THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Towards Sustainable Bioenergy

Governance, Resource potentials and Trade-offs

Oskar Englund

Department of Energy and Environment
Division of Physical Resource Theory

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2014

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OSKAR ENGLUND

Thesis for the degree of Licentiate of Engineering

Department of Energy and Environment
Division of Physical Resource Theory
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Author email: oskar.englund@chalmers.se

Cover:
Global land use per capita. See p. 2.

Reproservice
Gothenburg, Sweden
2014

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Abstract

The global energy system needs to be transformed from fossil dependent to renewable, to cope with the challenges of resource scarcity and climate change. Bioenergy can play an important role in this transformation, but land is scarce, and uncontrolled bioenergy expansion could have unacceptable consequences. This thesis contributes to the understanding of (i) how bioenergy governance can be improved to better safeguard sustainability; and (ii) the extent to which biomass can be used for energy, focusing on the potential for biodiesel from Brazilian oil palm.

In **Paper I**, we present sustainability criteria that may affect a range of stakeholders involved with short rotation coppice (SRC) bioenergy, and attempt to outline a framework for engaging relevant stakeholders in the development of sustainable SRC. In **Paper II**, we present an assessment of how biodiversity is considered in different types of sustainability standards. We discuss key barriers to, and challenges for, certification schemes in general, and conclude that all the assessed standards can, to a varying degree, be improved to better consider biodiversity. In **Paper III**, we analyse the economic potential of producing oil palm for biodiesel in Brazil in different policy scenarios, as well as the corresponding trade-offs with various conservation objectives. The results unveil a very large economic potential: Without causing any direct land use change emissions and without inflicting on high conservation value areas, a total of 71-89 Mha land could support production of 6.9-7.8 EJ/year of biodiesel, corresponding to 13-15% of the global petrodiesel demand.

Keywords: Bioenergy, governance, biomass potentials, trade-offs, certification, sustainability standards, biodiversity

List of appended papers

I. Englund O, Berndes G, Fredrikson F, Dimitriou J, 2012. Meeting Sustainability Requirements for SRC Bioenergy: Usefulness of Existing Tools, Responsibilities of Involved Stakeholders, and Recommendations for Further Developments. *Bioenergy Research*, 5(3):606-620

II. Englund O, Berndes G, (in press). How do Sustainability Standards Consider Biodiversity? *WIREs Energy Environ.*

III. Englund O, Berndes G, Persson M, (working document). Oil Palm for Biodiesel in Brazil: Potentials and Tradeoffs.

Acknowledgements

First of all, I would like to thank my supervisor Göran Berndes. You are an inspiration in the way you enjoy your work, and especially in the way you enjoy *my* work. Thank you for great support and supervision, and for being such a genuinely nice person.

I would also like to thank all my dear colleagues at Physical Resource Theory. The atmosphere at our division is something unique and definitely a contributing factor to why I am still here, and enjoying it. Keep it up, and always remember the epic description of our work at the division: "We do what we feel like, and then we call it Physical Resource Theory".

Many other persons have crossed my path throughout the years and left a memorable impression. To name only a few would be a dangerous task, and even more so to name many, so I prefer not to at all. But I do thank you.

Last but definitely not least, I would like to thank my dear friends and family, and in particular Marie and my dog Dino with whom I share a great life. You are the best.

Contents

Chapter 1

Introduction

The sustainable management of natural resources is one of humanity's most important challenges. Our present global level of consumption is already beyond what can be sustained over time, and with increasing global population and affluence, the demand for resources continues to increase (Rockström et al. 2009). Fossil resources are no exception – we continue to consume more while the resources decline. The extensive use of fossil fuels has also brought another great challenge: climate change, mitigation of which requires global efforts. Therefore, to allow future generations sufficient access to energy, and to avoid severe climatic effects, the use of fossil resources needs to be replaced. As an alternative to fossil fuels, bioenergy may contribute to solving both the challenge of sustainable resource management and the challenge of climate change mitigation.

The advantages of bioenergy are several: (1) Biomass is renewable, i.e., sustainably managed, the supply will never expire. At the conceptual level, it is therefore also CO2 neutral.. Using *carbon capture and storage* technology in bioenergy plants could possibly even help to decrease CO_2 concentrations in the atmosphere. (2) It has properties similar to fossil fuels. For example, solid biomass can replace coal, liquid biofuels can replace petrol and diesel, and biogas can replace natural gas, with only small alterations of current infrastructure and end-use applications. (3) In addition to biomass, other valuable ecosystem services can be provided by certain production systems, e.g., erosion control, water management, and climate control due to increased carbon sequestration. (4) It can help to increase energy security for many countries currently dependent on importing fossil fuels. (5) Developing countries with low population densities and underutilized land may have the potential to produce a surplus of biomass or biofuels, which they could export to other countries. This could strengthen the national economy, but also bring occupational opportunities and a general modernization of agriculture.

However, land is scarce. If all land were distributed evenly among all humans (Figure 1), we would each have about 0.5 ha of pasture (i.e., enough for about half a cow in Brazil) and 0.2 ha of cropland to sustain ourselves, in addition to hunting and gathering in our 0.55 ha forest and on our 800 m^2 grassland fields. If this is not sufficient to sustain our desired lifestyle, we would need to convert our forest or our grasslands in order to produce more goods, or free up pasture land by becoming vegetarian. This example may be impractical, but it illustrates that land is limited. In case of insufficient biomass supply, one easy option is to expand at the expense of natural ecosystems. However, this alternative is often disadvantageous, since it can cause, e.g., severe impacts on biodiversity and ecosystem services. In the case of bioenergy feedstock production, it could also delay the climate change mitigation benefits, due to carbon emissions from land use change (LUC) and decreased carbon sequestration capacity. In addition, as we phase out fossil energy using different policy instruments, e.g., a price on carbon emissions, the price for energy will increase. This will make it more profitable to produce feedstock for bioenergy and thus increase the price of land, which in turn could raise food prices and incentivize both land-grabbing and conversion of natural ecosystems.

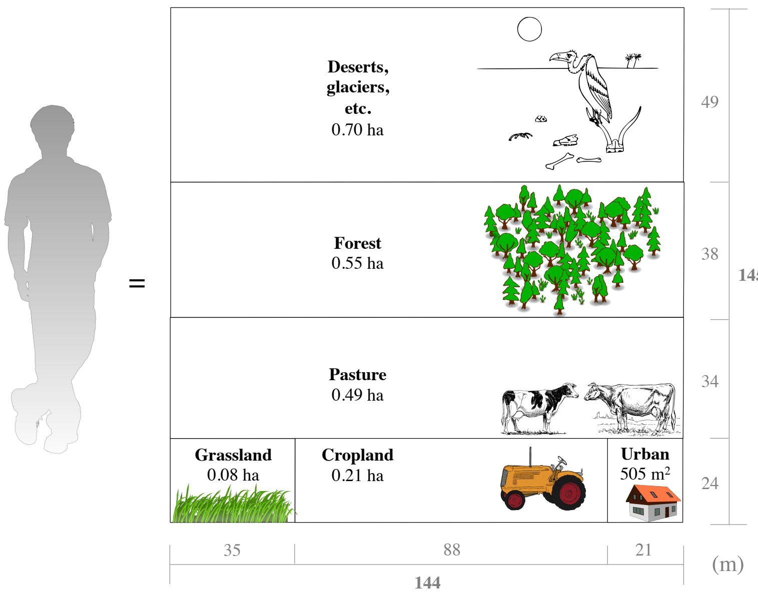

Figure 1: Global land use per capita. Compiled by the author based on data from Bringezu (2014). Note that it is difficult to distinguish between different land use categories, and that estimates therefore vary.

However, despite the evident risk for environmental and socioeconomic consequences, there is actually a large potential for sustainable bioenergy (see Chapter 3), but realizing this potential is complicated. In addition to knowledge of how to avoid bioenergy expansion having unacceptable consequences, we need better understanding of how production systems can be designed so as to provide multiple benefits. Another key is effective governance (see Chapter 2) that can utilize this knowledge while coping with the many trade-offs that characterize land management.

This thesis broadly aims to increase the understanding of (i) how bioenergy governance can be improved to better safeguard sustainability; and (ii) the extent to which biomass can be used for energy purposes, and the trade-offs involved in using different feedstock types and production systems. In **Paper I**, we discuss sustainability requirements for short rotation coppice (SRC) bioenergy, and attempt to outline a framework for engaging relevant stakeholders in the development of sustainable SRC production. In **Paper II**, we present an assessment of how biodiversity is considered in different types of sustainability standards for biomass, and discuss key barriers to, and challenges for, certification schemes. In **Paper III**, we analyse the potential for oil palm biodiesel in Brazil in different policy scenarios, taking into account different levels of environmental trade-offs. **Finally**, this thesis concludes with a few challenges of particular personal interest for future studies, based on the outcomes presented.

Chapter 2

Bioenergy Governance

National legislation constitutes the most basic rules and requirements for biomass production and bioenergy, restricting how the land is used and how agricultural, forest, and industrial activities are managed. The definition of "acceptable" land use and biomass production varies among nations and sometimes within countries as well, due to differences in legislation at the sub-national level. The capacity to enforce legislation also varies significantly between countries. Unless properly enforced, legislation can be very stringent but still ineffective. Due to the differences among nations in stringency and enforcement capacity, the environmental and socioeconomic consequences of new bioenergy production can vary greatly, from sustainable to disastrous, in the absence of additional governance.

In response to concerns about unintended consequences of the production and use of biomass for energy, producers of biomass feedstock in the private sector, as well as governmental and non-governmental organizations, have taken initiatives to develop criteria and indicators for sustainable bioenergy supply chains, as a means toward regulating the bioenergy sector. The sustainability certification schemes that are being developed or implemented by a variety of private and public organizations can apply to a variety of feedstock production sectors (notably forest and agriculture sectors) and bioenergy products, ranging from relatively unprocessed forest and agriculture residues to electricity and refined fuels, such as ethanol and biodiesel. They can apply to entire supply chains or only certain segments (Junginger et al. 2011; O'Conell et al. 2009; Stupak et al. 2011; van Dam et al. 2010). In addition, a number of non-operational sustainability standards exist, developed to guide or influence other actors involved in developing operational standards. Such guidelines have been developed by, e.g., International Tropical Timber Organization (ITTO), for sustainable management of tropical forests; International Federation of Organic Agriculture Movements (IFOAM), for organic agriculture; and the Global Bioenergy Partnership (GBEP), for sustainable bioenergy feedstock production. Many sustainability standards exist, both mandatory and voluntary, with varying scope. They also differ in how they prioritize different aspects of sustainability. For example, some may be very focused on the environmental performance of a production system, while others focus more on social aspects.

Studies show that there are many challenges associated with the current status of sustainability certification and standards (Englund et al. 2012; Junginger et al. 2011; O'Conell et al. 2009; Stupak et al. 2011; van Dam et al. 2010). According to non-certified producers, main barriers include high administrative complexity, high costs, and small market advantages (Pelkmans et al. 2013; Goovaerts et al. 2013). In addition, stakeholders along bioenergy supply chains may need to comply with different standards to maintain market access and to comply with legislative mandates. Consumers who try to make environmentally conscious purchasing decisions, and regulatory agencies and governments involved in enforcing sustainability standards, may find it difficult to manage a wide range of systems that use different criteria/indicators. Thus, the proliferation of schemes and standards has lead to confusion among actors involved, market distortion and trade barriers, an increase in commodity costs, and questions about the adequacy of systems in place and how to develop systems that are effective and cost-efficient (Pelkmans et al. 2013; Buytaert et al. 2011; Magar et al. 2011; van Dam & Junginger 2011). A recent study undertaken to monitor the actual implementation process of sustainability certification of bioenergy found that there is no global/common definition of how the sustainability concept should be translated into practice, i.e., how to measure sustainability and which criteria/indicators to use (Pelkmans et al. 2013). The study called for a globally harmonized approach and establishment of a common language, including terminology, to describe sustainability and how it should be verified/documented.

In addition to certification schemes, certain markets have developed their own rules and requirements that producers have to comply with to gain access. Stakeholders involved with bioenergy that is used within the European Union (EU) have to specifically consider the EU Renewable Energy Directive (RED), which mandates levels of renewable energy use within the EU and also includes a sustainability scheme for liquid biofuels and other bioliquids. However, it is relevant for all types of bioenergy (European Council 2009). In order to ease the process of proving compliance with the sustainability requirements, the EU-RED has approved a set of certification schemes that suffice to verify compliance with the EU-RED. This makes it easier for producers, since they only need to comply with one standard to gain access to several markets (i.e., both the market for certified goods and the EU-RED).

Finally, there is a set of tools that can be used to guide biomass production along a more sustainable path. For example: (1) Producer manuals can be designed to help producers prepare for complying with sustainability standards or at least avoid unnecessary environmental consequences; and (2) Environmental impact assessments (EIAs) can be used by funding agencies to verify that a proposed project complies with certain sustainability requirements.

Governance is an essential component of a sustainable bioenergy system. Legislation and regulation as well as sustainability standards, certification schemes, and other governance tools can all help to guide deployment of bioenergy production systems in the right direction. Effective governance can help mitigate negative impacts and promote best management practices, and contribute to shaping the way land is used to produce food and biomaterials.

Paper I Meeting Sustainability Requirements for SRC Bioenergy

Short rotation coppice (SRC) (e.g., willow or poplar) is considered an important biomass supply option for meeting the European renewable energy targets (Styles & M. B. Jones 2007). An expansion of SRC, especially in agricultural areas near the end user of biomass (e.g., heat and electricity plants for direct biomass combustion), is expected in several European countries.

In this paper we present an overview of existing and prospective sustainability requirements as well as of Member State (MS) reporting obligations in the EU-RED, and show how these *RED-associated* criteria may affect different stakeholders along the SRC bioenergy supply chain – from feedstock producers to energy consumers. We also attempt to outline a framework for engaging relevant stakeholders in the development of SRC. This framework has two purposes: (1) to facilitate the development of SRC production systems that are attractive from the perspectives of all stakeholders; and (2) to ensure that the SRC production is RED eligible.

Methodology

(1)
Existing or prospective sustainability criteria relevant for SRC were derived from the EU-RED, as described in Table 1. These *RED-associated* sustainability criteria were then sorted under specific categories to put them into a correct context and finally evaluated on their relevance for SRC bioenergy on a national level.

(2)
The stakeholder landscape was investigated using in-house experience and stakeholder consultation, to identify principal stakeholders involved in SRC bioenergy. A general SRC bioenergy supply chain was created (Figure 2) and the stakeholders' roles in meeting RED-associated criteria were discussed.

Table 1: Components of the EU-RED, from which existing and prospective sustainability criteria relevant for SRC were derived

Sustainability requirements for liquid biofuels, or bioliquids	**Monitoring and reporting obligations**	**Methodology for calculating GHG emissions savings**	**Sustainability considerations requiring no particular actions at present**
Currently not mandatory for SRC bioenergy, but may be so in future revisions EC recommends that they be included also in national sustainability schemes for solid and gaseous biomass, used in electricity, heating, and cooling.	Such obligations typically concern impacts due to production and use of bioenergy in general, i.e., no distinctions are made between liquid, solid, or gaseous biofuels.	Considering these in a sustainability framework for SRC bioenergy would support the involved stakeholders in producing bioenergy with high GHG emissions savings.	May be subject to reporting and monitoring obligations in the future, or even become additional sustainability requirements.

(3)
Producer manuals, environmental impact assessments (EIAs), and certification schemes can all provide guidance as well as contribute to the monitoring and verification of sustainable biomass production. In order to determine whether these tools, individually or combined, can be useful for ensuring that SRC bioenergy is produced in accordance with the RED-associated criteria, they were assessed in terms of their coverage in relation to these criteria.

- Ten producer manuals for willow and/or poplar coppice production, including site selection, planting, and harvesting, were collected and analysed.
- Nineteen EIAs were collected from bioenergy projects that include the establishment of plantations or large-scale agricultural operations, and/or construction of a biofuel processing plant. Depending on the nature of the assessed bioenergy projects, EIAs were sorted into three categories: Plantations, Biofuel plant, and Plantations and biofuel plant.
- A review of international sustainability certification schemes relevant for SRC bioenergy was performed. Based on this, the role of certification in national SRC bioenergy sustainability frameworks was discussed.

Main Findings

Eighteen sustainability criteria associated with EU RED were identified as relevant for stakeholders involved in SRC bioenergy (Table 1). These are related to (1) existing and prospective legally binding sustainability requirements, (2) reporting obligations for MSs, and (3) the methodology for calculating GHG emissions savings.

It is important that a sustainability framework is designed so as to facilitate stakeholder interaction to clarify the stakeholders' respective roles and responsibilities and to identify points where conflicts of interests may arise and where there are trade-offs between partially incompatible goals and objectives. Proper consideration of all relevant aspects therefore requires all stakeholders in the SRC supply chain to be engaged in the development of SRC production systems and requires a landscape perspective.

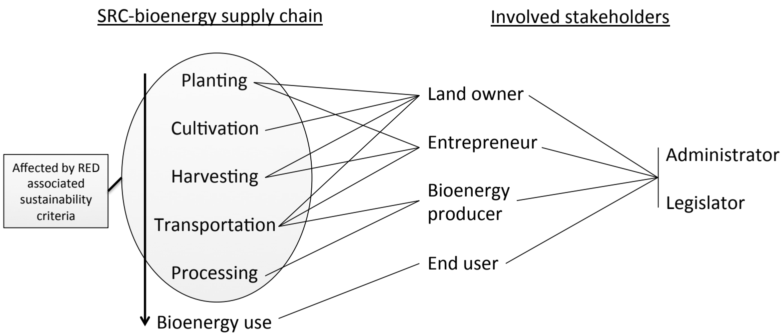

Figure 2: A typical SRC bioenergy supply chain, with indication of involvement of principal stakeholders in the different supply chain segments

Table 2: RED sustainability categories and associated sustainability criteria of national relevance for SRC bioenergy production

RED categories		Associated sustainability criteria	Current status
Biodiversity	1.1	Preservation of natural forests	Existing requirement
	1.2	Preservation of areas designated for nature protection purposes or for the protection of rare, threatened and endangered species	Existing requirement
	1.3	Preservation of highly biodiverse grasslands	Existing requirement
	1.4	Impacts on biodiversity	MS reporting obligation
GHG emissions	2.1	Preservation of peatlands	Existing requirement
	2.2	GHG emissions from extraction or cultivation of raw materials	GHG emissions savings calculation
	2.3	GHG emissions from processing	GHG emissions savings calculation
	2.4	GHG emissions from transport and distribution	GHG emissions savings calculation
	2.5	Carbon capture and replacement	GHG emissions savings calculation
	2.6	Co-generation of electricity, if producing bioliquids	GHG emissions savings calculation
Carbon stock	3.1	Preservation of wetlands	Existing requirement
	3.2	Preservation of continuously forested areas	Existing requirement
	3.3	Restoration of degraded land	GHG emissions savings calculation
	3.4	Restoration of contaminated land	GHG emissions savings calculation
Air, water and soil	4.1	Impacts on air quality	MS reporting obligation / Prospective requirement
	4.2	Impacts on water quality	MS reporting obligation / Prospective requirement
	4.3	Impacts on water availability	MS reporting obligation / Prospective requirement
	4.4	Impacts on soil quality	MS reporting obligation / Prospective requirement

Producer manuals, EIAs, and voluntary certification schemes can all be useful for ensuring that SRC bioenergy is produced with sufficient consideration given to the RED-associated criteria. However, they currently do not suffice for this purpose, neither individually nor combined.

Producer manuals need to be complemented to sufficiently cover the RED-associated criteria, and advice on how producers should monitor their activities in order to demonstrate compliance should be provided. *EIAs* also need to be extended to sufficiently consider all criteria, but they also need to be streamlined to become less time consuming and expensive. Regarding *voluntary certification schemes*, national sustainability frameworks for SRC need to be designed so that the producing stakeholders are well informed about the availability and relevance of certification options, which in most cases is likely to vary between countries. The coverage of certain certification schemes in relation to the RED-associated criteria also needs to be assessed on a country level, while continuously considering outcomes from the EC benchmarking process.

Thus, a sustainability framework for SRC bioenergy can have several components. Most importantly though – a sustainability framework needs to provide landscape level processes and engage all involved stakeholders. An appropriate institution should take a formal role in coordination, to ensure that developments are progressing in line with the interests of all stakeholders.

Paper II How do Sustainability Standards Consider Biodiversity?

Biodiversity presents a challenge for sustainability certification. While there is wide support for the objective to conserve biodiversity (e.g., the Convention on Biological Diversity has 193 parties and 168 signatures (CBD 2014)), operationalization into guiding principles, criteria/indicators, and legislation is complicated. For example, in 2009, the EU-RED established that raw materials used for the production of biofuels and bioliquids may not be produced on land that had the status of highly biodiverse grassland in or after January 2008 (European Council 2009). However, the European Commission is still in the process of operationalizing elements of the biofuel sustainability criteria, including clarifying some of the requirements that need to be met with respect to the biodiversity criteria, e.g., in relation to highly biodiverse grasslands.

In this paper, we present an assessment of how biodiversity is considered in different types of sustainability standards. First, biodiversity is defined and strategies for biodiversity conservation are discussed. Then, standards for sustainable production of biomass in agriculture and forestry are evaluated based on how they consider biodiversity, i.e., how they attempt to prevent actions that can threaten biodiversity and support actions that can conserve it. We also assessed how sustainability standards address the conversion of certain ecosystem types. Finally, key barriers to, and challenges for, certification schemes are discussed and recommendations are made for further development of sustainability standards.

Methodology

Four different categories of standards were considered: (1) standards for certification of sustainable forest management; (2) standards for certification of sustainable agricultural management; (3) standards for certification of sustainable production of specific crops commonly used as biofuel feedstock; (4) standards for sustainable production of unspecified biofuel feedstock. In addition, guidelines for development or implementation of standards that can be sorted under (1-4) were also considered. A total of 26 standards were selected for the assessment, including 11 forest management standards, 9 agriculture management standards, and 6 biofuel-related standards. All selected standards include a set of principles and criteria/indicators, or the equivalent (standards often differ in their terminology), indicating each standard's requirements for production to be considered sustainable or responsible.

Table 3: Overview of the schemes/organizations which standards were assessed

	Scheme/Organization	Abbreviation	Code
Forest management	Forest Stewardship Council (FSC)	FSC	F1
	Sustainable Forestry Initiative (SFI)	SFI	F2
	Finnish Forest Certification System (FFCS)	FFCS	F3
	Malaysian Timber Certification System (MTCS)	MTCS	F4
	Canadian Standards Association (CSA)	CSA-SFM	F5
	Green Gold Label (GGL)	GGLS5	F6
	Naturland	Naturland Forest	F7
	International Tropical Timber Organization (ITTO)	ITTO	F8
	African Timber Organization (ATO) / ITTO	ATO/ITTO	F9
	ITTO / International Union for Conservation of Nature (IUCN)	ITTO/IUCN	F10
	Ministerial Conference on the Protection of Forests in Europe	PEOLG	F11
Agricultural management	Global Partnership for Good Agricultural Practices (GLOBALGAP)	GLOBALGAP	A1
	KRAV - Swedish Organic Agriculture	KRAV	A2
	European Union (EU)	EU Organic	A3
	United States Department of Agriculture (USDA)	USDA-NOP	A4
	Green Gold Label Agricultural Source	GGLS2	A5
	Fairtrade	Fairtrade	A6
	Naturland	Naturland production	A7
	International Federation of Organic Agriculture Movements	IFOAM	A8
	Sustainable Agriculture Network / Rainforest Alliance	SAN/RA	A9
Biofuel related	Roundtable on Sustainable Palm Oil (RSPO)	RSPO	B1
	Roundtable on Responsible Soy (RTRS)	RTRS	B2
	Bonsucro	Bonsucro	B3
	Roundtable on Sustainable Biofuels (RSB)	RSB	B4
	International Sustainability & Carbon Certification (ISCC)	ISCC	B5
	Greenergy	Greenergy	B6

A general biodiversity focused *benchmark standard* was developed using seven *principles*, based on threats to, and strategies for conserving, biodiversity, under which 26 *criteria* were defined and sorted. The criteria were intended to translate the broadly formulated principles into concrete actions applicable to both agriculture and forest management.

The selected standards were then individually compared with the benchmark standard and for each benchmark criterion it was determined whether a specific standard was *compliant* or not. Based on this, the overall biodiversity *stringency* of a standard was then determined.

Given that land conversion may induce adverse effects on biodiversity, it was also investigated how the standards addressed conversion of certain types of ecosystems, namely: (i) tropical and subtropical forests; (ii) temperate forests; (iii) boreal forests; (iv) wetlands; (v) grass-, shrub- and woodlands; and (vi) degraded land.

Main Findings

In summary, the assessed biofuel-related standards had the highest level of compliance with the benchmark standard, complying on average with 72% of the benchmark criteria, compared to 61% for the agricultural standards and 60% for the forestry standards. Fairtrade and SAN/RA (agriculture), and RSPO and RTRS (biofuel) were the most stringent, while GGLS5 and PEOLG (forest), GLOBALGAP, EU Organic, NOP, and GGLS2 (agriculture), and ISCC (biofuel) were the least stringent (Table 4).

In general, the assessed standards consider *habitat destruction*, *-fragmentation*, *-degradation*, *-modification* and *overexploitation* well, while *invasive species and GMOs, research, awareness and education,* and *Energy use and GHG* are often poorly considered.

There are notably large differences in stringency between some standards having a similar scope. For example, IFOAM, which sets the “norms” for organic agriculture, is significantly more stringent than both EU Organic and NOP. In addition, KRAV endorses EU Organic, even though KRAV classifies as *Stringent* and EU Organic as *Unstringent*. Further, the SFI standard, which is a forest industry initiative, shows similar stringency as the FSC standard, which is often regarded as more thorough in its coverage of ecological issues (Clark & Kozar 2011). Furthermore, the high stringency in the Fairtrade standard, and to some extent also SAN/RA, was unexpected, as these are perceived to primarily focus on social aspects.

Regarding ecosystem conversion, forestry standards typically only protect areas that are considered high conservation value (HCV). They also tend to limit the HCV assessment requirements to include forested land only, i.e., they do not prevent conversion of highly biodiverse grasslands or wetlands into certified plantation forests. Agricultural standards cover more ecosystem types and typically do not provide for much flexibility: specific ecosystem types are either no-go areas or there are no conversion restrictions at all. The inflexibility that several of the agricultural standards apply may result in areas that could be beneficially converted into sustainable cultivation, such as some degraded grasslands, not being available. The biofuel-related standards are influenced by EU-RED and cover ecosystem conversion comprehensively, using a combination of HCV requirements and strict protection measures. Finally, some standards (EU Organic, NOP, and GGLS2) do not restrict land conversion at all. This may not be a large problem in countries with stringent legislation and sufficient enforcement capacity, but in countries where this is lacking, natural vegetation may be converted into certified agriculture, impacting biodiversity.

All the assessed standards can, to a varying degree, be improved to better consider biodiversity. The benchmark standard presented in this paper could be used to develop more concrete criteria/indicators that fit into the scope of individual standards. The further development of sustainability standards should aim for increased harmonization and reduction of heterogeneity of systems, while staying relevant for their intended production system. A balance needs to be found between stringency and comprehensiveness on the one hand and feasibility from a biomass-producer perspective on the other hand. It is important to avoid unnecessary requirements that increase administrative burden and cost without improving conservation outcome. Requirements that are too restricting/demanding may slow implementation and even prevent biomass production under the sustainability standard from reaching meaningful scale.

Land management is characterized by trade-offs, and standards therefore need to consider the goals and objectives of different stakeholders in order to be effective. Therefore, it is necessary for standard developers to involve a wide range of stakeholders in the development process. By doing so, a standard can be developed to reach acceptance among all stakeholders, be it NGOs, landowners, biofuel producers or traders. This process can also contribute to the development of shared views among diverse stakeholders involved in the public debate about bioenergy sustainability in general.

Table 4: Compliance with benchmark principles. Green (+) indicates considered; yellow (+/-) indicates partly considered; orange (–) indicates disregarded. F1-F11 constitute the eleven forestry standards, A1-A9 the nine agriculture standards and B1-B6 the six biofuel related standards.

Principle	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
1. Endangered species	+/-	+	+	+	+/-	+/-	+	+	+/-	+	+/-
2. Habitat destruction and fragmentation	+	+/-	+	+	+	+/-	+	+	+	+	+/-
3. Habitat degradation and modification	+/-	+	+/-	+/-	–	–	+	+/-	+/-	+/-	–
4. Overexploitation	+	+/-	+	+	+	+	+	+	+	+	+/-
5. Invasive species and GMOs	+	+/-	+/-	+/-	+	–	+	–	+/-	+/-	–
6. Energy use and GHG	+/-	+/-	–	+/-	+/-	+/-	+	+/-	+/-	–	+/-
7. Research, awareness and education	+/-	+	+/-	+/-	+/-	–	–	–	+/-	+	+
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**		
1. Endangered species	–	+	–	–	–	+	+/-	–	+/-		
2. Habitat destruction and fragmentation	+/-	+/-	+/-	+/-	–	+	+	+	+		
3. Habitat degradation and modification	+/-	+	+/-	+	+	+	+	+	+		
4. Overexploitation	+	+	+	+	+/-	+	+	+	+		
5. Invasive species and GMOs	–	+/-	+/-	–	–	+/-	+/-	+/-	+/-		
6. Energy use and GHG	+/-	+	–	–	–	+/-	+/-	+/-	+		
7. Research, awareness and education	+/-	–	–	–	+/-	+	+/-	–	+		
	B1	**B2**	**B3**	**B4**	**B5**	**B6**					
1. Endangered species	+	+	+	+/-	–	+					
2. Habitat destruction and fragmentation	+	+	+	+	+/-	+/-					
3. Habitat degradation and modification	+	+	+	+	+	+					
4. Overexploitation	+	+	+/-	+	+/-	+					
5. Invasive species and GMOs	+/-	+/-	+/-	+/-	–	+/-					
6. Energy use and GHG	+	+	+/-	+/-	+/-	+/-					
7. Research, awareness and education	+/-	+/-	+/-	–	+/-	+/-					

Chapter 3

Resource potentials and Trade-offs

Many studies have been made of the extent to which biomass can be sustainably used for energy, yet there are large variations in their estimates (Berndes et al. 2003; Smeets et al. 2007; Batidzirai et al. 2012), often due to differing methodologies and the way that "sustainably" is defined. Common for many studies is that they focus on the biophysical potential to produce bioenergy feedstock of some sort and then disqualify certain land use categories, on which production is considered to have unacceptable environmental or socioeconomic impacts. In addition to terrestrial biomass, there are reports of large biomass potentials from algae (C. S. Jones & Mayfield 2012; Singh & Cu 2010), a potentially highly land-efficient feedstock alternative.

IEA (2009) estimate the total global potential for sustainable bioenergy in 2050 to be 200-500 EJ/year, corresponding to 20-83% of the global energy demand (cf. the current biomass demand for energy: 50 EJ). Realizing this potential requires that we make use of excess residues from forestry and agriculture, but also that we use dedicated plantations of energy crops. The increased demand for land that expansion of energy crops would entail can be mitigated by crop yield improvements due to agriculture modernization, especially in developing countries, and livestock intensification, which can free up large land areas for biomass production in countries with low stocking rates.

However, we could also expand on natural vegetation, such as natural forests or grasslands, but in that case we would have to value the benefits of bioenergy against corresponding negative consequences from land conversion, such as carbon emissions from LUC and impacts on biodiversity and ecosystem services. For example, in **Paper III**, we show that 95% of the global demand for petrodiesel can be replaced with biodiesel from oil palm produced in Brazil. However, that would entail conversion of almost the entire Amazon rainforest, causing disastrous effects on biodiversity and such a large decrease in carbon stock that it would take over 70 years before there is even a contribution to climate change mitigation. This may be an extreme example, but in any case where natural vegetation is considered for conversion into biomass production, there are trade-offs that have to be taken into account. However, by expanding on lower quality land than is usually used for agriculture, such as moderately degraded land and/or where there is moderate water scarcity, there may be fewer trade-offs. On such land, there can also be better opportunities for designing production systems with multiple benefits, such as erosion control in addition to biomass production.

As discussed in *Chapter 2*, governance is an essential component in a sustainable bioenergy system. However, governance cannot guide deployment of bioenergy production systems in the right direction without proper understanding of the extent to which biomass can be used for energy, as well as the trade-offs involved in using different feedstock types and production systems.

Paper III Oil Palm for Biodiesel in Brazil – Potentials and Trade-offs

Oil palm is the most land-efficient and profitable tropical feedstock alternative for biodiesel (Butler 2010; Schwaiger et al. 2011). Today, 90% of the global palm oil production takes place in Indonesia and Malaysia, where 6 and 4 million hectares (Mha) of plantations have been established, respectively, mostly at the expense of tropical forests, resulting in impacts on biodiversity and causing greenhouse gas emissions associated with the forest conversion. While Brazil presently has only about 0.1 Mha of oil palm plantations (FAO 2013), roughly 565 Mha of land could support oil palm cultivation. The use of such suitable land would in many places have impacts on biodiversity and cause greenhouse gas emissions associated with forest conversion, but there are also large deforested areas, e.g., cattle pastures, where conversion to palm oil plantations could possibly bring benefits such as carbon sequestration and partial reversal of hydrological changes caused by the earlier deforestation.

The expansion of oil palm cultivation is considered a way to create jobs and improve incomes at the local level: according to government estimates, a family could increase its net income by more than 400% by shifting from traditional crops to oil palm cultivation (Butler 2010). The Brazilian government acknowledges the risks of environmental impacts, and the ambition is for plantations to be mainly established on degraded agricultural land (Butler 2011). So far, 5 Mha of new oil palm plantations have been authorized, out of a total 29 Mha of land identified as suitable in Brazil's agro-ecological zoning for Oil Palm (EMBRAPA 2010). However, the profitability of oil palm cultivation makes it an attractive option for existing and aspiring landowners in areas other than those pointed out by the government.

When effective, legislation, policies and enforcement can prevent cultivated systems from expanding at the cost of forests and other native vegetation, but the effectiveness varies (Sparovek et al. 2010). For example, Yui and Yeh (2013) showed that the extent and impacts of oil palm expansion in the Brazilian state of Pará differ dramatically depending on comprehensiveness and effectiveness of enforcement to ensure compliance with regulations. Large forest areas in Brazil can also be legally converted into cultivated systems (Sparovek et al. 2010). The Forest Act, which is the most important legal framework for conservation of natural vegetation on private agricultural lands, has recently been revised because, on the one hand, it has been found ineffective in protecting natural vegetation, and on the other hand, it is perceived as a barrier against development in the agriculture sector (Sparovek et al. 2012). The revised Forest Act allows the planting of oil palm toward compliance with legislation concerning the share of farm land reserved for natural vegetation (in the Legal Amazon and the Forest biome: 80% when the area is on native vegetation and 50% if already converted).

In this study, a spatially explicit modelling framework was used to: (i) quantify the economic biodiesel potentials based on determining the net present value (NPV) of establishing new oil palm plantations for biodiesel production under different scenarios; (ii) analyse trade-offs between oil palm biodiesel profitability and conservation objectives; and (iii) investigate whether pricing of carbon emissions from energy/industrial activities and LUC might steer oil palm production away from lands where conversion would bring the largest impacts on biodiversity or ecosystem carbon stocks. The scenarios include different oil, coal and carbon price developments as presented in World Energy Outlook 2012 (IEA 2012) and both the present and prospective situations concerning road infrastructure in Brazil.

Methodology

The net present value (NPV) of establishing new oil palm plantations (Eq. 1) was calculated for each hectare in Brazil in 45 future scenarios made up of different combinations of: (i) price projections on oil, coal, and carbon, (ii) levels of a potential LUC carbon price, (iii) establishment year, and (iv) models used for spatially estimating the potential palm oil yield.

Equation 1: Formula for determining NPV of establishing new oil palm plantations for biodiesel production

$$
\begin{aligned}
&NPV_{oilpalm}(t) \\
&= \mathit{Revenues\ from\ timber} - \mathit{Cost\ of\ establishing\ plantations} \\
&- \mathit{Cost\ of\ establishing\ mill} \\
&- \mathit{Carbon\ costs\ from\ LUC}\ (\mathit{or\ REDD\ revenues\ by\ avoiding\ it}) \\
&+ \sum_{n=1}^{25} \left[\frac{\mathit{Revenues} - \mathit{Cultivation\ costs} - \mathit{Milling\ costs} - \mathit{Trp\ costs} - \mathit{C\ costs}\ (N2O)}{(1+r)^n} \right]
\end{aligned}
$$

The willingness to pay for palm oil biodiesel was estimated based on projected global oil prices in the different IEA scenarios, with costs for refining oil into petrodiesel, and the EU carbon tax, added. The willingness to pay for residues (to use for bioenergy) was estimated based on projected coal prices, in some scenarios with a Brazilian carbon tax added. Different cost parameters for oil palm cultivation and milling were identified in literature. Brazilian studies were preferred when possible.

The 45 NPV datasets were then thoroughly analysed; the amount of land where oil palm establishments would be profitable was quantified for different land use / land cover (LULC) classes, as well as the corresponding biodiesel potentials and carbon stock changes. The time required to achieve net GHG emissions savings was estimated assuming 65% carbon savings from replacing petrodiesel with palm oil biodiesel.

Spatial data include:

(1) A *100 m Brazilian LULC map*, with data gaps (i.e., cells classified as "unclassified" or "other") filled using the Globcover dataset;

(2) *Potential production capacity for palm oil*, extracted from GAEZ 3.0, with production capacity of palm kernel oil added to the dataset using a linear relationship between palm oil and palm kernel oil yields;

(3) *Transportation costs*, i.e., a minimum estimate of the cost in each grid cell of transporting one tonne of palm oil to an export port, using either roads or waterways. The dataset was produced by performing a cost distance operation in ArcGIS, using official Brazilian data on roads, waterways and ports as inputs; and

(4) *Carbon stock change*, i.e., the difference in each cell between current carbon stocks and the amount of carbon that would be stored over time in oil palm plantations. Current aboveground, belowground, and litter carbon stocks were estimated based on an aboveground biomass dataset by Baccini (2012).

Main findings

The results unveil a large economic potential for palm oil biodiesel, large possible trade-offs as well as opportunities to meet multiple objectives:

Theoretically, Brazil could produce around 50 EJ/year of profitable biodiesel from oil palm, replacing 95% of the global petrodiesel demand. However, that would entail conversion of almost all forests in the legal Amazon, and a corresponding decrease in carbon stock with up to 48.8 Gt C, or 179 Gt CO_2, equivalent to about 5.8 times the global CO2 emissions from fossil fuels in 2012 (IEA 2012).

Without causing any direct land use change emissions and without impinging on high conservation value areas, a total of 71-89 Mha land could support production of 6.9-7.8 EJ/year of biodiesel, corresponding to 13-15% of the global petrodiesel demand (Figure 4).

An LUC carbon price would steer production away from forests and HCV areas if set sufficiently high: In the absence of an LUC carbon price, 86-91% of all forests in Brazil where oil palm production is possible would be profitable to convert. An LUC carbon price in line with the current price on voluntary carbon markets (22 $/t C) would only have a marginal effect on forest protection, but a price in line with the

EU ETS market in 2025, in a scenario with ambitious climate policies (124.6 $/t C), would protect all but 4% of these forests (Figure 3).

If all infrastructure plans in Brazil were realized by 2025, including the paving of all unpaved roads, the total biodiesel potential would increase by a mere 0.1-4.0%. Most of the area where additional oil palm planting would be profitable is presently forested (66-95%) and/or HCV land (50-85%).

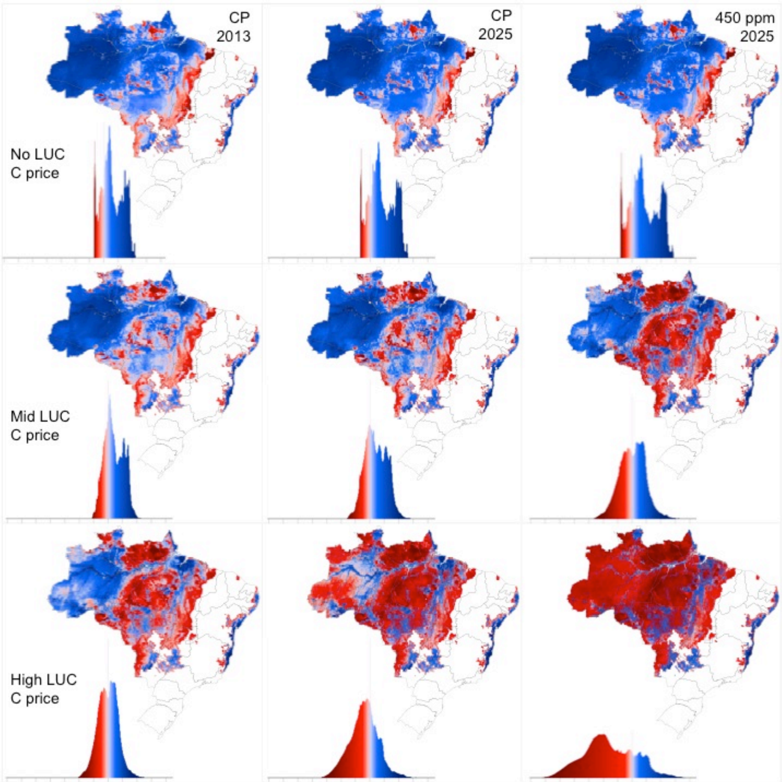

Figure 3: NPV of establishing new oil palm plantations for biodiesel production in selected scenarios, representative of the variation in results. Red indicates negative NPV and blue indicates positive NPV. Colours are darkest near the max/min values and lightest near zero. Scenarios: IEA 'Current policies' scenario (2013); IEA 'Current policies' scenario (2025); IEA '450 ppm' scenario (2025). Three levels of LUC carbon prices are shown for each scenario.

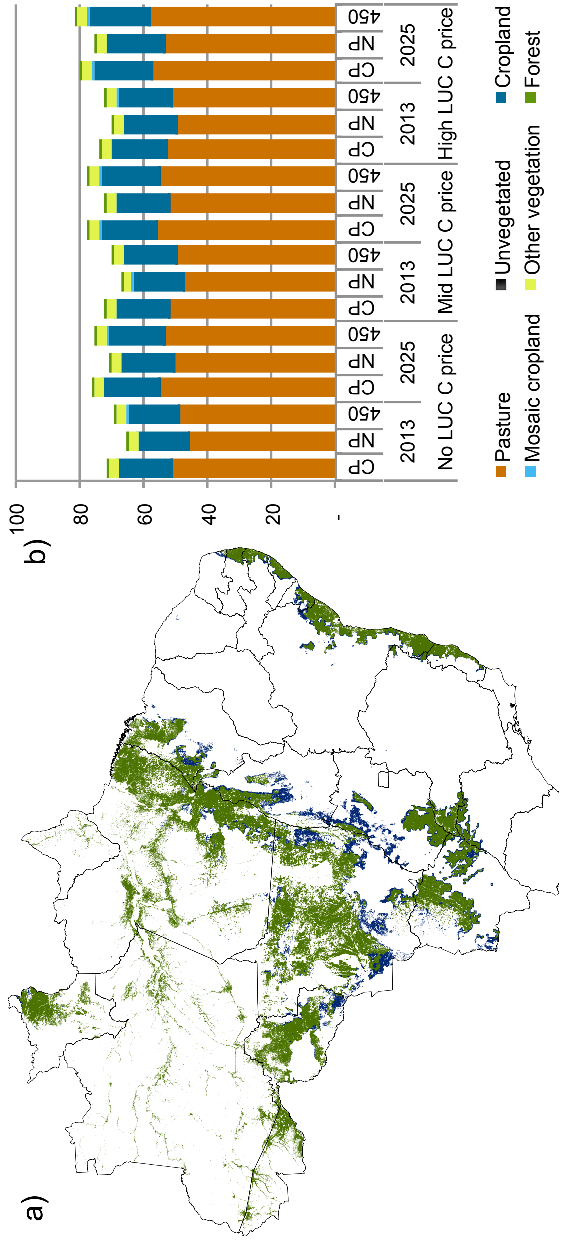

Figure 4: Areas where establishment of new oil palm plantations would (1) be profitable; (2) increase carbon stock; and (3) not impinge on land classified as HCV. a) shows the spatial distribution of this land in the scenario with the lowest potential (green) and highest potential (green + blue); b) shows quantified results for all scenarios aggregated in six LULC classes.

Chapter 4

Discussion and Outlook

Papers I and II contribute to the understanding of how bioenergy governance can be improved to better safeguard sustainability, and **Paper III** adds to the knowledge of biomass potentials and trade-offs. However, many challenges remain. Below, I discuss a few of particular interest for future studies.

Voluntary certification schemes involving third-party audits are generally believed to be essential to ensuring bioenergy sustainability (Stupak et al. 2013). Yet only 14% of global palm oil production and only 10% of the world's forests are certified (Fernholz & Kraxner 2012). Certified wood pellets also constitute a small proportion of the global trade (Goh et al. 2013). The majority of biomass that is produced is thus regulated mainly by national legislation. In regions with strong governance this may be sufficient; regulation can be strong, and may have impact at larger scales as well as be more cost efficient than extra-governmental control. In such cases, certification may add cost without any real benefits, unless an effort is made to reduce redundancy to cut unnecessary costs. However, voluntary certification is often more ambitious than legislation, more adaptable to regional differences and new knowledge, and can engage stakeholders better (Stupak et al. 2013). In addition, in regions with weak legislation and low capacity for enforcement, certification may be the only option for guiding and verifying sustainable biomass production. In such regions the local demand for sustainable products is often low, and certification is unlikely to be rapidly introduced without foreign demand. This prompts two basic questions:

1) To what extent can a strong legal framework in individual countries suffice to safeguard sustainable production of biomass for energy?
2) How can certified production reach a more significant scale, especially in countries with a weak legislative framework?

In pursuit of answers to the questions above, a first explorative study has been initiated on individual countries' legislative readiness to produce sustainable bioenergy, by assessing how their environmental legislation covers the main concerns about bioenergy raised in the EU RED. Also, their capacity for enforcing legislation is assessed by combining globally applicable indexes, which together indicate their general potential for enforcing legislation.

Paper III presents new insights in the potential, and corresponding trade-offs, of producing oil palm for biodiesel in Brazil and explores the effectiveness of a price on LUC carbon emissions in steering production away from forests and HCV areas. There is, however, a large need for further understanding of the extent to which biomass can be used for energy purposes, as well as the trade-offs involved in different feedstock types and production systems. The model developed for this paper can, and most likely will, be used in future studies to further add to this understanding.

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