waste/common lands
Who manages the crops?	Farmer			
Who funds management activities?	Farmer	Additional input costs to farmers (Rs. 2500-3000 / acre / year) Labour displacement from existing livelihood options	Increase in indebtedness in case further loans need to be taken to meet fertiliser/other costs	Potentially the ability to take financial risks for food crops reduced
Who has feedstock harvesting rights?	Farmer	Harvesting controlled by company demand /need (MB)	Monopoly of private lands and of products from them (MB)	(unknown)
Who has rights to purchase the produce?	Open market (RL) Company to whom contracted (MB)	Established market High dependence on single market point Monopolisation of produce (MB)	Food crop lands brought under bioenergy plantation	Increased amounts of food croplands brought under bioenergy plantations resulting in food insecurity

Cont...

Table 6.4 Cont...

Issues	Land ownership type (govt. / communal)	Potential Social Impacts		
		Direct	Indirect	Cumulative
Who gets access to by-products?	Seed cake would belong to company, any others could be accessed by community	Pruned branches and dried leaves available for fuel and manure	Reduction of drudgery in collection of leaf litter and fuelwood Possible cheap fertiliser equivalent (seedcake)	Resource removal leading to slower revival of wastelands / low productivity lands
Who sets the purchase price?	Contracting company (MB) Possibility of market prices (RL)	Assured returns Price aligned with 'minimum support price' so farmers not exploited	If price favourable, then more farmers attracted to undertake bio-energy plantations – greater land use change	Breaking down free market principle (MB)
What livelihood benefits are available to poor/landless?	Farm labour	Locally available labour opportunities	Loss of access to grazing lands compensated	Locally available wage labour opportunities created
Who carries the risk if projected yields are not realised?	Farmer Company – of not getting feedstock	Indebtedness	Loss of income & food source due to diversion of labour & other resources	Increased vulnerability
Is there possibility for vertical integration?	Currently none (MB) Possibility of farmers having a share in processing (RL)	Chances of higher returns Reduced individual risk Increased access to credit	Food crop lands diverted to bioenergy plantations	Local food insecurity Agri-business promoted
What ecosystem services are gained or lost?	Lost: grazing / fuelwood collection / usufruct collection Gained: soil condition improved Unknown: impact on water resources / biodiversity	Pressure on common / forest lands would increase Potential for improved agricultural yield		

this could possibly have considerable adverse, and long term, impacts on local societies. These initiatives can further increase the vulnerability of local farmers through indebtedness created by the company providing loans towards establishment and management of the plantations. If the farmers are unable to repay these loans it could result in a loss of assets as well as an unproductive crop (Borman et al. In Submission). This would be especially true if the expected yields are not realised, a risk that does not exist in the IOC-CREDA model. However, conversely, if the farmers are able to repay these loans it would enhance their credit-worthiness.

There is a clear mix of positive and negative social impacts – direct, indirect and cumulative – across the three models that have been investigated here. If the Biofuels Programme in India is to be effectively used as a vehicle for generating rural employment opportunities and promoting environmental security, the negative social impacts that it could have need to be appropriately addressed. Despite the lack of basic knowledge around the agronomics and economics of Jatropha production, the approach adopted by the implementing agency and the choices that they make will also have social impacts that can be identified with a reasonably good degree of certainty, and some of these would be negative as the case studies show. As more reliable information on the crop becomes available, a more detailed understanding of potential social impacts could be developed.

6.9 Conclusions

The approach to SIA presented above has enabled an understanding of the wider context within which specific bioenergy projects have been formulated; the major stakeholders and their respective expectations have been recorded; social impacts (positive and negative) across five social variables for different approaches have been ranked and mapped; and their potential direct, indirect and cumulative impacts have been identified.

That biofuel projects can have both negative and positive social impacts has been established based on the Indian case study presented here, as well the examples provided earlier. Through examining the assessment and analysis of specific social variables it has been found that change in land use to biofuels feedstock production has potential social risks in terms of the 'community resources' variable, independent of approach, scale, and choice of land type. For the other four variables there is significant scope for improvement for each of the investigated models.

The farmer-centred model has recorded the highest 'social score' as it adopts an inclusive approach and, to an extent, attempts to align the mandate of the facilitating agency with the needs of the local farmers. The government-centred model that excludes local communities from any decision making processes has registered the lowest score, while the corporate-centred model has an intermediate score as it does involve engagement with local farmers, but retains a higher degree of control over the process. What emerges is that the level of participation and inclusion of local communities in the planning, decision making and implementation of biofuel projects has a direct bearing on the type of social impacts that can be anticipated.

The SIA process for bioeneregy projects set out in this chapter provides policy makers and implementing agencies with a relatively easy-to-use and low resource-intensive tool that could be effectively used for identifying potential social risks and an opportunity to (re-) strategise accordingly. Further, the identified positive social impacts are indicators against which the intervention can be monitored from a social impact perspective during both its implementation and post-implementation phases. On the other hand, the negative social impacts need to be discussed and addressed so that they are either eliminated if at all possible, or minimised by formulating and adopting alternative strategies. As with the positive impacts, the outcomes of these alternative approaches could also be indicators for future monitoring. SIA can also help to spot natural resource management conflicts before they develop into larger scale problems.

For each of the identified negative social impacts it is now necessary to engage more formally with the stakeholders to define alternative approaches, assess the anticipated impacts on application of these alternatives, determine the additional costs that the intervention would need to incur to implement these alternative approaches, and finally define potential strategies for each. This is a complex exercise and would need to be undertaken in a fully consultative manner that includes all relevant stakeholders. For this, multi-stakeholder consultations need to be organised. All stakeholders – from policy makers to the targeted populations – should be adequately represented at this consultation for it to be effective. Facilitating multi-stakeholder consultations requires a specific skill set and experience in order to balance out differential power dynamics between the stakeholders and to ensure that each stakeholder group has an equal voice in the entire process. This is an extremely challenging, but nonetheless necessary, task. The methodology proposed here should preferably be implemented within a planning for sustainability approach (see Chapter 2). Both require active participation of stakeholders with the potential to integrate steps of the involvement process. Moreover, the information gathered by the SIA enquiry is a necessary input for the Sustainability Assessment of the impact of bioenergy feedstock production on social-ecological systems.

In conclusion, it is important to acknowledge that there is no perfect solution to this complex set of interactions between social, economic and environmental concerns that cut across interests at the local level to those at the national and global levels. There are tools such as the one presented here that could facilitate the design of optimally beneficial initiatives; nevertheless, getting the balance between these three key parameters absolutely right is almost certainly impossible. There are bound to be tradeoffs involved. The crucial question is whether, for a particular area and a particular set of stakeholders, these tradeoffs are mutually acceptable. For this, bioenergy projects need to incorporate impact assessment procedures as well as a 'learn as you grow' approach so that benefits to society are maximised.

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Chapter 7
Socioeconomic Impacts of Biofuels: Methodologies and Case Study Examples

Nicholas Ngepah

7.1 Introduction

Bioenergy, and liquid biofuels in particular, is increasingly gaining ground in the energy, economic development, climate change and agricultural policies of most countries (IEA 2004). The emphasis placed on biofuel depends on the priorities of the particular policy agenda. Developed countries concerned about climate change and, therefore, the reduction of Green House Gas (GHG) emissions through the use of clean energy, may include biofuels as one of their options (Matthiews 2007). However, conflicting results of carbon balance analyses makes this issue increasingly debatable, especially for first generation biofuels (IEA 2004). In both developed and developing countries, there are energy security concerns and countries are looking at biofuels as one of the possible solutions (Wright 2006).

In developing countries, the production of biofuel feedstock is largely seen as a way to stimulate rural development, create jobs, and save foreign exchange (Kojima and Johnson 2006). The introductory chapter of this book presents an explicit link between agricultural feedstock production and bioenergy. Generally, biofuel production can enhance agricultural production, spilling-over from biofuel feedstock production to other cash and food crop production. The establishment and operation of biofuel processing plants can also boost the non-agricultural sector. This combination can result in the absorption of on-farm as well as off-farm labour, leading to higher employment and poverty reduction in both agricultural and non-agricultural sectors. For the foreseeable future, particularly in Africa, reducing poverty will depend largely on agricultural growth (IBRD/World Bank 2009). The World Bank (2008) has underscored the importance of agriculture in pro-poor growth, especially in Sub-Saharan Africa (SSA): GDP growth in agriculture is four times more effective in extreme poverty reduction than GDP growth originating from other sectors; in developing countries 75% of the poor live in rural areas and are dependent on agriculture; but only 4% of official development aid goes to agriculture. SSA countries rely heavily on agriculture for overall growth, but this sector is highly taxed with only 4% of total government spending being allocated to the sector.

Understanding the rural development implications of biofuel expansion is therefore a key issue when considering if biofuel is a viable and appropriate land use option. The previous chapters in this book have largely dealt with the potentially negative social and environmental implications of bioenergy expansion. A key justification for biofuel is the development potential it can bring, which needs to be substantive to justify tradeoffs against the potential environmental costs. Economic considerations for biofuel are complex and multi-faceted and need to take into consideration both macro and micro economic issues. It is important to consider not only the degree of income generation, but also the equity of distribution. This chapter introduces approaches to address two key concerns in the economics of biofuels feedstock production: crop suitability according to resilience to price volatility and potential for poverty reduction, and the productivity divide between small scale and commercial farming. First, it proposes a framework to assess the suitability of various crops for use as biofuel feedstock in view of two important policy challenges – agricultural price volatility and poverty reduction. Second, it provides a methodology for assessing productivity differences between subsistence and commercial farming and highlights some of the underlying factors. The rest of the chapter is structured as follows: section 7.2 examines crop suitability using price volatility criteria; section 7.3 investigates the poverty implications; section 7.4 investigates the causes of differences in productivity of small- and large-scale farms; section 7.5 concludes with a summary of findings and a discussion of the subsequent biofuel and development policy implications.

7.2 Feedstock Demand Enhancement, Price Stability and Agricultural Production

Agricultural commodity price volatility has been identified as a major risk affecting the decision making process of farmers (Hueth and Ligon 1999). Price volatility always affects agricultural output supply negatively because farmers (especially in developing countries) do not have the means to hedge against this risk (Subervie 2008). One important consequence of biofuel expansion in developing countries would be an increase in effective demand for agricultural produce, stabilising prices due to its ability to absorb excesses in times of positive supply shocks. With carefully managed policy, this can translate into sustained agricultural production at higher prices, with income poverty reduction potentials for farmers. The Food and Agricultural Organisation of the United Nations (FAO 2002) has noted high price volatility of agricultural commodities like maize, wheat, soybeans, rapeseeds and cotton, all of which are good candidates for biofuel. This section uses common frameworks discussed in the literature[23] to analyse the crops that are likely to benefit from biofuels in terms of market price stabilisation, which in turn may result in supply enhancement.

7.2.1 Methodology

Two broad frameworks exist in the literature of agricultural supply response analysis: the Nerlovian expectation model, used to estimate speed and level of adjustment of actual acreage to desired acreage,

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[23] Mainly of Nerlove (1958), which has been adapted in various ways by Holt and Aradhyula 1990; Chavas and Holt 1990 1996; Antonovitz and Green 1990; Guillaumont and Bonjean 1991; Holt 1993

and the profit maximisation framework, used to derive the supply function. The profit maximisation model requires detailed (sometimes micro) information on inputs, prices and output. These data are seldom available in time series and at macro scale and, therefore, this chapter will discuss the more suitable Nerlovian model. The Nerlovian model, after Nerlove (1958), enables the determination of both short and long run elasticities, and also allows for the introduction of non-price variables. The model is designed to assist farmers in making the decision whether to produce or not. It theorises that the desired production area (A_t^*) is determined by the expected price (P_t^*), and the actual acreage (At) adjusted to desired acreage with lags (Narayana and Parikh 1981). With parameters βi and a random error u, the model is formalised as follows:

$$A_t^* = \beta_0 P_t^{*\beta_1} e^u \qquad (1)$$

$$\frac{A_t}{A_{t-1}} = \left(\frac{A_t^*}{A_{t-1}^*}\right)^{\delta} \quad 0 < \delta \le 1 \qquad (2)$$

$$\frac{P_t}{P_{t-1}} = \left(\frac{P_t^*}{P_{t-1}^*}\right)^{\gamma} \quad 0 < \gamma \le 1 \qquad (3)$$

This reasoning in terms of desired and actual acreage presupposes that farm land is abundant and that farmers can either increase or reduce their desired and actual production area at will, in order to control the level of output (Y). However, in situations where farm land is relatively scarce, level of output can be adjusted though other factors of production, e.g. degree of intensiveness. In such reasoning, the above reasoning would hold better for output rather than acreage, and acreage would be a regular factor of production. This is what is assumed henceforth in the rest of the model. After substitution of (2) and (3) in (1) and taking logs, the general structural form equation can be written as:

$$\begin{aligned} \ln Y_t &= \beta_0\gamma\delta + \beta_1\gamma\delta \ln P_{t-1} + [(1- \\ &-(1-\gamma)(1-\delta)\ln Y_{t-2} + [\delta u_t - \delta(\end{aligned} \qquad (4)$$

In (4), δ and γ are adjustment parameters, Y_t is supply or acreage at time t and ln is the natural logarithm. With the inclusion of other exogenous non-price variables X_t, the final reduced form of the equation can be expressed empirically as:

$$\ln Y_t = \alpha_0 + \alpha_1 \ln Y_{t-1} + \alpha_2 \ln Y_{t-2} - \alpha \qquad (5)$$

Where α are short run parameters and ε is an error term.

Literature on the use of this model has been marked by specification problems, particularly related to climate, price and risk variables. The highly varying elasticities recorded can be attributed to variable specifications, as well as to methodologies employed. Various attempts have been made to improve specification. For example, the introduction of relative instead of absolute prices in a competing crop concept (Mythili 2008). However, although the effect of competing crops can be envisaged in a crop-for-food market, it cannot in a crop-for-fuel market since biofuel production has not yet reached a significant scale. For this reason, only the prices of the crops in question have been included in this chapter. In order to specify the risk variable, in this case price, researchers often use the standard deviation from the trend or mean. Examples include those of Behrman (1968) and Subevie (2007). In this chapter, price risk is defined following Ghatak and Seale (2001), who used the first lag of the square deviation of market prices from its mean within each time period, weighted by the number of observations. Price risk (*PV*) is the square of deviation of market prices (P) in each time period (t), from the mean of price variable (*P-bar*) divided by the number of observations (*n*):

$$PV_t = \frac{1}{n}(P_t - \bar{P})^2 \qquad (6)$$

The final empirical model to be estimated is equation (5) to which price volatility variable has been added. The dependent variable considered is quantity supplied for the selected crops and land area under each crop is considered a part of X_t.

$$Y_{it} = \alpha_{i0} + \alpha_{i1} Y_{it-1} + \alpha_{i2} Y_{it-2} - \alpha_{i3} P_{it-1} + \alpha_{i4} PV_{it} \qquad (7)$$

where *i* is crop index and *PV* is price uncertainty.

Empirically, many time-series research results have highlighted the importance of the effect of price instability on a farmer's decision to produce. A few examples include Lin (1977), who estimated the responsiveness of wheat supply to price instability in Kansa (1950-1975) and obtained a value of -0.06, and Chavas and Holt (1996) who obtained a value of -0.033 for US corn between 1954 and 1985. The importance of this model for biofuel crops is that it does not require much crop level input data. Crop output, acreage and prices can be used to estimate the model. In equation (7), the price and price risk variables are likely to correlate with the model error term. As such, the estimation procedure has to be heteroscedasticity consistent such as robust estimation which is suitable for addressing this problem and the possible problem of bias due to the presence of outliers.

7.2.2 Case study example

South African data from the Department of Agriculture (2007) is used as a case study for equation (7). A sub-sample spanning 1982 to 2006 is considered. Expected market prices and expected price risk are one period lags of prices and price risks respectively. The crops considered in this analysis are those which have been proposed for biofuel production in South Africa (sugarcane for bioethanol; sunflower, canola and soybeans for biodiesel)[24], as well as a few potential crops for which data is available (maize, wheat, sorghum and groundnut).

Since most agricultural time series are not stationary[25] at levels, the first step in estimation of equation (7) starts with the analysis of the time series properties of the variables in the data. The most prominent

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[24] See Department of Minerals and Energy (2007)

[25] A stationary stochastic time series is one in which a joint distribution of any set of observations is invariant to a change of time origin (Box and Jenkins 1976). In the presence of non-stationarity, Ordinary Least Squares (OLS) yield biased estimates.

and frequently used methods in the literature are the Augmented Dickey Fuller (ADF) test of Dickey and Fuller (1979; 1981) and the Phillips and Perron (PP) test of Phillips and Perron (1988). The results from both of these tests are compared in this chapter.

Equation (7) is estimated using two procedures comparatively – robust estimation and Ordinary Least Squares (OLS). The dynamics of agricultural production involve natural and market shocks which may generate outliers with considerable leverage on the data. It has been shown that, in the presence of outliers, the approach of re-estimating sample with deleted outlying observations is not the most reliable (Darnell 1994 and Maddala 1992). The presence of outliers, especially those with bad leverage points can inflate the error variance and hence the standard errors. In such cases, the confidence interval becomes stretched, thereby decreasing the efficiency of estimation. After the OLS estimations for each crop, this chapter uses the Cook's (1977) D to determine the presence of and leverage exerted by outliers, in which case, robust estimates are considered over OLS. The Cook's D for i^{th} observation is computed as follows:

$$Cook's D_i = \frac{r_i^2 . h_{ii}}{\rho.(1-h_{ii})} \tag{8}$$

Where r_i is the studentized residual, h_{ii} the leverage of i^{th} observation and ρ is the number of parameters. An outlier is considered present if $D_i > 2/\sqrt{n}$. In the presence of influential outliers, preference is given to the results of robust regression, otherwise OLS applies.

Various methods for robust regression analysis are employed by various statistical packages[26]. The variant used in this work is the Iteratively Reweighted Least Squares used by STATA9. This involves iteratively assigning weights to observations such that the better behaved ones receive higher weights. In extreme cases (Cook's d > 1), weights can be set to missing so that such very influential observations are not included in the analysis at all.

Empirical Results

Descriptive statistics and trends of variables

The descriptive statistics of variables are presented in Table 7.1 and time evolutions in Figures 7.1a and 7.1b.

The variables, particularly price and price risk, exhibit substantial deviations from their means. Sugarcane yield shows the greatest deviation from the mean, but has the least deviations in acreage, price and price risk. Maize shows a higher level of variability in yield and price risk than other crops. The highest standard deviation for price risk is recoded for sorghum. For biodiesel crops, the highest standard deviation from the mean is recorded for sunflower yield and acreage, and for groundnut price and price volatility. In terms of trends, the period from 1996 onwards has witnessed rising, but also volatile, tendencies in all the variables across all crops.

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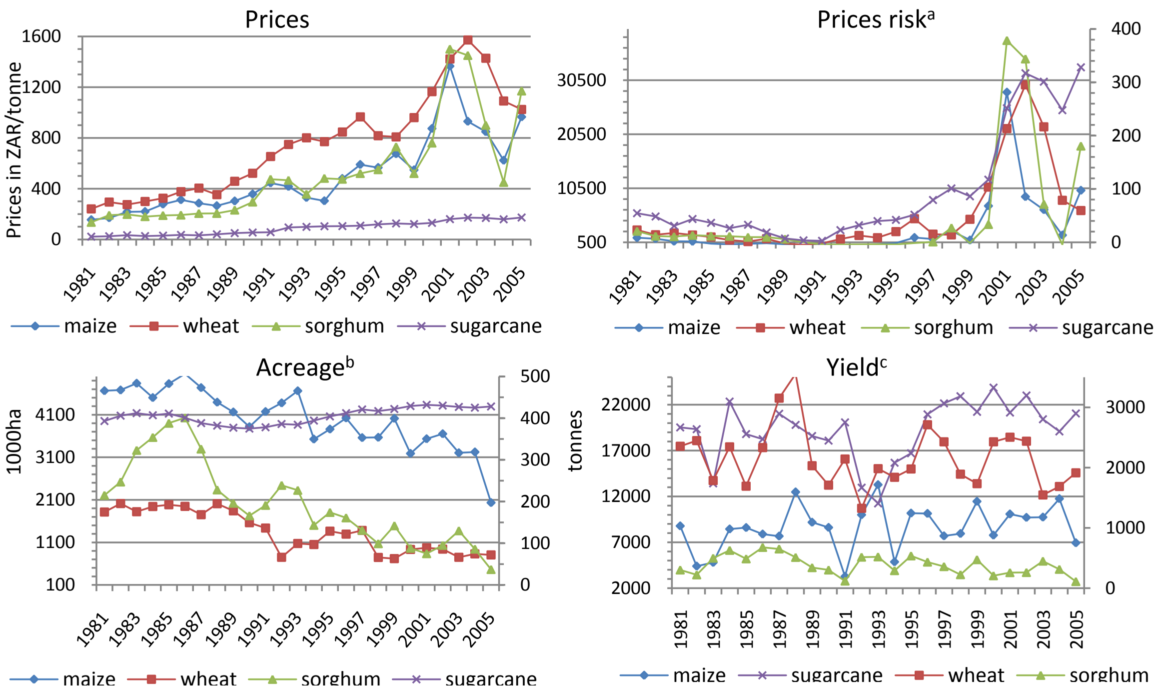
[26] Packages like SAS, STATA, S-PLUS, E-VIEWS and LIMDEP use different methods such as Least Absolute Deviations, Least Trimmed Mean Squares, Weighted Least Squares, etc.

Table 7.1: **Descriptive statistics for bioethanol and biodiesel crops**

Variable	Obs	Mean	Std. Dev.	Min	Max
Bioethanol Crops					
Yield in tonnes x 1000					
Maize	25	8625.84	2477.39	3277.00	13275.00
Wheat	25	2158.52	505.39	1324.00	3557.00
Sorghum	25	387.28	160.73	110.00	677.00
Sugarcane	25	19270.08	3203.46	11244.00	23876.00
Acreage (ha)					
Maize	25	4007.16	701.58	2032.00	5063.00
Wheat	25	1348.88	482.04	718.00	2013.00
Sorghum	25	194.48	100.80	37.00	401.00
Sugarcane	25	405.64	18.79	375.00	432.00
Prices (Rand per tonne)					
Maize	25	500.99	301.56	155.05	1365.91
Wheat	25	745.08	392.62	241.40	1572.05
Sorghum	25	513.17	384.98	135.27	1500.00
Sugarcane	25	90.21	52.88	22.78	173.59
Price Risk					
Maize	25	5247.47	7918.86	802.44	39970.78
Wheat	25	10094.96	9236.63	2148.21	37539.00
Sorghum	25	7269.50	12859.65	10.72	52498.72
Sugarcane	25	161.85	123.72	19.13	413.40
Biodiesel crops					
Yield in tonnes x 1000					
Sunflower	25	518.64	248.41	183.00	1212.00
Soybeans	25	108.19	75.47	21.40	272.50
Groundnut	25	107.20	38.97	52.00	222.00
Acreage (ha)					
Sunflower	25	473.24	130.76	270.00	828.00
Soybeans	25	72.28	41.42	22.00	150.00
Groundnut	25	145.32	72.84	40.00	246.00
Prices (Rand per tonne)					
Sunflower	25	896.16	561.20	223.00	2238.04
Soybeans	25	931.72	606.94	241.00	2487.16
Groundnut	25	1499.17	1130.76	434.00	5049.89
Price Risk					
Sunflower	25	17247.63	21330.52	1833.21	97001.20
Soybeans	25	19642.52	26346.17	2141.10	114488.50
Groundnut	25	62100.31	119126.7	4141.18	601572.80



Note: [a] sugarcane is on the secondary y-axis; [b] sugarcane and sorghum are on secondary y-axis; [c] wheat and sorghum are on secondary y-axis

Figure 7.1a: **Time series evolution of bioethanol crops**

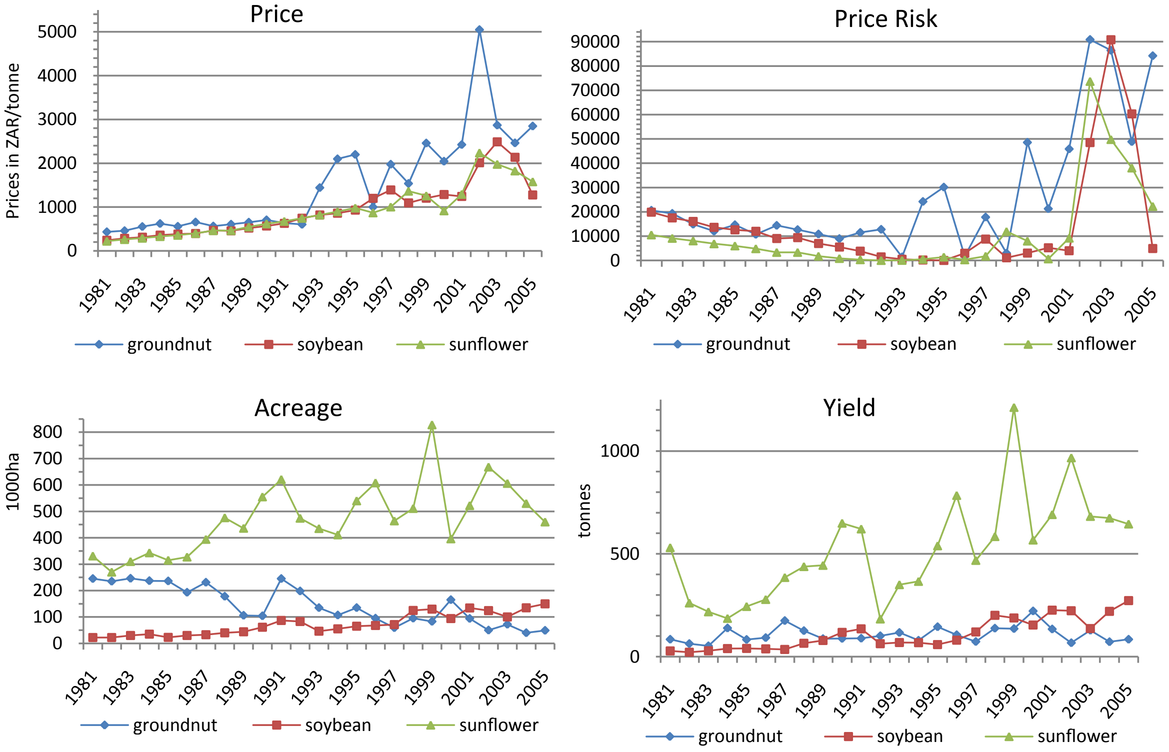


Figure 7.1b: **Time series evolution of biodiesel crops**

Generally, the prices of maize and sorghum have been more volatile than other crops with price displaying an overall upward trend. This high volatility seems to coincide with the agricultural market deregulation process that took effect after the 1996 'Marketing of Agricultural produce Act (Act No. 47 of 1996)' was passed. By the end of 1998 all price control boards had stopped operating, resulting in the removal of price controls.

Unit root and outliers investigation

The unit root[27] results are reported in Table 7.2. Apart from the wheat price risk where the PP test results disagree with those of the ADF test, the test results agree in all other cases. For the yield variables, the test results reveal that sugarcane, sunflower and soybeans are integrated of order one i.e. I(1), and are of zero order, i.e. I(0), for the other crops. Sugarcane acreage is found to be I(2), the rest I(1). The results also suggest that the data generating process for prices and price risk for all crops is I(1), with the exception of sorghum which has a I(0) process for price risk.

The Cook's distance is compared against the critical values in Table 7.3. They are computed as two divided by the number of observations in each case. The outcome indicates the presence of outliers with significant leverage for wheat (observation 25), sorghum (observations 11 and 25), sunflower (3, 12 and 20) and soybeans (observation 12). Maize data does not indicate the presence of outliers, while sugarcane and groundnut data exhibit some outliers, but their influence is not significant. Overall the simple OLS results do not deviate significantly from those of the Robust estimation in situations of low leverage outliers.

Estimation results

Following the results of the unit root test in Table 7.2, the following bioethanol crop variables are first differenced in the estimation process: sugarcane yield, all price variables, and price risk for maize, wheat and sugarcane, and acreage for maize, wheat and sorghum. Acreage of sugarcane is specified in second difference, with all the rest at level. All biodiesel crops are specified in first difference except groundnut yield, which is included at level. Table 7.4 gives the results of OLS and Robust estimates.

Overall, the performances of the various OLS models are satisfactory. In most cases the independent variables contributed about 40 to 70% to the variability of the dependent variable. The overall F-test is significant for all the models.

In the performance of individual crop variables, the first lag of the dependent variable is insignificant, with negative signs for maize and sorghum. It is significantly positive for sunflower and soybeans. One percent increase in previous year's supply results in a 0.23 and 0.11 increase in the current year supply of sunflower and soybeans respectively. The area planted is significant with positive sign in all cases. A percentage increase in area planted brings about a 2, 0.73, 1.4 and 1.5 percent increase in yields of maize, wheat, sorghum and sugarcane respectively, and a 1.2, 0.82 and 0.74 percent increase in yields of

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[27] A stochastic linear data generating process is said to contain a unit root if a root of the characteristic equation of the process is one. In the presence of a unit root, the process is non-stationary, i.e. its moments are time dependent. In such cases, stationarity can be achieved by differencing the series. If first differencing renders the process stationary, then the process is said to be integrated of order one (I(1)).

Table 7.2: **Unit root results**[28]

Var.	**level**			**1st difference**			**2nd difference**			
	Lag	**stat**	**p-val**	**Lag**	**stat**	**p-val**	**Lag**	**stat**	**p-val**	
Bioethanol Crops										
Maize										
Y_t	0	-4.903	0.000	-	-	-	-	-	-	I(0)
A_t	2	0.879	0.993	1	-3.565	0.007	-	-	-	I(1)
P_t	1	-1.189	0.678	3	-4.367	0.000	-	-	-	I(1)
PV_t	2	-0.993	0.756	3	-5.789	0.000	-	-	-	I(1)
Wheat										
Y_t	0	-3.657	0.005	-	-	-	-	-	-	I(0)
A_t	1	-1.227	0.662	0	-5.906	0.000	-	-	-	I(1)
P_t	2	-1.709	0.427	0	-3.658	0.005	-	-	-	I(1)
PV_t	2	-1.674	0.444	1	-2.613	0.090[29]	0	-5.557	0.000	I(1)
Sorghum										
Y_t	0	-3.232	0.018	-	-	-	-	-	-	I(0)
A_t	3	0.429	0.983	2	-3.361	0.012	-	-	-	I(1)
P_t	0	-4.068	0.001	-	-	-	-	-	-	I(0)
PV_t	3	-0.161	0.943	3	-3.531	0.007	-	-	-	I(1)
Sugarcane										
Y_t	1	-2.135	0.231	0	-6.437	0.000	-	-	-	I(1)
A_t	2	-1.151	0.694	1	-2.363	0.152	1	-4.780	0.000	I(2)
P_t	1	-1.251	0.651	0	-5.667	0.000	-	-	-	I(1)
PV_t	1	-1.336	0.613	0	-5.384	0.000	-	-	-	I(1)
Biodiesel Crops										
Sunflower										
Y_t	1	-1.816	0.373	0	-3.467	0.009	-	-	-	I(1)
A_t	3	-1.951	0.308	2	-3.680	0.004	-	-	-	I(1)
P_t	3	-1.107	0.712	3	-3.985	0.002	-	-	-	I(1)
PV_t	3	-0.750	0.833	3	-5.234	0.000	-	-	-	I(1)
Soybeans										
Y_t	1	-1.386	0.589	0	-4.919	0.000	-	-	-	I(1)
A_t	3	-0.710	0.844	2	-3.014	0.034	-	-	-	I(1)
P_t	3	-0.880	0.795	3	-4.348	0.000	-	-	-	I(1)
PV_t	2	-1.755	0.463	3	-5.234	0.000	-	-	-	I(1)
Groundnut										
Y_t	0	-4.195	0.001	-	-	-	-	-	-	I(0)
A_t	1	-1.036	0.740	2	3.978	0.002	-	-	-	I(1)
P_t	1	-1.026	0.744	3	-3.232	0.018	-	-	-	I(1)
PV_t	1	-1.640	0.463	3	-3.341	0.013	-	-	-	I(1)

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[28] There are other possible means of estimation, for example following up with co integration test and using error correction mechanism, however this requires a long enough time series (at least 30 observations) and /or very parsimonious specification, which is not possible in our case with only 25 observations.

[29] Philip_Perron P-val is 0.044, indicating an I(1)

Table 7.3: **Outlier critical values for data**

At level	0.16
2 lags	0.173913
2 lags and fd	0.181818
2 lags and sd	0.190476

sunflower, soybeans and groundnut respectively. The price variable is also significantly positive for all crops except soybeans. The resulting increase in supply following a percentage increase in price is 1.5 percent for maize, 0.5 for wheat, 1.7 for sorghum, 0.5 for sugarcane, 0.37 for sunflower, and 1.19 for groundnut. The price risk variable also has the theoretically expected sign (negative) in all cases, but is not significant for wheat, sugarcane and soybeans. This is consistent with the graph of evolution of the variables. The price variables show less fluctuation for wheat and sugarcane. Supply shrinks by 0.5 percent for maize, 0.6 percent for sorghum, 0.19 for sunflower and 0.36 for groundnut, following a one percent increase in price volatility as a deviation from the mean. All intercepts are negative, but significant only for sorghum and sunflower.

The estimation results suggest that, for bioethanol, maize yield has the strongest responsiveness to area planted, followed by sugarcane, sorghum and lastly wheat. For biodiesel, sunflower, followed by soybeans, has the strongest responsiveness. This suggests that maize is the most suitable crop, followed by sugarcane and sorghum, in bioethanol production and sunflower followed by soybeans in biodiesel production. There is a significant supply reduction of sorghum and maize following volatility or risk in prices. Therefore, in the light of price volatility concerns, sorghum and maize can be prioritised. For biodiesel, groundnut supply shrinks the most as a result of price volatility.

Compared with past studies, the results reported in this chapter are unique in the sense that they are based on crop-specific analysis rather than aggregate agricultural output response. In general, the elasticity of supply with respect to price volatility is of higher magnitude than that obtained for the USA by Chavas and Holt (1996) for maize. However, other countries less developed than South Africa would show even higher responsiveness of supply to price volatility. This translates the fact that in less developed countries, farmers (especially small-scale ones) are less protected against price (and other) risks than in developed countries.

However, the results should be used/applied with caution. In the first place the dataset used is biased towards large scale farmers, and therefore will not capture issues of concern to small scale farmers. It is likely that, at the microeconomic level where small scale farmers use part of the yield for their own consumption, more output will be devoted to own consumption during periods of falling prices and/or higher price risk. The second reason for caution is that the poor may not necessarily have significant access to the benefits accruing from price increase as a result of biofuel production from these crops. Therefore, the socio-economic impacts of biofuel crop production, particularly with regard to poverty, require investigation. This is addressed in the next section.

7.3 Poverty

Although there is some pessimism about the development impacts of biofuels, specifically questioning the socio-economic sustainability and efficiency (Mayat 2007), proponents of biofuel have put forth some counteracting arguments. Knight (2007) for example postulates that biofuel may be the spark

Table 7.4: **OLS and robust regression results for bioethanol and biodiesel crops**

Variable	**OLS**			**Robust Regression**		
	Coef	**SE**	**p-val**	**Coef**	**SE**	**p-val**
Bioethanol Crops						
Maize	Rsq: 0.49; F-stat:4.82			F-stat: 5.27		
Y_{t-1}	-0.166	0.202	0.395	-0.031	0.162	0.850
A_t	1.92	0.883	0.042^{**}	2.085	0.712	0.009^{**}
P_{t-1}	1.434	0.594	0.026^{**}	1.511	0.479	0.005^{***}
PV_{t-1}	-0.501	0.279	0.060^{*}	-0.545	0.225	0.025^{**}
α_0	-10.61	9.147	0.261	-12.669	7.377	0.102
Wheat	Rsq: 0.492; F-stat:4.73			F-stat: 3.97		
Y_{t-1}	0.093	0.184	0.457	0.081	0.208	0.617
A_t	0.724	0.221	0.004^{***}	0.715	0.250	0.010^{**}
P_{t-1}	0.542	0.287	0.074^{*}	0.530	0.211	0.051^{*}
PV_{t-1}	-0.150	0.153	0.245	-0.162	0.173	0.373
α_0	-0.387	2.591	0.883	-0.182	2.925	0.951
Sorghum	Rsq: 0.69; F-stat:10.35			F-stat: 14.59		
Y_{t-1}	-0.189	0.162	0.257	-0.038	0.133	0.780
A_t	1.121	0.250	0.000^{***}	1.362	0.219	0.000^{***}
P_{t-1}	0.724	0.295	0.024^{**}	1.664	0.555	0.008^{**}
PV_{t-1}	-0.090	0.087	0.311	-0.612	0.273	0.037^{**}
α_0	-4.597	2.675	0.102	-5.87	2.199	0.016^{**}
Sugarcane	Rsq: 0.487; F-stat:4.01; Rt MSE: 0.18			F-stat: 2.98		
Y_{t-1}	0.150	0.268	0.583	0.202	0.243	0.415
A_t	1.513	0.711	0.033^{**}	1.183	0.647	0.059^{*}
P_{t-1}	0.493	0.212	0.058^{*}	0.435	0.246	0.081^{*}
PV_{t-1}	-0.251	0.273	0.371	-0.191	0.247	0.517
α_0	-1.235	5.434	0.823	-0.540	4.917	0.914
Biodiesel Crops						
Sunflower	Rsq: 0.78; F-stat:16.56			F-stat: 55.95		
Y_{t-1}	0.119	0.150	0.438	0.231	0.081	0.010^{**}
A_t	1.166	0.301	0.001^{***}	1.205	0.163	0.000^{*}
P_{t-1}	0.546	0.382	0.170	0.366	0.208	0.094^{*}
PV_{t-1}	-0.239	0.222	0.295	-0.191	0.111	0.097^{*}
α_0	-3.134	1.413	0.039^{**}	-3.373	0.767	0.000^{*}
Soybeans	Rsq: 0.89; F-stat:44.11			F-stat: 46.73		
Y_{t-1}	0.106	0.115	0.227	0.205	0.103	0.077^{*}
A_t	0.819	0.286	0.010^{**}	0.897	0.284	0.000^{***}
P_{t-1}	0.521	0.767	0.505	0.144	0.760	0.852
PV_{t-1}	-0.196	0.382	0.613	-0.054	0.378	0.887
α_0	-1.006	0.928	0.292	-0.554	0.920	0.554
Groundnut	Rsq: 0.51; F-stat:11.2			F-stat: 8.7		
Y_{t-1}	0.099	0.177	0.582	0.093	0.192	0.635
A_t	0.740	0.206	0.002^{***}	0.748	0.225	0.004^{***}
P_{t-1}	1.188	0.459	0.018^{**}	1.192	0.500	0.028^{**}
PV_{t-1}	-0.360	0.203	0.093^{*}	-0.362	0.222	0.119
α_0	-4.103	2.344	0.0.96	-4.117	2.551	0.123

Note: OLS stands for Ordinary Least Squares, Coef, SE, p-val and Rt MSE for coefficient, standard error, probability of non-significance and Root Mean Square. The variables are according to equation (7) and are log specified. ***, ** and * indicate rejection of null hypothesis at one, five and ten percents respectively. All variables are specified in log form.

needed for a green revolution in developing countries. Along the same line, Chaturvedi (2006) argues that such agro-revolution can spark a new development paradigm in the developing world. As such, biofuel production can be a solution for poverty (Read 2004) especially for the agriculturally dependent rural population. Based on a pro-poor growth model, this section develops a framework for testing crop suitability against poverty objectives. The model also compares the effects of factors of production (labour, capital, etc). This makes it possible (though somewhat indirectly) to understand whether poverty reduction is a consequence of employment of the poor on farms or their ownership of (value chains on) farms.

7.3.1 Methodology

The framework developed in this section is based on the growth-inequality-poverty literature. There is consensus in both theory and experience that economic growth and the resulting distribution of its fruits are the two means by which poverty reduction occurs (Bourguignon 2003; Easterly 2002; Ravalion 2004). Following the pro-poor growth theory, Son and Kakwani (2006) show that for societal mean income (μ) and percentage share of the income of the bottom *px100* of the population *L(p)*, the growth rate of the mean income of the bottom *p* percent of the population is:

$$g(p) = \Delta \ln(\mu L(p)) \tag{9}$$

If this growth rate *(g(p))* is greater (less) than zero, for all *p*, then poverty has decreased (increased) unambiguously between two periods. They suggest a pro-poor growth rate (γ^*) to be the area under the poverty growth curve as follows:

$$\gamma^* = \int_0^1 g(p)dp = \int_0^1 \Delta \ln(\mu L(p))\, dp \tag{10}$$

$$\text{Or } \gamma^* = \gamma - \Delta\ln(G^*) \tag{11}$$

This means that pro-poor growth rate is equal to the growth rate of societal mean income (γ) minus the rate of change of inequality ($\Delta\ln(G^*)$). If inequality decreases (increases) in a given period, then the pro-poor growth rate is greater (less) than the actual growth rate for that period. Instead of rates of change, equation (11) can also be considered at level, such that poverty is a function of production and inequality. The following notations are adopted for variables in the poverty framework: the Foster-Greer-Thorbecke (1987) family of poverty indices P^{α} ($\alpha = 0,1,2$), income *y*, inequality index ϑ and δ parameters. The proposed framework for poverty based on the pro-poor growth theory is as follows:

In equation (12), the prevailing poverty rate is a function of production and inequality levels. Taking the double log of (12) and introducing the error term ε_{pt} gives the following functional form:

$$P_t^{\alpha} = \delta_0 y_t^{\delta_1} \theta_t^{\delta_2} \tag{12}$$

In order to evaluate the impact of various factors of production on poverty, the income variable in equation (13) is substituted by its underlying determinants in a simple Cobb-Douglass production function.

$$lnP_t^{\alpha} = \delta_0 + \delta_1 lnY_t + \delta_2 ln\theta_t + \varepsilon_{pt} \tag{13}$$

Equation (13) can be estimated by replacing Y_t with time series of crop output or value and (15) can be estimated with the different inputs used in the production of the crops.

$$lnP_t^{\alpha} = \delta_0 + \delta_1 \ln\left(K^{\beta_1} L^{\beta_2}\right) + \delta_2 ln\theta_t + \varepsilon_{pt} \tag{14}$$

$$lnP_t^{\alpha} = \delta_0 + \delta_{11} \mathrm{lnK_t} + \delta_{12} lnL_t + \delta_2 ln\theta_t + \varepsilon_{pt} \tag{15}$$

7.3.2 Case study example

Again, the case study here is at the macroeconomic level of crops for South Africa. The same crops are considered as in the previous section and data for yields and values are from the South African Department of Agriculture (2007). Capital and labour force were compiled using farm budgets obtained from various farmers: maize, wheat and sorghum from the Broksby area in the North West Province and Bergville in Kwazulu-Natal; sunflower and soybeans from the MMI[30] farmers network in Limpopo and Mpumlanga; and sugarcane employment from the Cane-growers Association. Information on employment for the production of wheat, sorghum and groundnut was obtained from GRAINSA. This data was used in conjunction with total agricultural employment and capital, to generate the shares for each crop. It was assumed that these shares mimic the weight in value of each crop in total agricultural value over time. Using these, time series of employment and capital shares for each crop were generated.

The Theil–index was preferred over the Gini coefficient for the measurement of overall income distribution[31] (θ), because it has the advantage of being additive across subgroups. The poverty variable was captured by the Foster, Greer and Thorbecke (1984) family of poverty indices[32]. Both poverty[33] and inequality data were taken from the South African Development Indicators[34] (Presidency of South Africa 2009). After outlier investigation following the method outlined above, the Equations are estimated using the Robust estimation method.

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[30] MMI stands for Maphura Mahkura Incubators. It is an NGO that works closely with small farmers in the Limpopo and Mpumalanga provinces of South Africa.

[31] This decomposition is relevant for a multi-racial society like South Africa where within and between inequality are likely to affect production differently such that total inequality would give only average effects.

[32] For an increasing ordered vector of household incomes $(y_1, y_2, ..., y_n)$, a strictly positive poverty line z, i^{th} household's income shortfall $g_i = z - y_i$, number of poor households $q = q(y;z)$ and total number of households $n = n(y)$, and $\alpha(\geq 0)$ a parameter of poverty aversion, the FGT class of poverty measures p^{α} is defined as:

$$P^{\alpha}(y;z) = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{g_i}{z}\right)^{\alpha}$$

[33] Poverty data assumes a national poverty line of ZAR 388 per month.

[34] This data is published by the Ministry of National Planning at the Presidency of South Africa. The poverty and inequality data in this publication are based on the bi-annual All Media and Products Survey (AMPS) data, collected by the South African Advertising Research Foundation (SAARF), from over 20000 households spanning 1993 to 2009. Although this data is not without controversy (Seekings 2007), it is suitable for the analysis in this paper for two reasons. The first is that it gives the most comprehensive time series for poverty and inequality available. The second is that the alternative data source, the Income and Expenditure Surveys (IES) of the National Statistics, is seemingly plagued by even greater irregularities (Ardington et al 2006; Simkins 2004; van der Berg et al 2006).

Empirical Results

The results of the empirical analysis are presented together with possible interpretations. The summary statistics for crop value, capital and labour inputs, poverty and inequality measures are presented in Table 7.5. Outlier results are considered to be the same as in section 7.2 above.

Poverty estimates for bioethanol crops (maize, wheat, sorghum, sugarcane) are given in Tables 7.6A and 7.6B for equations (13) and (15) respectively. The estimates are for yield and values for equation (13) and capital and labour for equation (15). Judging from the model F-statistics and P-values, all the equations have acceptable performances. Only the between-group Theil inequality show the theoretical negative sign[35]. Based on this, the other inequality component (total and within group) have been

Table 7.5: **Descriptive statistics for crop value, inputs and inequality and poverty**

Log of Variable	Obs	Mean	Std. Dev.	Min	Max
Log of yield in Rand Value					
Maize	16	15.75	0.48	14.85	16.85
Wheat	16	14.57	0.44	13.74	15.38
Sorghum	16	12.36	0.42	11.79	13.14
Sugarcane	16	14.78	0.41	13.93	15.23
Groundnut	16	12.44	0.51	11.57	13.42
Soybean	16	12.35	0.90	10.90	13.94
Sunflower	16	13.67	0.68	12.60	15.16
Log Labour (Indices)					
Maize	16	5.00	0.29	4.52	5.57
Wheat	16	3.82	0.29	3.27	4.35
Sorghum	16	1.61	0.49	0.56	2.47
Sugarcane	16	4.02	0.20	3.64	4.39
Groundnut	16	5.85	2.22	2.28	10.14
Soybean	16	1.60	0.51	0.72	2.35
Sunflower	16	2.92	0.45	2.24	3.71
Log of capital (indices)					
Maize	16	6.42	0.48	5.51	7.46
Wheat	16	5.24	0.48	4.01	5.99
Sorghum	16	3.03	0.41	2.45	3.75
Sugarcane	16	5.45	0.47	4.30	5.89
Groundnut	16	3.11	0.49	2.11	4.03
Soybean	16	3.03	0.92	1.26	4.55
Sunflower	16	4.35	0.71	2.87	5.77
Log of Inequality and poverty					
Between-group inequality	16	-0.73	0.14	-1.07	-0.60
Poverty incidence	16	3.89	0.07	3.71	3.97
Poverty intensity	16	3.16	0.10	2.94	3.30
Poverty severity	16	2.67	0.13	2.40	2.83

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[35] This implies that using an overall income distribution indicator for a multiracial society like South Africa will not give expected results, since the effects within and between-group components of inequality may tend to phase-out each other in the total inequality effect.

excluded from the analysis. In all the other equations, inequality has the expected poverty exacerbating effect for all measures of poverty.

The maize yield has a negative effect on poverty incidence and a positive effect on poverty intensity and severity, although these effects are not significant. The maize value shows a positive impact on poverty, but it is significant only for poverty severity. One percent increase in the maize value results in 0.140

Table 7.6A: **Poverty estimates with yield values for bioethanol crops**

Parameters	**Yield**			**Value**		
	P0	**P1**	**P2**	**P0**	**P1**	**P2**
Maize						
log y	-0.001 (-0.01)	0.033 (0.68)	0.042 (0.64)	0.034 (0.97)	0.095* (1.87)	0.140* (1.96)
$\log T_B$	0.480*** (5.80)	0.614*** (4.17)	0.720*** (4.31)	0.583 (4.79)	0.867*** (4.39)	1.103*** (4.47)
C	4.244*** (10.57)	3.308*** (4.63)	2.815*** (3.47)	3.775*** (7.73)	2.290** (2.89)	1.272 (1.29)
F(2, 13)	17.02	8.69	9.28	22.64	14.23	13.57
P-VAL	0.000	0.004	0.003	0.000	0.001	0.001
Wheat						
log y	0.101** (2.38)	0.174** (2.24)	0.258** (2.54)	0.076** (3.24)	0.142** (3.06)	0.180** (2.73)
$\log T_B$	0.461*** (7.86)	0.589*** (5.47)	0.733*** (5.23)	0.582*** (7.94)	0.891*** (6.18)	1.133*** (5.51)
C	3.460*** (10.73)	2.270*** (3.84)	1.248 (1.62)	3.209*** (10.54)	1.751** (2.93)	0.872 (1.02)
F(2, 13)	32.52	16.66	15.98	41.14	22.42	17.80
P-VAL	0.000	0.000	0.000	0.000	0.000	0.000
Sorghum						
log y	-0.005 (-0.16)	-0.006 (-0.11)	-0.030 (-0.45)	0.017 (0.59)	0.055 (1.16)	0.058 (0.92)
$\log T_B$	0.482*** (3.50)	0.585*** (3.50)	0.776*** (3.67)	0.498*** (5.68)	0.664*** (4.67)	0.788*** (4.19)
C	4.268*** (19.44)	3.556*** (9.16)	3.409 (6.95)	4.042*** (12.05)	2.973*** (5.47)	2.538*** (3.53)
F(2, 13)	17.80	8.98	8.43	18.50	11.43	9.36
P-VAL	0.000	0.004	0.005	0.000	0.001	0.003
Sugarcane						
log y	-0.092** (-2.05)	-0.159* (-1.90)	-0.171 (-1.62)	0.058 (1.64)	0.103 (1.49)	0.117 (1.32)
$\log T_B$	0.520*** (7.65)	0.660*** (5.20)	0.821*** (5.12)	0.591*** (5.66)	0.791*** (3.88)	0.968*** (3.70)
C	3.364*** (7.89)	2.076** (2.61)	1.562 (1.55)	3.469*** (7.45)	2.220** (2.44)	1.648 (1.41)
F(2, 13)	29.60	13.49	13.11	24.02	9.89	9.30
P-VAL	0.000	0.001	0.001	0.000	0.003	0.003

Table 7.6B: **Poverty estimates with inputs for bioethanol crops**

Parameters	**P0**	**P1**	**P2**	**P0**	**P1**	**P2**
	Maize			Wheat		
log K	0.053^{*} (1.87)	0.092^{*} (1.70)	0.110 (1.39)	0.039^{*} (1.82)	0.071^{*} (1.84)	0.080 (1.22)
log L	-0.006 (-0.20)	-0.045 (-0.78)	-0.071 (-0.88)	0.053^{*} (1.84)	0.082 (1.59)	0.100 (1.27)
$\log T_B$	0.642^{***} (6.71)	0.849^{***} (4.47)	1.023^{***} (3.82)	0.522^{***} (6.48)	0.722^{***} (4.97)	0.873^{***} (3.96)
C	4.039^{***} (23.77)	2.971^{***} (8.81)	2.356^{***} (4.96)	3.870^{***} (31.81)	3.007^{***} (13.74)	2.511^{***} (7.55)
F(3, 12)	26.19	10.41	7.75	25.34	14.26	9.22
P-VAL	0.000	0.001	0.004	0.000	0.000	0.002
	Sorghum			Sugarcane		
log K	0.053^{***} (3.71)	0.085 (1.29)	0.062 (0.67)	0.022 (0.90)	0.038 (0.82)	0.042 (0.62)
log L	-0.034^{**} (-2.91)	-0.017 (-0.32)	-0.014 (-0.19)	-0.097^{**} (-2.09)	-0.138^{*} (-1.80)	-0.151 (-1.19)
$\log T_B$	0.596^{***} (14.19)	0.721^{***} (3.73)	0.817^{**} (3.00)	0.465^{***} (5.36)	0.596^{***} (3.68)	0.730^{**} (3.05)
C	4.209^{***} (28.14)	3.456^{***} (22.89)	3.101^{***} (14.57)	3.721^{***} (18.72)	2.839^{***} (7.65)	2.368^{***} (4.32)
F(3, 12)	98.51	7.28	5.10	21.06	9.88	6.64
P-VAL	0.000	0.005	0.017	0.000	0.002	0.007

Note: T_B stands for Between-group Theil inequality measure. K, L and C are capital, labour and constant terms. P-VAL is the model probability of non-significance. Values in parentheses below each coefficient are their respective p-values. ***, ** and * indicate rejection of null hypothesis at one, five and ten percents respectively. All variables are specified in log form.

percent increase in poverty severity. Since maize is a staple food for poor households, this result may be capturing a price effect, that is that a high value (implying high prices) leads to the very poor allocating a higher proportion of their income to food. This is plausible since the physical quantities of maize output do not show significant impact on poverty. Employment in maize production has a negative, but insignificant, effect on poverty. Capital in maize production increases poverty, but the effect is significant only for poverty incidence. A percentage increase in capital for maize production results in a 0.053 percent increase in the poverty ratio. This may imply that the relatively less poor of the poor invest (insufficiently) in maize production, and have a lower output (not enough to break even), which prevents them from covering their capital cost. The insignificant effect on poverty intensity and severity could be understood in the sense that the abjectly poor may not participate in the production process, while maize employment has a negative but insignificant effect on all poverty measures.

Wheat quantity and value both have a significant poverty enhancement effect across all measures of poverty. This is not unexpected because, while capital use in wheat increases poverty, labour is insignificant, with a positive coefficient. Sorghum quantity has a negative impact on poverty, while the sorghum value has a positive impact on poverty, but neither is significant for all of the poverty measures. Sorghum capital and labour show positive and negative effects on all poverty measures respectively, but are significant only on poverty incidence. A percentage increase in capital and labour used in sorghum production results in a 0.053 percent increase and a 0.034 percent decrease in poverty incidence respectively. The fact that capital and labour have similar magnitudes, with opposing signs, can explain the weak and insignificant effect of sorghum quantity and values on poverty.

Sugarcane yield has a negative effect on all poverty measures, and is significant on poverty incidence and intensity. A 1 percent increase in sugarcane quantity leads to 0.092 and 0.159 percent reduction in poverty incidence and intensity respectively. The effect of the value of the crop on poverty (though positive) is not significant. This suggests that the poverty reducing effect of sugarcane production comes via employment and not through the ownership of value chain by the poor. This is also confirmed by the coefficients of capital and labour in sugarcane. While capital (though positive) is insignificant on poverty, employment has negative effects on all poverty measures, and is significant for poverty incidence and intensity. A 1 percent increase in employment in the sugarcane sector leads to 0.097 and 0.138 percent reduction in poverty incidence and intensity respectively.

Poverty estimates for the biodiesel crops (groundnut, soybean and sunflower) are given in Tables 7.7A and 7.7B using equations (13) and (15) respectively. Table 7.7A gives the estimates for yield and values (equation 13), and Table 7.7B gives the estimates for capital and labour (equation 15). The model

Table 7.7A: **Poverty estimates with yield values for biodiesel crops**

Parameters	**Yield**			**Value**		
	P0	**P1**	**P2**	**P0**	**P1**	**P2**
Groundnut						
$\log y$	-0.048* (1.77)	-0.095** (2.05)	-0.093 (1.33)	0.027 (0.96)	0.075* (1.78)	0.069 (1.07)
$\log T_B$	0.454*** (6.83)	0.552*** (4.90)	0.688*** (4.04)	0.535*** (5.32)	0.776*** (4.84)	0.895*** (3.86)
C	3.995*** (26.57)	3.122*** (12.28)	2.732*** (7.10)	3.948*** (13.19)	2.804*** (5.87)	2.471*** (3.58)
F(2, 13)	32.48	19.62	12.16	21.45	14.47	9.98
P-VAL	0.000	0.000	0.001	0.000	0.001	0.002
Soybean						
$\log y$	0.013 (0.57)	0.025 (0.58)	0.051 (0.97)	0.021 (1.07)	0.046 (1.30)	0.073 (1.59)
$\log T_B$	0.510*** (5.27)	0.660*** (3.72)	0.875*** (3.99)	0.589*** (4.70)	0.844*** (3.72)	1.153*** (4.40)
C	4.194*** (46.74)	3.519*** (21.40)	3.044*** (14.96)	4.061*** (23.56)	3.208*** (10.27)	2.591*** (7.17)
F(2, 13)	21.25	9.99	10.33	24.39	12.25	15.41
P-VAL	0.000	0.002	0.002	0.000	0.001	0.000
Sunflower						
$\log y$	0.075*** (4.91)	0.150*** (4.00)	0.112* (1.83)	0.047** (3.08)	0.110** (3.27)	0.088* (1.92)
$\log T_B$	0.566*** (15.57)	0.739*** (8.35)	0.787*** (4.83)	0.688*** (9.28)	1.076*** (6.60)	1.031*** (4.69)
C	3.820*** (41.60)	2.755*** (12.32)	2.528*** (6.46)	3.744*** (21.45)	2.454*** (6.73)	2.228*** (4.30)
F(2, 13)	121.40	35.57	12.20	57.28	29.30	13.31
P-VAL	0.000	0.000	0.001	0.000	0.000	0.001

Table 7.7B: **Poverty estimates with inputs for biodiesel crops**

Parameters	**P0**	**P1**	**P2**	**P0**	**P1**	**P2**
	Groundnut			Soybeans		
log K	0.018** (2.61)	0.015* (1.69)	0.089 (1.01)	0.001 (0.05)	0.001 (0.02)	-0.007 (-0.10)
log L	-0.132** (-2.17)	-0.099** (-2.20)	-0.018 (-0.25)	0.036 (0.78)	0.078 (0.94)	0.142 (1.33)
logT_B	0.614*** (10.29)	0.837*** (4.45)	0.966*** (3.42)	0.576*** (4.78)	0.806*** (3.74)	1.061*** (3.86)
C	4.233*** (40.25)	3.490*** (31.46)	3.125*** (18.73)	4.247*** (77.55)	3.620*** (36.91)	3.232*** (25.87)
F(3, 12)	62.57	10.23	6.55	15.28	7.92	7.76
P-VAL	0.000	0.001	0.007	0.000	0.004	0.004
	Sunflower					
log K	0.036* (1.69)	0.038 (0.73)	0.034 (0.52)			
log L	-0.004 (-0.13)	-0.032 (-0.50)	-0.051 (-0.64)			
logT_B	0.647*** (7.78)	0.766*** (3.91)	0.883*** (3.58)			
C	4.189*** (71.33)	3.464*** (25.04)	3.020*** (17.36)			
F(3, 12)	30.90	8.04	7.16			
P-VAL	0.000	0.003	0.005			

Note: T_B stands for Between-group Theil inequality measure. K, L and C are capital, labour and constant terms. P-VAL is the model probability of non-significance. Values in parentheses below each coefficient are their respective p-values. ***, ** and * indicate rejection of null hypothesis at one, five and ten percents respectively. All variables are specified in log form.

F-statistics and P-values indicate that all the equations have good performances. Inequality has the expected poverty exacerbating effect on all measures of poverty in all the models.

Groundnut yield has a negative effect on all poverty measures, but the effect is not significant for poverty severity. A 1 percent increase in groundnut output brings about a 0.048 and 0.095 percent fall in poverty incidence and intensity. Its value shows a positive impact on poverty, but it is significant only for poverty intensity, with a percentage increase in value leading to 0.075 percent higher poverty intensity. Capital in groundnut production is significantly associated with higher poverty incidence and intensity. A one percent increase in capital leads to 0.018 and 0.015 percent higher poverty incidence and intensity. Labour use in groundnut cultivation contributes to poverty reduction, but is insignificant for poverty severity. A percentage increase in employment for groundnut cultivation leads to 0.132 and 0.099 percent reduction in poverty incidence and intensity respectively.

Both yield and value of sunflower are associated with higher poverty and are significant for all three poverty measures. One percent increase in yield (value) leads to 0.075, 0.150, and 0.112 (0.047, 0.110 and 0.088) percent increases in poverty incidence, intensity and severity respectively. Capital and labour have positive and negative coefficients on all three poverty measures, but only the coefficient of capital is significant for poverty incidence. As with maize, this may imply that poor households invest (insufficiently) in sunflower production, with lower output (not enough to break even). Neither soybean yield nor value show any significant effect on poverty. Capital and labour use in soybean cultivation also have no significant impact on any of the poverty measures.

If the purpose of a biofuel strategy/policy is to target (income) poverty reduction, then these findings would suggest the following: In South Africa the priority crops should be sugarcane for bioethanol and groundnut for biodiesel. Other crops like maize and sunflower would require stronger support for small farmers. The findings also suggest that poverty reduction comes mainly via employment of the poor on farming units. There is a suggestion that investment in farming by the poor is often inadequate and only results in poverty exacerbation. The implication is that the capital base of the poor must be broadened for them to effectively participate in farming. This should be done without stifling commercial farming, which in itself can lead to poverty reduction through adequate or increased employment. These recommendations hold for sugarcane, groundnut and maize. The use of maize (a staple food crop) for biofuel is likely to pose a fundamental food security problem to the poor in the non-farm sector, since an increase in the price of maize is likely to cause the poor to allocate a higher proportion of their income to food, leading to more poverty. However, one has to bear in mind the weakness of the data used in this case study. Given that the data is likely to underestimate or completely ignore most of the subsistence producers whose production is mainly for their own consumption, the poverty impact could equally experience a downward bias in the models estimated here. The causes of under-performance of small-scale farmers relative to commercial farmers is important for biofuel policy and it is worth examining further. This is done in the next section.

7.4 Subsistence/Commercial Farming Divide

Most developing country farms are small scale – less than two hectares on average. This farm type represents about 80% of farm holdings in Africa (Wiggins 2009). There has been a longstanding debate over the relationship between farm size and farm productivity (Vollrath 2007). Collier (2002), for example, calls for large commercial farms to be placed at the forefront of agriculture in order to achieve any revolution in African agriculture. Although some studies have shown that small farms in developing countries produce more per hectare than large farms in developing countries (Eastwood et al 2010), Ngepah (2009) documents the case of productivity falling faster over time on small farms in the South African sugarcane sector. This section proposes a simple framework to analyse the possible land productivity differences between small and large farms and some of the factors that are at the root of these differences.

7.4.1 Methodology

The applicable model for farm productivity performance comparison considers the production functions y_l and y_s for large- and small-scale farmers respectively, and assumes that both farmer categories have the same technology, such that production is a function of the product of inputs (X_l for large-scale and X_s for small-scale farmers), with i denoting a specific input type:

$$y_l = Ae^{\lambda t}\Pi_i X_{li}^{\alpha_i} \qquad (16)$$

$$y_s = Ae^{\lambda t}\Pi_i X_{si}^{\beta_i} \tag{17}$$

Π is the product operator, α and β are respective parameters for large-scale and small-scale production functions and λ the productivity growth rate.

In attempting to explain the widening productivity differential between large- and small-scale farmers, a model is developed by taking the ratio of equations (16) and (17) in log linear form:

Dividing (16) by (17) and taking the log results in:

$$\log y_l - \log y_s = \log(\Pi_i X_{li}^{\alpha_i}) - \log(\Pi_i X_{si}^{\beta_i}) \tag{18}$$

$$\Delta_p y = \sum_i \alpha_i \log X_{li} + \sum_i \beta_i \log X_{si} \tag{19}$$

The model suggests that the difference in the log of productivity ($\Delta_p y$) between small-scale and large-scale farms is caused by differences in the log of their respective production functions. Equations (16), (17) and (19) can be specified in cross-section, time series or panel data functional forms. The application to the South African sugarcane sector considers the panel data application to cane production across regions and time.

7.4.2 Case study example

The case study considered is a panel of small- and large-scale sugarcane farmers in South Africa. To suit the dataset, equations (16), (17) and (19) are specified in panel functional forms with *j* regions and *t* time periods in natural logarithmic form (*ln*) as follows:

$$\begin{pmatrix} \ln y_{it} = \beta_0 + \lambda t + \beta_1 \ln N_{it} + \beta_2 L_{it} + \beta_3 \ln F_{it} + \beta_4 \ln CH + \\ \beta_5 \ln IR_{it} + \beta_6 \ln OI_{it} + \beta_7 \ln Nred + \beta_8 \ln Lr_{it} + \beta_9 \ln LE_{it} + \eta_j + \varepsilon_{jt} \end{pmatrix}_{l,s} \tag{20}$$

The subscripts *l,s* denote turn by turn consideration of equation (18) as large- and small-scale farms respectively, $\eta_j + \varepsilon_t$ is a composite error term including unobserved region-specifics effects. The empirical specification of (19) in panel data form is:

$$\Delta_p y_{jt} = \left(\sum_i \alpha_i \log X_{li}\right)_{jt} + \left(\sum_i \beta_i \log X_{si}\right)_{jt} + \eta_j + \varepsilon_{jt} \tag{21}$$

$$\begin{aligned} \Delta_p y_{it} &= \alpha_0 + \alpha_1 \ln F_{it}^l + \alpha_2 \ln IR_{it}^l + \alpha_3 \ln CH_{it}^l + \alpha_4 \ln L_{it}^l + \alpha_5 \ln F_{it}^s + \alpha_6 \ln IR_{it}^s \\ &+ \alpha_7 \ln CH_{it}^s + \alpha_8 \ln L_{it}^s + \alpha_9 \ln Nred_{it} + \alpha_{10} \ln LE_{it} + \alpha_{11} \ln LR_{it} + \eta_j + \varepsilon_{jt} \end{aligned} \tag{22}$$

In equation (20), N stands for land hectares, in (20) and (22), F, CH, L, are fertiliser, chemicals and labour respectively, and Nred, IR, LE and LR are area of land redistributed[36], irrigation expenses, life

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[36] The rationale for including land area redistributed from white (mainly large-scale) to blacks (mainly small-scale) farmers is that it could be one of the contributors to the gap, not just for itself, but for the fact that it comes with some (although small) farm support packages to small farmers. The redistribution process started in 1994.

expectancy and literature rates respectively. The input variables are all expected to have a positive effect on agricultural production. The variables are land, labour, fertiliser use, irrigation expenses, chemical use and other inputs[37] and are defined in per hectare terms. Other variables included in the model were life expectancy, adult literacy rate and cumulative land redistribution. Land redistribution data was obtained from Presidency of South Africa (2009) published by the Presidency of South Africa. The land redistribution variable is theoretically expected to have positive impact on production for small-scale farming and a negative impact on large-scale farming. Life expectancy and literature rates were taken from the World Bank (2008).

All data related to the sugarcane sector originated from the South Africa Cane Growers Association (SACANEGROWERS). This data was obtained from a panel of small- and large-scale growers organised around fifteen milling areas for the period 1998 to 2007. Input information for small-scale growers was not available for all years. The assumption was made that the gap in input use between large and small farmers varied across regions, but remained constant over time. This allowed for the artificial generation of missing input data. Land productivity differences were generated as indicated in equations (18) and (19) above. A number of variables (less than 20%) had missing data between periods. The missing values were interpolated on the assumption that the series follow a relatively smooth path over time (see Vollrath 2007: p215). Thus for a variable X, with missing value at time s, falling between two observations at time *t* and , *t*+*n*, $t+n$, $X_s = X_t + (s-t)(X_{t+n} - X_t)/n$. This technique was applied particularly to input of small-scale farmers.

In the estimation of the three panel data models, a choice has to be made between the use of fixed (FE) and random effect (RE) models. Hausman tests were carried out to compare both specifications in order to make the right choice. The test, developed by Hausman (1978) is based on the idea that, under the null hypothesis of no correlation between individual effects (η_i) and the other regressors in the model, both ordinary Least Square (OLS) and generalised least squares (GLS) are consistent, but OLS is inefficient, whereas under the alternative hypothesis, only OLS is consistent. The test statistics indicate whether the two sets of coefficients (OLS and GLS) are significantly different.

The summary statistics for the agricultural output and inputs and other determinants are in Table 7.8.

Figure 7.2 presents the evolution of the large-scale/ small-scale productivity gap from 1998 to 2007. It suggests a significant increase over time. The values for each year are averages for all the cane growing localities.

The fixed effect estimation results are presented in Tables 7.9A for large and small-scale sugarcane production and 7.9B for productivity difference.

Judging from the probability of Fisher, the overall model statistics are satisfactory for all three models. The coefficient of land redistribution is negative for large-scale and positive for small-scale producers, but neither is significant. This insignificance is not surprising for two reasons. Firstly, for the small-scale producers, land does not significantly affect output. Secondly, even though the land variable is

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[37] A sum of all other inputs not specified among the main ones.

Table 7.8: **Summary statistics for small-/large scale production**

Variable	Obs	Mean	Std. Dev.	Min	Max
Large-scale					
Output (tons)	136	1116474	325150.7	275863	1998841
Output (tons/ha)	136	74.78	15.81	42.02	108.61
Fertiliser (R/ha)	136	1081.4	418.59	488.58	2854.59
Chemicals (R/ha)	136	514.03	235.80	182.46	1270.58
Labour(R/ha)	136	190.92	135.26	25.31	823.77
irrigation(R/ha)	136	678.91	241.34	327.12	1359.47
Other inputs(R/ha)	136	4100.04	1762.19	1695.45	8473.29
Area under cane (ha)	136	20444.79	7102.17	6225	33328
Area harvested (ha)	136	15334.68	4878.57	3975	26253
Small-scale					
Output (tons)	136	194692.7	119006.5	35306	522937
Output (tons/ha)	136	52.52	28.02	10.03	177.90
Fertiliser (R/ha)	136	871.42	598.52	1.56e-09	2707.50
Chemicals (R/ha)	136	210.22	172.74	1.56e-09	839.36
Labour(R/ha)	136	641.58	828.26	1.56e-09	7599.74
irrigation(R/ha)	136	395.81	818.92	1.00e-05	3214.09
Other inputs(R/ha)	136	3358.6	2471.95	1.56e-09	10060.36
Area under cane (ha)	136	5715.934	3807.2	1201	18008
Area harvested (ha)	136	4583.47	3317.24	531	16238
Other variables					
Land redistributed (ha)	136	216293.9	83685.44	135084	403273
Life expectancy[38]	136	55.06	6.31	44.61	62.93
Literacy rate	136	0.91	0.01	0.90	0.92

Source: Author, using data from SA Cane growers Association

Figure 7.2: **Evolution of Large- and Small-scale productivity Gap**

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[38] Due to the fact that life expectancy and literacy data could not be found and the disaggregate level for the different mill regions, national averages were considered.

Table 7.9A: **Fixed effect estimation results for large- and small-scale production**

Dependent Variable: Sugarcane output (Tonnes)						
	Large-Scale			**Small-Scale**		
	Coef[39]	**SE**	**p-val**	**Coef**	**SE**	**p-val**
ln *land*	0.286	0.130	0.030^{**}	0.127	0.075	0.093^{*}
ln *fer*	-0.044	0.060	0.463	-0.247	0.129	0.058^{*}
ln *irrig*	0.129	0.067	0.055^{*}	0.270	0.159	0.092^{*}
ln *Chem*	0.015	0.046	0.749	-0.193	0.098	0.050^{**}
ln *lab*	0.021	0.021	0.323	0.024	0.049	0.624
ln *Oinputs*	0.151	0.066	0.024^{**}	-0.394	0.159	0.014^{**}
ln Landred	-0.032	0.024	0.185	0.069	0.055	0.214
Cross yield	0.213	0.034	0.000^{***}	1.299	0.177	0.000^{***}
Constant	4.265	1.226	0.001^{***}	4.112	2.661	0.125
OBS	**136**			**136**		
R^2	**0.54**			**0.57**		
F(8, 114)	**11.93**			**18.69**		
***Prob* > F**	**0.000**			**0.000**		
Hausmanχ^2	**66.17 (FE)**			**48.81 (FE)**		
***Prob* > χ^2**	**0.000**			**0.000**		

Note: Coef, SE, and p-val stand for coefficient, standard error, and probability of non-significance. FE is fixed effect. ***, ** and * indicate rejection of null hypothesis at one, five and ten percents respectively.

significant for large-scale models, there is always a remarkable difference between area under cane and area effectively harvested for both large-scale and small-scale growers. Generally, the coefficients of all other inputs are larger (but insignificant in most cases) for small-scale farmers. This suggests that land redistribution should also be accompanied by the identification of constraints to accessing other inputs, especially fertiliser and irrigation facilities. The results of the determinants of productivity difference in Table 7.9B below corroborates this interpretation.

Large-scale farmers' use of fertiliser has significant positive impacts on the productivity gap, while chemical and labour uses attenuate the difference, with only chemical being significant. All small-scale inputs have a negative impact on the gap, with only fertiliser and irrigation having a significant effect. A A 1 percent increase in large-scale fertiliser and irrigation usage increases the gap by 2.14 and 0.68 percent respectively, while it decreases the gap by 2.03 and 0.72 percent respectively for small-scale usage. The significant negative impact of large-scale chemical use on the gap suggests a type of positive externality. Other factors considered are land redistribution and human capital (life expectancy and

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[39] Variables are evaluated are three significance levels: *** denote 1% lev$^{el, **}$ 5% and * 10% level of significance.

Table 7.9B: **Fixed effect estimation results for large/small productivity difference**

Dependent Variable: log of ratio of large- and small –scale outputs per ha			
	Coef[40]	**SE**	**t-stat**
Large-scale inputs per ha			
ln *fer*	2.142*	1.184	1.81
ln *irrig*	0.679***	0.187	3.62
ln *Chem*	-2.138*	1.157	-1.85
ln *lab*	-0.038	0.060	-0.64
Small-scale inputs per ha			
ln *fer*	-2.028*	1.183	-1.71
ln *irrig*	-0.715***	0.121	-5.91
ln *Chem*	-1.901	1.158	-1.64
ln *lab*	-0.034	0.027	0.214
Other determinants			
ln *Landred*	-0.094	0.070	-1.35
ln *le*	-0.295	0.454	0.65
ln *literate*	-2.041***	0.694	-2.94
Constant	-10.50***	2.539	-4.14
OBS	**136**		
R^2	**0.58**		
F(11, 111)	**14.03**		
Prob > F	**0.000**		
Hausmanχ^2	**57.32**		
Prob > χ^2	**0.000**		
Note: Coef, and SE, stand for coefficient and standard error. FE is fixed effect. ***, ** and * indicate rejection of null hypothesis at one, five and ten percents respectively.			

literacy rate). These all have attenuating effects on the gap, but only the literacy rate is significant. There is a need, therefore, to strengthen the human capital and input capacities of small-scale producers. Other potential factors, which are not analysed here, are disparities in the effect of market forces. However, the effect of this is likely to be insignificant for South Africa, given that the mills guarantee the market for both small and large-scale producers.

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[40] Variables are evaluated are three significance levels: *** denote 1% level, ** 5% and *10% level of significance.

7.5 Conclusions

Amidst various concerns and conflicting views about the possible impact of biofuel production on agriculture in developing countries, the agricultural sector poses certain challenges on which biofuels can have an impact. Three most notable of these are: price uncertainty, which hampers agricultural expansion; poverty reduction impacts of agriculture; and the challenges of small-scale farming. The purpose of this chapter has been to suggest methodologies for the selection of crops suitable for biofuel production according to price risk and poverty criteria and to develop a framework for the analysis of differences in productivities of small- and large-scale farms. The methodologies have been applied to case studies within South Africa and the results suggest that:

- In view of price volatility concerns, sorghum and maize top the list of preferences for bioethanol and groundnut for biodiesel. These are crops for which biofuel can stabilise prices (at higher levels), thereby enhancing supply.
- If (income) poverty reduction is the policy objective, then sugarcane for bioethanol and groundnut for biodiesel should be prioritised. Other crops like maize and sunflower would require stronger support for small farmers. In general, poverty reduction comes mainly as a consequence of employment on farms. There is a suggestion that investment in farming by the poor is often inadequate and (if they are left unsupported) can result in poverty exacerbation. The implication is that the capital base of the poor must be broadened for them to effectively participate in farming, without stifling commercial farming which also provides a means of poverty reduction through adequate or increased employment. The use of maize (a staple food crop) for biofuel production is likely to pose a fundamental food security problem to the poor in the non-farm sector, since increases in the price of maize is likely to result in a higher proportion of their income being spent on food.
- Differences in fertiliser usage, irrigation access and illiteracy are elements that mainly contribute to the productivity difference between large and small scale farmers. Chemical use by large-scale farmers attenuates the gap, suggesting a type of positive externality. The implication is that any conflict between small and large-scale farmers is likely to jeopardise the productivity of small farms.

The policy recommendations, especially from the first two sections should be considered with some caution. It is important to note the weakness of the data in these sections. The data is likely to underestimate or completely ignore most of the subsistence producers, whose production is mainly for their own consumption. This is however of relatively limited importance in South Africa, but may be more serious in other regions. This exercise still remains of use to policymakers, though the poverty impact could experience a downward bias. In addition, compared to other developing countries in Africa, there are two main characteristics specific to South Africa that can influence the above findings. Firstly, although considerable remittances and social grants go to rural households (statistics South Africa 2002), they are hardly enough to meet the fundamental needs of the poor and generate sufficient savings for agricultural investment. Secondly, there is a sharp division between small- and large-scale farms with large-scale production often saturating the markets and squeezing the profit margins of small-scale farmers. Besides, South African arable land is not only relatively scarce, but it is less fertile compare to other developing countries. These may explain why poverty reduction in agriculture is mainly a result of employment of labour on large farms.

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Chapter 8
Conclusions

Jaime M. Amezaga and Jennifer A. Harrison

Biomass energy is, and will continue to be, one of the options available for renewable energy worldwide. As Bob Scholes argued in the Foreword to this book, however, biomass energy is not automatically either sustainable nor free of adverse impacts. The balance depends on the chosen methods of feedstock production, the technologies applied for conversion into energy and the modes of deployment. Recently, we have witnessed an intense international debate on bioenergy, provoked mainly by the expansion of liquid biofuels driven by targets in developing countries. Out of this debate numerous initiatives have emerged promoting diverse approaches to ensuring the sustainability of bioenergy production. This book is a contribution to these efforts.

With the support of the European Commission EuropeAid Co-operation Office, the RE-Impact project consolidated expertise from partners in South Africa, Uganda, India, China, Austria and the UK to produce a resource for practitioners and local decision-makers with an interest in methods to assess the sustainability of bioenergy in developing countries. From their position bioenergy production takes a different perspective. Traditional biomass is still the main source of energy in many of these countries, and frequently a driver of environmental degradation. In such cases, a transition to modern forms of biomass production is a necessary requirement for sustainable development. On the one hand, biofuels could become a source of income through exports to developed countries with mandatory targets. On the other hand, locally produced biofuels could be a critical source of renewable energy paid in local currency. Given the proper conditions biomass-energy could be an engine for rural development and poverty reduction due to its capacity for employment and generation of new sources of income in cash deprived areas, as well as providing a reliable and affordable energy supply.

In spite of all these potential benefits, whether producing feedstock for bioenergy production is the best land use option remains an open question. The potential for negative environmental, social and economic impacts remains. Certification can provide a filtering mechanism for exports to developed countries but there is still a strong need for approaches that are able to take a context specific perspective. Issues of scale and the particular physical and socio-economic characteristics of a place, which can only be properly assessed from a developing country perspective, come into play. There is a huge variety in terms of species, processing chain, market end use, scale and drivers for implementation. As a result "one-size-fits-all" type assessments are unlikely to be able to cover all aspects. There is a sharp contrast between the impacts at community, national or global level with potential tradeoffs appearing at all scales. One example is the minimal capacity of communities to influence carbon sequestration at a global scale through engaging in bioenergy projects, although these very communities are surely going to be impacted by climate change. Biodiversity impacts, certainly a problem at national scale, can range from negligible to livelihood-threatening at the community level. One particular issue of concern in developing countries is the often poorly-defined land tenure arrangements. National level priorities for economic growth might not be aligned with the rights of local communities to access communal land; whilst detailed economic analyses of apparently attractive models of bioenergy feedstock production can show minimal or negative impacts on poverty reduction. Only contextual knowledge and a detailed appreciation of the effects on stakeholders can shed light on all these issues.

Ideally, sustainable bioenergy production in developing countries should be driven through sound national policy and legislation and not by an unregulated rush to attend expected market demands or ill-conceived policy objectives. However, it is always difficult from a decision-maker's perspective to distinguish false claims from real impacts without a proper framework for evaluation, and more so in developing countries where frequently there are no specific procedures in place or data to support them. This book is precisely oriented to enable this analysis at the regional or national policy level, although many of the approaches could also be used at the scale of individual projects. It has been designed to have a general applicability to all bioenergy projects, although particular attention has been given to liquid biofuels. There is also a focus on feedstock production rather than on the whole chain from field to market.

The proposed road map for policy evaluation takes as its starting point a planning for sustainability approach, based on multi-stakeholder consultation, with strong roots in objectives-led Strategic Environmental Assessment (SEA). The core of the whole process is the development of a long term vision that is agreeable to all stakeholders. The vision is then underpinned by specific principles which are further described in criteria, indicators and minimum measures which should not be exceeded. A key point is that all measures must be achieved for a development proposal to be considered sustainable, with tradeoffs already decided when defining the measures and not in relation to a specific project proposal. The local definition of vision and principles allows a better incorporation of the unique sustainability concerns in developing countries. As discussed in Chapter 2, not all countries are ready to embrace full participatory planning processes. However, attention to local needs and stakeholder concerns are critical components which may take different forms more amenable to a particular socio-political situation.

Planning for sustainability consultations should be underpinned by in-depth analyses of the impacts on water, greenhouse gases, biodiversity, society and the economy. Whether bioenergy feedstock plantations will result in downstream flow reductions will depend on the particular land use change. Where proposed plantations are to be established in areas dominated by short, seasonally-dormant vegetation, flow reduction is a likely outcome. The same applies where irrigation is required to achieve commercially viable yields. Chapter 3 presented an overview of the tasks required for the hydrological assessment of proposed land use changes. Bioenergy has a role to play in providing renewable energy while reducing greenhouse gas (GHG) emissions but only if the biomass is produced sustainably, which is often not the case in developing countries. Life Cycle Assessment was the methodology proposed in Chapter 4 to evaluate the amount of GHG emissions saved by a bioenergy system as compared to a reference fossil fuel powered system. This methodology calculates the emissions from both systems from "cradle to grave" but generally does not include the timing of emissions and emissions saved. Short term GHG emissions targets should be balanced with the long term objective of providing renewable energy. Bioenergy expansion has a real risk of resulting in biodiversity loss, especially in the tropics where there is a high concentration of biodiversity and a multitude of land use pressures. Careful planning both at the strategic level and at the plantation level can greatly reduce the level of biodiversity loss. Measuring or monitoring biodiversity impacts, however, is complex and can be costly. Chapter 5 presented a step by step approach based on a first cut screening and a decision tree. For a strategic perspective the Biodiversity Intactness Index (BII) method is recommended because it is based on specialist input rather than raw data, frequently unavailable in developing countries. Social impacts have often been overlooked in traditional environmental assessments. However, Social Impact Assessment is a mature methodology for identifying and managing the social consequences of development initiatives, and should be a critical component of the assessment process. Chapter 6 showed an adaptation of the general methodology, using liquid biofuels development in India as a case study. The participatory analysis of the expectations of major stakeholders and impacts, both positive and negative, across five social variables provides a clear picture of the potential tradeoffs involved with different modes of production. The crucial question is whether, for a particular area and set of stakeholders, these tradeoffs are mutually acceptable. The active participation of stakeholders required to elucidate this question can be incorporated within the main planning for sustainability process. Finally bioenergy, and particularly biofuels, could be seen in developing countries as a way to stimulate rural development, create jobs, and save foreign exchange. For the foreseeable future, particularly in Africa, reducing poverty will depend largely on agricultural growth which is four times more effective in extreme poverty reduction than growth from other sectors. Understanding the rural development implications of bioenergy expansion is, therefore, a key issue when considering whether it is an appropriate land use option. Chapter 7 demonstrated a methodology, applied to South African case studies, to analyse three economic challenges: price uncertainty which hampers agricultural expansion; poverty reduction impacts of feedstock production; and the challenges of small-scale farming. In the particular case analysed, poverty reduction appeared to be mainly as a consequence of employment on farms and not small-scale production. This could be a particularity of South Africa; however it showcases how economic analysis should also support decision-making.

After the recent biofuel rush, much has been achieved in better understanding the real impacts of bioenergy and the potential benefits. Well-run collaborative processes have produced solid certification standards and, at least in Europe, there have been drastic changes in policy imposing severe sustainability constraints and tougher GHG emissions savings. Still, the key to sustainability will be in the developing countries themselves. Independently of European and USA targets, access to energy and poverty reduction are intrinsically linked and modern bioenergy should be carefully considered as one of the options to address both. This can only be achieved through informed policy formulation and implementation based on local sustainability requirements. We hope that the approaches presented in this book could help to promote better design and assessment of future policies.

Fulfilling the promise of sustainable development has become a major concern for proponents of modern bioenergy initiatives. The increased global demand for bioenergy products provides many opportunities for socio-economic benefits and rural development in developing countries; however there are also numerous tradeoffs and potential negative impacts that must be taken into account as the level of production increases. There is therefore a clear need to understand both positive and negative impacts from a developing country perspective. This book introduces a selection of suitable approaches that can be used to assess individual aspects of bioenergy production, based on up to date knowledge, thorough assessment and worked out examples from developing countries. It is aimed at the regional or national policy level rather than at the scale of individual projects although many of the principles are applicable at local level as well. Indeed, it is a central concept in the proposed framework that the assessment of sustainability has to start at the early stages of policy design and cannot be left to individual projects.

About the Editors

Dr Jaime M. Amezaga is a Senior Lecturer on Environmental Policy and Sustainability in the School of Civil Engineering and Geosciences and the Newcastle Institute for Research on Sustainability at Newcastle University. He has been the Principal Investigator of the RE-Impact project, which is part of more than a decade of experience in the coordination of interdisciplinary and multinational research projects in Europe, Africa, Asia and South America. His main interest is policy and situational analysis of technical and natural resource challenges in sustainable water, land use and energy management.

Graham von Maltitz is a Senior Researcher at the Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa in the Ecosystems Process and Dynamics Group. Graham has 25 years of experience working in southern African ecosystems with a focus on the interface between humans and sustainable ecosystem processes. He has a special interest in the management of resource use on communally owned land, and the interface between resource degradation and sustainable development.

Samantha Boyes is a Research Associate with the Centre for Land Use and Water Resources Research (CLUWRR) in the School of Civil Engineering and Geosciences at Newcastle University who has interests and expertise in sustainable resource management, particularly hydrological impacts of changing land use patterns.