Sustainability of bioenergy chains: the result is in the details

Duurzaamheid van bio-energieketens: het resultaat zit in de details

(met een samenvatting in het Nederlands)

Sustentabilidad de las cadenas de bio-energía: el resultado está en los detalles

(con un resumen en Español)

Proefschrift

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Chapter 1: Introduction

1. The need for transition to sustainable energy resources

Global use of modern biomass energy is in its infancy, especially in the transportation sector. Recently, various aspects of the production and use of bioenergy, especially so-called first-generation biofuels, have been criticised and debated in the scientific and non-scientific literature (Henke *et al.* 2005; Patzek *et al.* 2005; Charles *et al.* 2007; Escobar *et al.* 2008; Moore 2008; Rabbinge 2008a). Food commodity prices increased sharply between 2004 and the summer of 2008, and many analysts and commentators pinpoint the market development of biofuels as one of the main causes (BBC 2007; Wroughton 2008), a key factor allegedly being the subsidised production of biofuels in the European Union and the United States (Monbiot 2005; Ferrett 2007). In addition, some attribute deforestation in Malaysia and Indonesia, as well as conversion of the Brazilian Cerrado and Amazon into sugarcane and soybean fields, to the accelerating demand for biodiesel. Furthermore, it is claimed that this may lead to changes in carbon storages (Fargione *et al.* 2008; Searchinger *et al.* 2008). Moreover, it is asserted that the N_2O release related to energy crop production may largely negate the global warming reduction achieved by using biomass instead of fossil fuels (Crutzen *et al.* 2008). Biofuels including palm and soybean oil are therefore not considered climate neutral with respect to greenhouse gas (GHG) emissions. On the contrary, some are believed to result in greater emissions than their fossil counterparts. All in all, and especially when considering serious concerns that the production and use of bioenergy resources will cause depletion of water resources and soils, critics regard the increased use of bioenergy as a highly dubious strategy to stimulate sustainability and mitigate global warming.

At the same time, it is expected that the global population will reach approximately nine billion around the year 2050 (UNPD 2006). Economic development is also expected to increase substantially over the next few decades. These trends imply that demand for energy, food and other natural resources will increase substantially over the next 100 years (UN 2005), which raises the following worldwide concerns.

Firstly, atmospheric concentrations of GHGs are increasing sharply, the largest contributor being combustion of fossil fuels (IPCC 2007a). Land-use changes due to deforestation and various developments in the agricultural sector are the second most important contributor (IPCC 2007a). In order to stabilise the atmospheric concentrations at sustainable levels, GHG emissions must be reduced drastically in the coming decades — to less than half of the global emissions in 1990 (IPCC 2007a).

Secondly, fossil fuel resources are limited and dwindling. In the coming decades it will become increasingly difficult and costly to extract these resources (OECD/IEA 2007; OECD/IEA 2008a). Furthermore, the available oil, coal and natural gas reserves are unequally distributed around the globe (IEA 2006a). Total commercial energy use is currently about 450 EJ per year and is expected to double or triple before the end of this century, assuming ‘business as usual’ (BP 2008; OECD/IEA 2008a). The unequal distribution, the dependence of many countries on imports, and the growing demand are expected to result in mounting geopolitical tensions and conflicts over these reserves.

Thirdly, the global demand for food (especially protein) is expected to increase in the coming decades. This will put mounting pressure on natural resources and the available agricultural land. As most (70%) of the world’s poor live in rural areas and depend on agriculture for their livelihoods, an expanding and increasingly efficient agricultural sector is crucial for sustainable poverty reduction (FAO 2005). As 80% of people without electricity live in rural areas of the developing world (IEA 2002), access to affordable and reliable energy, preferably locally generated, is a second basic necessity for rural poverty reduction (Turkenburg *et al.* 2000).

To summarise, for the coming decades and beyond there is a great necessity to reduce GHG emissions and ensure energy security, especially in rural areas in developing countries, without compromising other needs, including maintenance of food and water supplies and biodiversity. Major transitions are needed to reverse current trends and achieve greater sustainability. It is generally recognised that no single sector or technology can address the entire challenge of meeting the increasing demand for energy supplies while mitigating climate change. Therefore, it is necessary to develop a diversified portfolio of available options and to implement all those that can contribute to sustainable development (IPCC 2007a).

2. Bioenergy and its contribution as a renewable energy source

Of the currently available options, many consider bioenergy to be important, because of its substantial growth potential (IEA Bioenergy 2007; IPCC 2007a; OECD/IEA 2008a; OECD/IEA 2008b). In contrast with fossil fuels, use of biomass for energy (i.e. bioenergy) has the potential to reduce GHG emissions, but only if the biomass is sustainably produced (Dornburg *et al.* 2008b). It is a versatile energy source; it can be used to produce heat and power as well as solid, liquid and gaseous fuels. Due to rising prices of fossil fuels and decreasing production costs of modern bioenergy carriers, the competitiveness of bioenergy has improved considerably over the past ten years. Hoogwijk *et al.* (2009) estimate that, by the year 2050, primary bioenergy could supply 130 to 270 EJ at a cost of less than 2 US$ per GJ. This is roughly half the price of coal-fired energy (approx. 4.4 US$/GJ) that is projected by IEA for the year 2030 (OECD/IEA 2008a). Most countries already have a variety of available biomass energy resources or could develop a potential resource. This is an energy supply option that is far more evenly distributed around the globe than oil, coal or natural gas. Another advantage of bioenergy is that its production can contribute to rural development by generating incomes and investments in rural areas where the biomass is produced (Smeets *et al.* 2007). For all these reasons, modern bioenergy is a key option in many countries’ energy policy and its use is projected to increase considerably in the next few decades (REN21 2008).

Bioenergy is currently the most important *renewable* energy source. In 2005 it accounted for about 10% of the world’s primary energy use of approximately 500 EJ per year (commercial and non-commercial), while hydro-energy accounted for about 5%[1] and other renewable energy sources for less than 1% (IPCC 2007b). Traditional bioenergy use – that is, combustion of solid biofuels for cooking, heating and lighting – constitutes approximately 80% of the total worldwide bioenergy consumption and is concentrated in developing countries (IEA 2006a; IPCC 2007b). Modern bioenergy use – that is, commercial production of energy from biomass for heat, power generation and transportation fuels – is much lower, but still significant, at 9 EJ per year (1.8% of total worldwide primary energy use) and growing rapidly (IEA 2006a; IPCC 2007b; OECD/IEA 2008a).

Worldwide, it is estimated that 45 GW of biomass-based power production capacity and 235 GWth of heat production capacity had been installed by the end of 2006 (REN21 2008). Biomass combustion for heat and power accounts for over 90% of the current production of secondary energy carriers from biomass. Biofuels – mainly ethanol and to a far lesser extent biodiesel – account for approximately 1.5 EJ (about 1.5%) of transportation fuel use worldwide. Global ethanol production has more than doubled since 2000, while the production of biodiesel, starting from a much smaller base, has undergone a manifold expansion. In contrast, crude oil production has increased by only 7% since the year 2000 (WWI 2007). Several studies project that the use of modern bioenergy will increase rapidly over the next few decades; estimates for the year 2050 range between 100 and 400 EJ (Turkenburg *et al.* 2000; IPCC 2007b; Dornburg *et al.* 2008b; OECD/IEA 2008a).

3. Biomass resources and a well-functioning biomass market

For the expected demands for bioenergy to be sustainably met in the coming decades, crucial pre-conditions are sufficient biomass resources and a well-functioning biomass market that can assure reliable, affordable, lasting and environmentally sound biomass supplies. Various countries, including Brazil, Canada, Finland, the Netherlands and Sweden, have gained considerable experience in building biomass markets (Faaij *et al.* 2005). In 2005, trading in biomass ethanol accounted for an estimated 10% of the worldwide ethanol consumption, Brazil being by far the leading exporter (Walter et al. 2007). In 2006, Canada produced about 1.2 million tonnes of wood pellets, of which a high proportion was exported to Europe. An estimated 0.7 million tonnes of Canadian wood pellets were used to fuel European power stations (Peksa-Blanchard *et al.* 2007). International trading in biofuels and related feedstocks may provide win-win opportunities to the national partners involved: for many importing countries, it is a pre-condition for meeting their self-imposed energy targets; for exporting countries, especially small and

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[1] The IPCC expresses the amount of electrical energy that is generated hydro-electrically, by wind turbines and photovoltaically in terms of the quantity of fossil fuels that would otherwise be used to generate the same amount.

medium-sized developing countries, export markets are essential if they are to establish bioenergy industries (Zarrilli 2006).

An important requirement for a secure, long-term supply of biomass energy is the certainty that sufficient resources will continually be available. Several categories of biomass resource can be considered for evaluation: residues from forestry and agriculture, various organic waste streams and, most importantly, dedicated production of various types of biomass[2]. Eliminating the high and low extremes from potential estimates by Berndes *et al.* (2003), Hoogwijk *et al.* (2005) and Smeets *et al.* (2007) leads to the conclusion that forest residues could possibly supply 30-150 EJ and organic waste 5-50 EJ per year. Currently, some 14 million hectares of agricultural land are being used to produce biofuels, which represents approximately 1% of the entire cultivated land in the world (IEA 2007). The potential of biomass resources depends largely on the amount of available land, taking into account that the growing worldwide demand for food must be met, biodiversity protected, soils and water reserves sustainably managed and a variety of other sustainability requirements fulfilled. Because the greater proportion of the future availability of biomass resources for energy depends on all these conditions, it is impossible to present the future potential of biomass energy production as one simple figure.

The theoretical potential of biomass energy resources derived from energy crops grown on currently available agricultural land (arable and pastoral) is estimated to be 0-700 EJ per year up to and including 2050. A less extreme estimate, assuming that the technological progress projected for that period will materialise, is 100–300 EJ per year (Berndes *et al.* 2003; Hoogwijk *et al.* 2005; Smeets *et al.* 2007), which could be achieved without jeopardising the world's future food supply. A significant proportion (about 200 EJ in 2050) of this potential biomass production could be developed at low production costs (in the order of 2 €/GJ), assuming that this land is used for perennial crops (WEA 2000; Hoogwijk *et al.* 2005). Dornburg *et al.* (2008b) estimate that if only limited land is available – i.e. if large areas are excluded from biomass production in order to conserve nature, because water is moderately or very scarce, or because the land is severely degraded – only about 80 EJ/yr might be available from energy crops. Under the same circumstances, additional amounts of about 80 EJ/yr from agricultural and forest residues and about 60-100 EJ/yr from surplus forest growth are likely to be available.

In the same period, the potential from biomass grown on marginal and degraded lands, which have lower productivity and higher costs, is estimated to be about 100 EJ per year (WEA 2000; Hoogwijk *et al.* 2005). The potential contribution to biomass energy production of the huge area of degraded soils (about 10% of the global land area) has not yet been clearly assessed. Dornburg *et al.* (2008b) estimate that using severely degraded land for energy crops could increase the biomass potential by about 30-45%. Thus, the total potential could amount to 400 EJ per year, with energy crops making the largest contribution. This approximately equals the current fossil energy use of about 390 EJ per year (IEA Bioenergy 2007).

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[2] The analysis in this thesis is restricted to forestry and agriculture residues and dedicated biomass production on land, the latter having the main focus.

Promising world regions for biomass production are: (1) the Commonwealth of Independent States (CIS) and the Baltic States; (2) the Caribbean and Latin America; and (3) sub-Saharan Africa (Smeets *et al.* 2007; Hoogwijk *et al.* 2005). Together, Eastern Europe, the CIS and the Baltic States have an estimated bioenergy potential from energy crops of 50-220 EJ per year, according to Smeets *et al.* (2007), or 80-130 EJ per year, according to Hoogwijk *et al.* (2005). Hoogwijk *et al.* (2009) estimate the bioenergy potential of South and Central America to be 30-100 EJ per year, whereas Smeets *et al.* (2007) give a range of 50-220 EJ per year. All these figures are for the year 2050.

Smeets *et al.* (2007) show that the calculated biomass potentials depend largely on several underlying assumptions. A key assumption is increasing rationalisation of agriculture, especially in developing and transitional countries, i.e. countries changing from a centrally planned economy to a free market economy. There are opportunities for considerably higher productivities, which could more than compensate the growing demand for food. In addition, the development and deployment of perennial crops, which are characterised by high yields and energy contents, are of key importance in the long run. The ‘bottom-up’ approach taken by Smeets *et al.* (2007) to calculating the biomass potentials enables scenario parameters to be translated into changes in the key variables that determine the impacts of the production systems analyses.

4. Possible impacts and performance of bioenergy chains

The increasing biomass energy demand and production go hand in hand with growing concerns as to the performance of bioenergy chains, especially regarding their socio-economic and environmental impacts. Various studies demonstrate that using biomass to produce heat and electricity is competitive when cheap, or even that ‘negative-cost’ biomass residues or wastes are available (van Loo *et al.* 2002; WEA 2004; Ahrenfeldt *et al.* 2005; Faaij 2006; IEA 2006b; IPCC 2007b). However, biofuels such as rapeseed methyl-esther and ethanol from starch and sugar crops, grown in moderate climate zones, are unlikely to reach truly competitive price levels in the coming decades, despite continuing improvements in production efficiencies and yields (IEA 2004). In recent years, subsidies for the production of biofuels have been rapidly increased; in 2007, they were estimated to have reached about US$ 15 billion for the OECD as a whole (OECD-ITF 2007).

In some countries, including Brazil, the costs of producing ethanol were approximately equal to, or even less than, the cost of producing gasoline in 2006-2007 (Goldemberg 2007). This may soon occur in other countries as production costs continue to decline. In addition, new conversion technologies are being developed that make use of lignocellulosic feedstock, either derived from waste materials or grown as dedicated energy crops on a wide variety of land types (IEA 2006b). In the long term, the production of so-called second-generation biofuels – i.e. methanol, di-methyl esters (DME), hydrogen, methane via Synthetic Natural Gas (SNG), Fischer-Tropsch liquids, and ethanol produced from lignocellulosic biomass – offers much better prospects for competitive prices. Partly, this is due to lower feedstock prices and the versatility of producing lignocellulosic biomass under varying circumstances. Furthermore, (advanced) gasification and hydrolysis technologies still under development show potential for efficient and competitive biofuel production, which may involve co-production of electricity (Hamelinck *et al.* 2006).

If the cost targets for lignocellulosic production techniques are met, a new supply of biofuels will become available, with large resource availability around the world. In order to make bioenergy competitive with fossil fuels on a large scale, biomass production (especially from dedicated energy crops), conversion technologies and bioenergy infrastructures require further development and optimisation (IEA Bioenergy 2007).

Governments, NGOs and international organisations now consider sustainable production and use of biomass resources to be a key requirement for market access in a growing number of countries (Zarrilli 2006; Cramer *et al.* 2007).

As previously indicated, the use of mainly first-generation biofuels has been heavily criticised because of their dubious potential to reduce GHG emissions. Recent studies have considered whether GHG emissions from indirect land clearance (Fargione *et al.* 2008; Searchinger *et al.* 2008) or N_2O release from energy crop production (Crutzen *et al.* 2008) could drastically diminish or even reverse the GHG emission reduction due to cultivation of energy crops. Many other studies, including IEA (2004), Armstrong *et al.* (2002), JRC (2004), Larson (2006), Farrell *et al.* (2006), von Blottnitz *et al.* (2007) and Wicke *et al.* (2009), have assessed the net GHG emission reduction potential of bioenergy carriers. On the basis of these results, analysts have concluded that bioenergy systems *can* reduce GHG emissions. However, some examples of bioenergy production systems have been found to increase GHG emissions, critical factors being the local conditions and land-use management systems involved.

The GHG emission reduction potentials of several first-generation biofuel production chains are fairly limited. Ethanol made from grain or sugar beet is estimated to have GHG emission reduction potentials of 20-40% or 35-55%, respectively (IEA 2004). The GHG emission reduction potential of biodiesel made from rapeseed is estimated to be 10-65% (IEA 2004; JRC 2004). These production chains are short-term alternatives for conventional production of transportation fuels. Second-generation biofuels made from perennial, lignocellulosic crops can offer GHG emission reduction potentials of approximately 70-110%; thus, these crops are generally more efficient than annual crops (IEA 2004; Larson 2006).

It should be noted that a set of assumptions determines the results of such studies. Net avoided GHG emissions depend on the reference system and the efficiency of the biomass production and utilisation chain. Other parameters that need to be considered are leakage effects, allocation of emissions to by-products and main products, trade-offs between GHG emissions and costs, carbon stock dynamics, up-stream energy inputs, efficiency of the energy systems, GHG emission factors of the various processing steps, and the permanence of GHG emission reduction (IEA-Task38 2008). The variability of calculated GHG emission results due to the complexities involved and the sensitivity of the results to the assumptions made is illustrated by authors including Gustavsson *et al.* (2002), Larijssen *et al.* (2008) and Wicket *et al.* (2009).

The environmental and socio-economic impacts of biomass energy production – for example, on biodiversity, water and nutrient content of soils, and local welfare – typically depend on local conditions and management. The large spatial variations in climate, hydrology, soil qualities and land availability demand a detailed and local analysis of the possibilities for, and impacts of, energy crop production (Dornburg *et al.* 2008b).

Scientific publications on the biodiversity effects of energy crop production draw wide-ranging and even contradictory conclusions. With a view to achieving formulated targets for biodiversity on a global scale (CBD 2006), various spatial scales and both short- and long-term effects of energy crop production must be taken into account (CBD and MNP 2007). On a local scale, biodiversity may benefit from energy crop production if intensive agricultural practices are replaced by low-intensity energy crop production systems (Dornburg *et al.* 2008b). On a global scale, however, agricultural lands may only become available if food production regions shift (for example, as a result of trade liberalisation) and if food productivity is increased. Thus, global biodiversity effects are closely related to land-use dynamics, and especially to the causes of abandonment of agricultural land (Dornburg *et al.* 2008b).

The future ability of the agricultural sector to supply food will strongly depend on the development of agricultural technology, protein production chains, and management and distribution systems. The future demand for food will depend on population growth, economic development and dietary changes. Although – technologically speaking – it seems feasible to produce enough food for nine billion people using less agricultural land (Evans 1998), to do so without compromising sustainability will present a formidable challenge (Tilman *et al.* 2002; Rabbinge 2008b). The demand for conventional energy crops to produce transportation fuels is expected to push up the prices of agricultural commodities (OECD/FAO 2007) and may reduce average food consumption in some world regions, including sub-Saharan Africa (IFPRI 2007). According to NEF (2008) and UDOP (2008), the contribution of biofuel production to the food-price inflation in 2004-2008 was 9% of the 58% grain price increase, 17% of the 54% food oils price increase and 3% of the 10% sugar price increase. Other significant drivers of food-price inflation are increasing input costs, changes in consumption habits and the growing global population (NEF 2008; UDOP 2008). Although the use of lignocellulosic crops does not directly compete with the production of food or feed, it may do so indirectly as a consequence of competition for land and other production means. Positive socio-economic impacts are, however, also possible. Energy crops can offer a new source of income and investments in the agricultural sector and may thus reduce poverty in rural areas of developing regions.

Therefore, in both socio-economic and environmental terms the production and consumption of biomass to fulfil energy needs is not necessarily sustainable. As most of the biomass energy potential must be developed through cultivation, a variety of sustainability criteria need to be met to avoid conflicts with food and feed production. In addition, GHG emissions and water depletion must be minimized, biodiversity conserved, soil and water quality maintained and socio-economic requirements met. It should be noted that rationalisation of agriculture can have beneficial effects. Furthermore, it is feasible to produce biomass on marginal and degraded lands that are unsuitable for production of food or feed, with possible ecological benefits (Dornburg *et al.* 2008b).

5. Recent initiatives to ensure the performance of bioenergy production chains

Various countries and stakeholder groups acknowledge that it is essential to ensure the sustainability of biomass energy production and trade in fast-growing markets. Possible strategies that have been worked on in recent years include developing sustainability principles, criteria, indicators and standards, as well as establishing biomass certification schemes.

Several European countries, including the Netherlands (Cramer *et al.* 2007), the UK (Bauen *et al.* 2007) and Germany (Fehrenbach 2008a), have recently taken initiatives to develop a bioenergy certification system, as well as principles and criteria to define sustainable biomass energy production and trade. The European Commission is currently developing sustainability criteria to be laid down in a European bioenergy certification system. In the context of these initiatives, GHG emission reduction is regarded as an important criterion for guaranteeing sustainable production and utilisation of biomass resources. The European Commission has proposed stipulating a GHG emission reduction due to the use of biofuels and other bioliquids of at least 35% (EC 2008). In late 2008, the European Parliament proposed a stricter GHG emission reduction of 45% (EUBIA 2008). Methods and models for calculating GHG balances are currently being developed at national and EU levels (Cramer *et al.* 2007; Bauen *et al.* 2007; Fehrenbach *et al.* 2008; Fehrenbach 2008a; EC 2008).

The need to ensure sustainable biomass production through proper procedures and policies is also acknowledged by various international bodies, such as the International Bioenergy Platform of the FAO (FAO 2006), the G8 Bioenergy Partnership (GBEP 2008), the WTO (WTO 2008) and the UNCTAD (UNCTAD 2002). Discussion of issues related to the production of biofuels and commodities including palm oil, soybeans and sugarcane (all of which can be used as biofuel feedstock) have triggered initiatives such as the establishment of roundtables at which all stakeholders in the production chain are represented. The Roundtable on Sustainable Biofuels (RSB 2008a) recently released a draft version of principles and criteria for sustainable biofuels. In addition, various NGOs including the WWF (WWF 2006), Birdlife (Birdlife-International 2005) and Solidaridad (Solidaridad 2006), as well as companies including DaimlerChrysler (DaimlerChrysler 2006) and Shell (Voss 2004), have launched a range of initiatives (i.e. pilot projects, policy papers and working groups) to realise more sustainable biomass production chains.

Among the countries and stakeholders that are developing biomass certification systems there is general consensus that it is important to include economic, social and environmental criteria in evaluating the sustainability of bioenergy projects. However, differences are also evident in the strictness, extent and level of detail of these criteria, reflecting diverse interests and priorities. In addition, there are matters of content to be resolved, such as the precise formulation of sustainability principles and criteria and the selection of indicators related to these criteria. This process is highly complex, because many stakeholders are involved and a large number and a wide variety of biomass production systems and settings have to be taken into account. Other questions that are arising concern market governance. For example, the question of how to safeguard the sustainability of biomass energy production is still open. Fundamental choices have to be made on the issues of how criteria and standards of sustainable biomass production and supply can be determined, implemented in the market, and policed by authorities.

6. Objective, research questions and outline of thesis

The main objective of this thesis is to provide an understanding of how the feasibility and sustainability of large-scale production, supply and use of bioenergy can be determined *ex ante*. This is addressed in the context of bioenergy for local use or trading on a regional level, taking account of the complexities and variabilities of underlying factors such as food demand and land use.

To this end, the following research questions have been formulated:

I. How can areas be selected *ex ante*, within specific world regions, that offer good short- and long-term prospects for biomass energy production, taking into account biological and climatic limitations, human food and animal feed demand, the need to maintain forests and biodiversity, and agricultural, environmental and energy policy directions?
II. How can the economic performance of large-scale biomass energy production and trading systems be determined for specific regions?
III. What initiatives are currently being taken in biomass energy certification and, more specifically, in the development of principles, criteria, indicators and methodologies to determine impacts and guarantee sustainable biomass energy production for a wide range of regions and biomass sources?
IV. What are the possibilities and limitations of adopting a unified approach to defining sustainable biomass and bioenergy production for a wide range of regions and biomass sources, focusing on calculation of GHG emission reductions?
V. How can the environmental and socio-economic impacts of a particular bioenergy chain be assessed *ex ante* with respect to various land-use scenarios?

These research questions are addressed in Chapters 2 to 8, as indicated in Table 1.

Table 1: Overview of which research questions are addressed in each chapter of this thesis.

Chapters	Research questions				
	I	II	III	IV	V
2	●	●			
3	●	●			
4		●			
5			●	●	
6				●	●
7				●	●
8	●	●	●	●	●

Chapter 2 assesses the potential of bioenergy resources in Central and Eastern European countries (CEEC), a world region with a promising biomass potential. The biomass resources considered are agricultural and forestry residues, wood from surplus forest and biomass from energy crops. Cost levels are analysed for short- and long-term production of biomass from various resources (i.e. energy crops and residues) using various production systems. The results of this analysis are presented as cost-supply curves.

Chapter 3 focuses on the short- and long-term potential, in a promising area of Argentina, of large-scale production of biomass for local use or export to Europe. The resource considered is biomass from energy crops; i.e. switchgrass, which is converted into pellets for heating or electricity production, and soybeans, which are converted to biodiesel. The short- and long-term economic performance of these bioenergy chains is calculated using cost levels for various production and logistical systems, in order to gain insight into the economic feasibility and possible limitations of large-scale biomass energy production in this world region.

Chapter 4 assesses whether biofuels trading from the CEEC to the Western European market would be profitable enough to ensure a supply of biofuels. The approach taken is to estimate the cost performance of the energy carriers (pellets from willow, or ethanol) that would be delivered.

Chapter 5 gives a comprehensive overview of initiatives in bioenergy certification taken as of October 2007, from the viewpoint of various stakeholders, including governments, NGOs, companies, and international bodies. Five different governance approaches to implementing a biomass certification system are compared and discussed. Recommendations are made for further development of certification. In this context, special attention is given to the issue of GHG emissions due to bioenergy systems, as discussed in Chapter 6.

Chapter 6 analyses the possibilities and limitations of adopting a unified approach to estimating the GHG reduction potential and cost-effectiveness of a wide range of biomass energy technologies. A unified methodology and a user-friendly software tool are used to assess GHG balances and cost-effectiveness of the various biomass energy systems.

Chapter 7 estimates the socio-economic and environmental impacts of large-scale bioenergy production from switchgrass and soybeans on a regional level in Argentina. It also investigates to what extent regional impacts of the development of such production capacity can be analysed *ex ante*, using available methodologies and data sources.

Chapter 8 summarises and evaluates all the results from Chapters 2 to 7, highlighting the possibilities and limitations of determining *ex ante*, on the regional level, the feasibility and sustainability of large-scale biomass energy production for local use or trading, taking into account the complexities and variabilities of the underlying factors involved. Conclusions are drawn with respect to the main research questions of this thesis (see above). Also, some recommendations are made for future research and policy development.

Chapter 2: Biomass production potentials in Central and Eastern Europe under different scenarios[3]

Abstract

A methodology for the assessment of biomass potentials was developed and applied to Central and Eastern European countries (CEEC). Biomass resources considered are agricultural residues, forestry residues, wood from surplus forest and biomass from energy crops. Only land that is not needed for food and feed production is considered as available for the production of energy crops. Five scenarios were built to depict the influences of different factors on biomass potentials and costs. Scenarios, with a domination of current level of agricultural production or ecological production systems, show the smallest biomass potentials of 2–5.7 EJ for all CEEC. More favourable scenarios show a highest potential of 11.7 EJ (85% from energy crops, 12% from residues and 3% from surplus forest wood) when 44 million ha of agricultural land become available for energy crop production. This potential, however, is only realizable under high input production systems and most advanced production technology, best allocation of crop production over all CEEC and by choosing willow as energy crop. The production of lignocellulosic crops and willow in particular, best combines high biomass production potentials and low biomass production costs. Production costs for willow biomass range from 1.6 to 8.0 €/GJ HHV in the scenario with the highest agricultural productivity and from 1.0 to 4.5 €/GJ HHV in the scenario reflecting the current status of agricultural production. Generally the highest biomass production costs are experienced when ecological agriculture is prevailing and on land with lower quality. In most CEEC, the production potentials are larger than the current energy use in the CEEC in the more favourable scenarios. Bulk of the biomass potential can be produced at costs lower than 2 €/GJ. High potentials combined with low cost levels give the CEEC major export opportunities.

1. Introduction

Nearly two-thirds of renewable energy sources (RES) in the European Union (EU) originate from biomass, including waste (Fischer *et al.* 2001). For the near future, increasing biomass use is considered to be essential in meeting the targets set out by the EU (Faaij 2006). Besides, biomass can—unlike wind or hydropower—be used as RES in the transport sector. Biomass sources are wastes, energy crops, agricultural residues or residues from forests. The utilization of energy crops in the near future is uncertain, but on the longer terms potentially the largest contributor to bioenergy production. As the potential

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[3] Published in Biomass and Bioenergy (2007), volume 31, issue 6, p.345-366. Co-authors are: Andre Faaij (Utrecht University), Iris Lewandowski (Utrecht University, Shell), and Günther Fischer (International Institute for Applied Systems Analysis).

from residues and wastes is already utilized to a high degree in the EU, a further growth in biomass production should come from energy crops (Faaij et al. 2003). Since June 2003, the growing of crops as renewable energy is encouraged in the Common Agricultural Policy (CAP) reforms by promoting the use of energy crops on fallow land and in the form of subsidies (DG Agriculture 2004).

A large increase in energy crop production requires large land areas in the EU. However, the resources of good quality land area is limited and the production of biofuels will compete with food production and demands from the forest industry as well as from environmental protection and conservation considerations. Furthermore, an extension of biofuel production will only occur when their prices can compete with those of fossil fuels. Low costs for biofuel options are therefore needed in the future. At the same time, the ongoing expansion of the EU and the inclusion of the Central and Eastern European Countries (CEEC) in agricultural and energy EU policies create potential. Agriculture plays—and is expected to play in the mid term—an important role in the CEEC (Baum *et al.* 2004). Besides this, the share of employment in the agricultural sector is still large (Baum *et al.* 2004).

In the future, ongoing rationalization of agriculture in the CEEC is expected. This will lead to increased productivity and economic performance. On the other hand, unemployment and an increase in abandoned land are expected as well. This can put high pressure on the socio-economic developments in rural areas in the CEEC. Several countries in the CEEC region are characterized by large land resources, comparatively low labour and agricultural production costs and relatively low productivity compared to Western European countries (WEC), see e.g. (EUROSTAT 2003a; Lewandowski *et al.* 2006a). Using potential surplus land in the CEEC for biomass production could provide economically interesting biomass supplies and in the same time offer an alternative economic activity to rural regions affected by changes in agriculture. Whether this concept is feasible and to what extent such targets could be obtained by trading biofuels between Eastern and Western Europe, has never been investigated.

Several national institutes and universities or other European (inter-) national organizations have already studied bioenergy potentials and supply and demand of bioenergy in the CEEC countries (Fischer *et al.* 2001; Roman 2000; Fenyvesi *et al.* 2000; MZP 2003; Rogulska *et al.* 2003; Senter Novem 1997; Fischer *et al.* 2004). These studies, however, only give a rough picture of the possible bioenergy potential in these countries and do not address potential land-use changes over time. Therefore, these studies do not allow for an adequate and comprehensive research on the possibilities of trading biofuels from CEEC to WEC. Most of the studies are based on country statistics for agriculture and forestry and give limited information about the methodology used.

A unified methodology is, however, required for a good analysis of the biomass potential results to make comparisons between countries and regions in the CEEC. Apart from Fischer *et al.* (2001) and Fischer *et al.* (2004) most studies are performed on a national level. In reality, there will be differences in cost levels, productivity and availability of land between the regions within the CEEC. A regional biomass assessment—instead of a study on a country level—is therefore needed to identify the differences at this level of detail. Most studies give no or little attention to energy crop production in the CEEC. The reason given in these studies is that energy crop production is considered as not feasible or too expensive at this moment.

However, this can change in a short time when EU countries need to fulfil the targets of the EC Biofuels Directive (which sets as reference values a 2% market share for biofuels in 2005 and a 5.75% share in 2010) (EC 2003a) and with increasing prices for fossil fuels. It is also known that such crops can represent a much larger potential than residues and forest wood (Hoogwijk *et al.* 2005; Smeets *et al.* 2007). Therefore, energy crop production should be included in the biomass potential assessment. Only the studies (Fischer *et al.* 2001; Fischer *et al.* 2004) relate the biomass potential with the land-use in the CEEC. However, these studies do not take into account that production and demand of food products have their influence on the size of the agricultural area available: a change in food demand (e.g. cereal demand) is important as it influences the land area required for food production. Changes in production and demand should thus be included when assessing land-use patterns in a country.

Policies on demand for food and energy change over time; this has a large impact on the available biomass as well. An important requirement for a secure long-term trade of biomass resources from CEEC to WEC is the certainty that sufficient resources are available in the long term for a constant supply. Therefore, the biomass potential assessment should not only look at the present situation but should also include future trends by the use of scenario analysis. Only the Czech (MZP 2003) and Hungarian (Fenyvesi *et al.* 2000) studies show some trends in supply and demand of biomass resources to 2010. The other studies focus on the present situation in the CEEC. Finally, no studies, including the studies from the studies (Fischer *et al.* 2001; Fischer *et al.* 2004), combine cost levels with a biomass potential study. However, this is—as also mentioned by (Weger *et al.* 1998) —an important barrier (or driver) for further development of biomass production. Cost relations should therefore be included in the analysis as the biomass production as trade will only be feasible when this concept is profitable for the stakeholders in the CEEC.

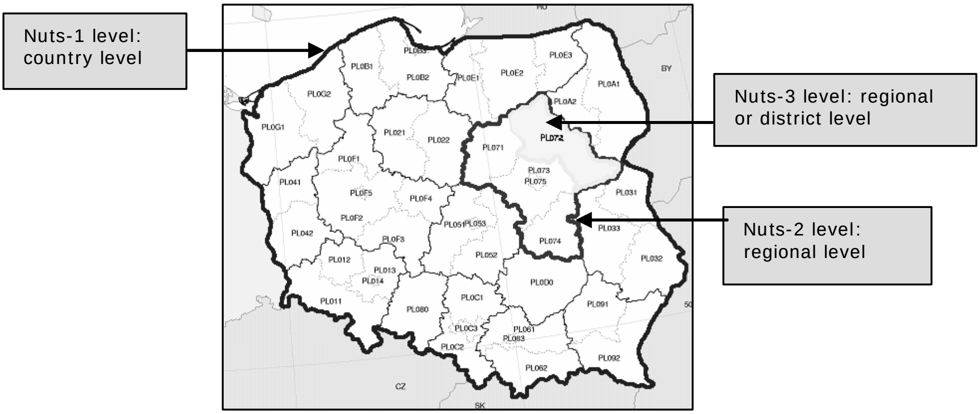
The conclusion is that a unified methodology is missing to compare the results of the biomass potential assessment for the CEEC on a regional, national and international level. Another problem is the lack of attention to land-use, policy and demand changes over time, which can be included in scenarios. There has been only limited research on the costs and prices of biomass, although this is and can be an important barrier for the development of biomass production in the CEEC.

A key question in this study is whether the bioenergy potential in the CEEC is indeed large enough to supply biofuels to the European market and under what conditions such potentials can be developed. The aim of this study is therefore to implement a biomass potential assessment on a regional level for the CEEC, which is based on scenarios. Land-use changes over time are included in the analysis and impacts of policy choices can be assessed. As cost levels for biomass production need to be included in the analysis, final deliverables are the cost–supply curves from different resources (energy crops, residues) under different production systems for the CEEC in relation to the scenario conditions.

2. Methodology

The regional biomass potential assessment is implemented for the CEEC Estonia, Lithuania, Latvia, Poland, Romania, Bulgaria, Hungary, Czech Republic and Slovakia. This study uses a standardized methodology to assess the biomass potential of the CEEC. The methodology is based on the study from Smeets *et al.* (2007), which is a bottom–up approach to assess the global biomass potential on a country-to-country basis. The methodology from Smeets *et al.* (2007) is applied on a so-called NUTS-3 region level (see figure 1). NUTS stand for 'Nomenclature of Territorial Units for Statistics' and are the statistical regions of Europe and the Accession Countries (EUROSTAT 2002). NUTS-3 regions are regional or district levels within a country (EUROSTAT 2002).

Figure 1: Map of Poland showing NUTS-1, -2 and NUTS-3 regions. NUTS-3 regions are the level of detail for the biomass potential assessment in the CEEC in this study.



A general overview of the methodology of the regional biomass potential assessment is given in figure 2. The total available biomass potential in a NUTS-3 region is the sum of biomass from energy crops, wood from surplus production forest, agricultural and forest residues. The regional biomass potential assessment is based on land-use changes over time for a set of scenarios. A scenario, with a defined set of parameters, requires a certain demand for food and forest products. A certain area of agricultural land and forestland will be needed to meet this demand. The size of this area will depend on (1) demand and (2) the defined production system (yield or productivity levels), see figure 2. The current land minus the required future land for crop, livestock and wood production gives the possible surplus available land for biomass production, which can be used for energy crop cultivation.

The amount of biomass from energy crops is calculated by multiplying the available land for energy crops with the productivity data for energy crops. The available land for the energy crop depends on three different factors (Hoogwijk *et al.* 2005; Smeets *et al.* 2007):

- Demand for food and forest products: only surplus land that is not needed to fulfil the food and wood demand is available for the production of energy crops (see Section 2.1);
- The productivity of the selected agricultural production system (see Section 2.2);
- Allocation procedures defining which land quality is used for each crop and the extent and geographic scope (e.g. regional, country level or beyond) considered to which land-use patterns are allowed to change (see Section 2.3).

Table 1 gives an overview of data sources in this study.

Figure 2: General overview of the main components of the methodology for the biomass potential assessment.

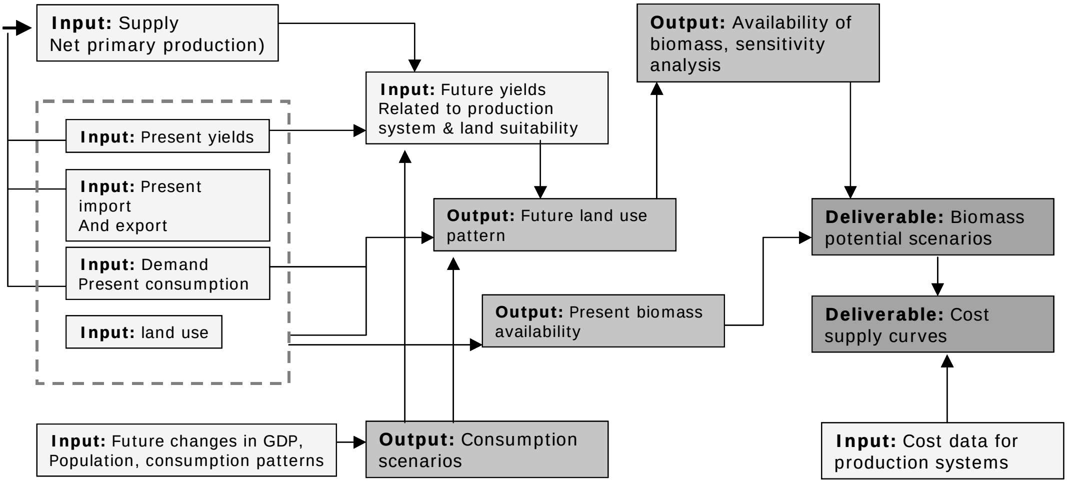


Table 1: Data sources used for the regional biomass potential assessment.

Data need	Kind of data	Source
Demand for food production	Current food production, crop yields and related land-use on NUTS-3 region level in CEEC (1995-2000)	(EUROSTAT 2003b). Expert judgements (Weger 2004; Rogulska *et al.* 2004; Roman 2004; Raconczga 2004a)
	Future food demand and production	(Boedeker 2003)
Demand for wood production	Forest demand, supply and trade on country level to 2030	(Kangas *et al.* 2004)
	The total required round wood production to the year 2020	(UN-ECE 2004)
	Total required removals to meet calculated demand round wood	(Schelhaas *et al.* 2004)
Livestock productivity	Feed conversion efficiency (ton feed / ton meat), carcass weight	(Bouwman *et al.* 2003; RIVM 2001; DG Agriculture 2001)
Productivity data for agricultural crops	Potential productivity data and land suitability data for a selected range of crops[1] for the high input (HI) rain-fed production system	(Fischer 2004)
	Yield and land suitability data for other crops than listed in[1]	(Fischer 2004; IIASA 2002; FAO 2000; Poostchi 2001; FAOSTAT 2004)
	Productivity of permanent grasslands on land with different suitability and under different production systems	(Hamnett 2003; Královec 2003; Selge 2003; Breymeyer (ed.) 1990; Lee 1998; Géza 1995; Bouwman 2004). Expert judgements: (Weger 2004; Roman 2004)
	Maps and information on irrigated areas	(Roman 2004; Raconczga 2004a; IIASA 2002; FAOSTAT 2004; Siebert *et al.* 2002)
Productivity data for forestry	Productivity data for forestry	(Weger 2004; Roman 2004; Schelhaas *et al.* 2004; UN-ECE 2000; UN-ECE 1996)
	Ratios felling / ha, removal / ha	(Schelhaas *et al.* 2004)
Cost data for energy crop production	Land rents	(Weger 2004; Roman 2004; DG Agriculture 2003; Estonian Land Board 2003; Prosterman *et al.* 2003; Trivelli 1997; Dumitru 2002; Kopeva 2002; Burger 1998)
	Wages	(Weger 2004; Raconczga 2004a; ILO 2000)
	Costs for fertilizers (N, P and K)	(FAOSTAT 2004; DG Agriculture 2003), national information sources : (Weger 2004; Rogulska *et al.* 2004; Roman 2004; Raconczga 2004b)
	Required input levels N, P, K	(Kaltschmitt *et al.* 1997)

[1] Selected crops received from (Fischer 2004). Personal communication: data received on 50x50 km grid cell for CEEC based on AEZ methodology. are: wheat, grain maize, potato, sugar beet, rapeseed, sunflower, “other cereals”, “total cereals”, silage maize, willow, poplar and miscanthus.

2.1. Food demand and demand for forest products

The food demand is calculated as the sum of domestic utilization, import and export rate. The domestic utilization of food in a country is largely influenced by its population growth and GDP. The FAO projections (Boedeker 2003) form the basis for this calculation of the estimated required food production in the CEEC countries. The projections for required food production and demand (crop and meat products) are available for the years 1997–1999, 2015 and 2030. FAO projections were used because they are developed for the long term (to 2030), are available on country level and provide a consistent database for all CEEC. These parameters are adapted for the set of defined scenarios (see table 3) if assumptions differ largely from the assumptions of the FAO projections.

The required amount of forest products is related to the domestic consumption of forest products, import and export in a country. The consumption of forest products is strongly related to the growth of GDP in a country. Information about the amount of required forest products (sawn wood, wood based panels and paper board) is related to the amount of required roundwood that is needed to produce these forest products. In this study the EFSOS scenarios (Kangas *et al.* 2004; UN-ECE 2004; Schelhaas *et al.* 2004) are translated to the set of five developed VIEWLS scenarios that are used in this regional biomass potential assessment.

2.2. Productivity

The level of productivity in forest, livestock or crop production is one of the main parameters in the scenarios for the regional biomass potential assessment. An important factor for the level of productivity is the selected production system, which is characterized by its management practices. We will discuss these characteristics for crop, livestock and forest in the following sections.

2.2.1. Livestock productivity: feed conversion efficiency

The feed conversion efficiency FCE (tonne feed/tonne meat) is an indicator for the productivity level of a livestock production system. Meat production divided by the FCE gives the required animal feed that is needed to perform the calculated livestock production. Livestock production systems differ in their production process. FCE levels are higher for pork and poultry compared to beef or sheep production. Livestock production systems require considerable amounts of animal feed, consisting of food crops, crop residues and crop by-products, fodder crops and grass. Increases in the FCE have an impact on the required crop production in a region because less feed production is required for the same amount of meat production. Furthermore, a more intensive livestock production system requires in general more concentrated feeds (protein content) and feed grains.

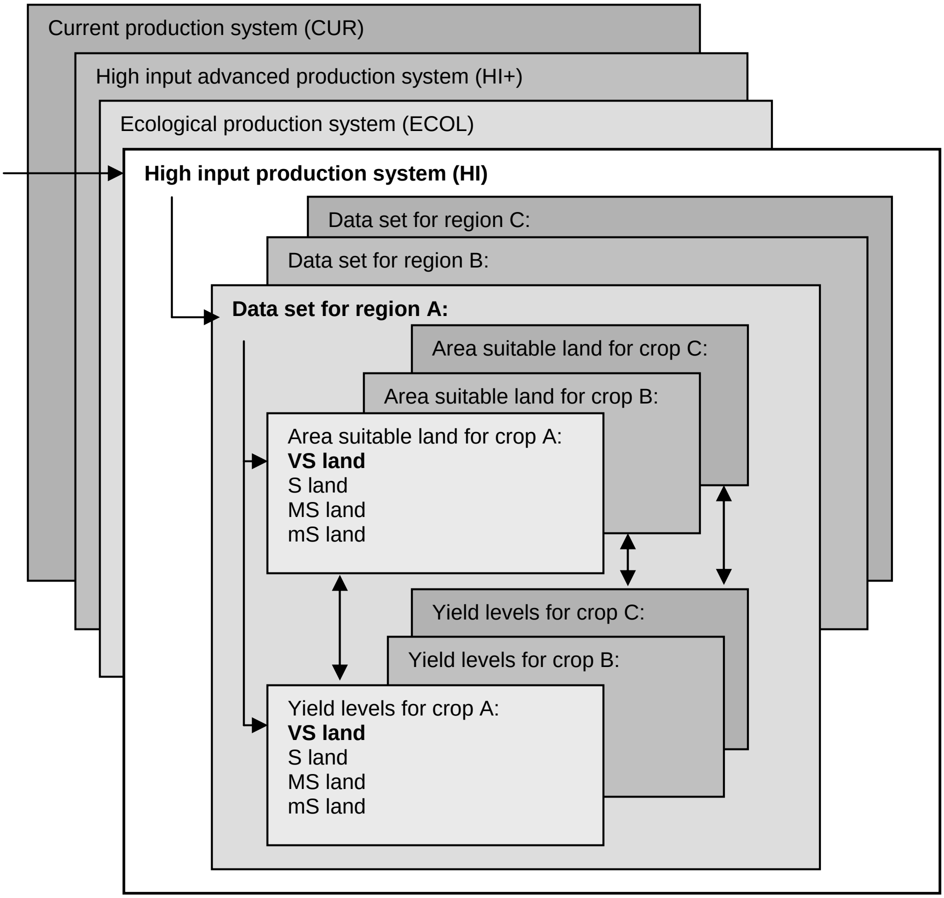
Not many data are available about FCE levels in the CEEC. Beside this, livestock productivity data are expressed in various units. Therefore, different sources were used to receive livestock productivity information (see table 1). In the IMAGE model (RIVM 2001) the FCE leads for all scenarios to the same end-value in 2090, which we assume to be the most efficient FCE that can be achieved. The only difference between the scenarios is in which year this most efficient FCE is achieved. Based on the data from RIVM (2001) and Bouwman *et al.* (2003) we have defined different levels of FCE on country level for the livestock production systems belonging to the VIEWLS scenarios. FCE levels are related to different feed fractions per scenario.

2.2.2. Productivity of agricultural crops: yield levels

The productivity of crops is determined by the agricultural production system and the land suitability on a NUTS-3 region level. The land suitability for a crop is determined by rainfall, temperature, soil quality and slope. Land suitability for a crop can have a strong variation in a geographical area. The production system is determined by management practices including the level of inputs, kind of machinery and technology used. For the regional biomass potential assessment we have developed an approach that enables us to show both the impact of the production system as well as the variation of land suitability classes on agricultural productivity levels in a region. Per production system (described below), we have developed a database with information about the area of suitable land and the related productivity levels per crop (see also figure 3). The land suitability classification per crop is based on the agroecological zone (AEZ) methodology from Fischer *et al.* (2000) and contains five different land suitability classes: very suitable land (VS), suitable land (S), moderately suitable land (MS), marginally suitable land (mS) and not suitable land (NS).

The data from Fischer (2004) provide potential productivity data and land suitability data for a range of selected crops (see table 1) for the high input (HI) rain-fed production system. The potential productivity is the productivity potentially achievable in a grid cell without management limitations (Fischer *et al.* 2000). The data are given in grid cells from 50 x 50 km. Each grid cell is linked to a grid cell number and a country number in an Excel database. As the selected level of detail in the model is the NUTS-3 region, grid cell data were converted to a NUTS-3 region level by estimating for each grid cell for which percentage it was situated in a selected NUTS-3 region. Data were not provided for all crops (Fischer 2004), yield and land suitability data for the other crops are derived from data sources listed in table 1. This database is used as a basis to derive yield levels and land suitability data corresponding to other agricultural production systems than the HI rain-fed production system. Table 2 describes the mean features of the various production systems used here in different scenarios (see also table 3 in Section 3). The following sections describe in more detail these production systems and how the yield levels for these production systems were derived.

Figure 3: Systematic overview of database in the VIEWLS model for land suitability and productivity data per crop for all NUTS-3 regions in the CEEC, for a set of defined agricultural production systems.



2.2.2.1. Current agricultural production system

The 'current agricultural production system' reflects the currently practiced agricultural management system in the CEEC. Average current yield levels are available from EUROSTAT (2003b) on a NUTS-3 region level. Further subdivisions of these yield levels to land suitability classes are not available from EUROSTAT (2003b), neither the dataset on land availability related to this production system. Therefore, the statistical yield data are compared with the calculated average yield levels, on data from Fischer (2004) and IIASA (2002), available for different agricultural production systems and land suitability classes. For the development of the dataset on the amount of available land for the 'current agricultural production system', the dataset from the production system is used, developed from Fischer (2004) and IIASA (2002), of which the yield levels where most comparable with the yield levels from the dataset from EUROSTAT (2003b). In practice, in most cases the low to intermediate intensive management system was used. For the development of a dataset of the yield levels for the 'current agricultural production system', the ratio between the average yield levels is calculated from EUROSTAT (2003b), Fischer (2004) and IIASA (2002) for the selected agricultural production system: [average yield level statistics / average calculated yield level] * [yield level specific land suitability class]. The ratio is used for the development of the yield levels for the different land suitability classes.

2.2.2.2. Ecological production system

The basic concept of the 'ecological production system' is that environmental risks or damages should be avoided. (FAO 2003) mentions that yield levels drop by 10–30% when high external input systems are converted to organic management. Yields do, however, not always fall when conversion starts from traditional low-input systems (FAO 2003). Yield levels and land suitability data provided by IIASA (2002) for intermediate and low input production system are used here as reference data for the ecological production system. Although yield levels and land suitability data based on the intermediate production system are used for the ecological production system, it must be kept in mind that the level of technology and management is very high for this production system. The assumptions for the performance of the ecological production system are different from those of the intermediate production system.

2.2.2.3. High input production system

In the 'high input production system' intensive farming is performed and optimal management practices are applied. High inputs are used to achieve maximum yields. The yield levels and land suitability data from Fischer (2004) on a grid cell level are provided for a selective number of crops. The data for AEZ from IIASA (2002) provide yield levels and land suitability data on a country level for the intermediate and low input production system for a wider range of crops. To make a comparison between the high input and low to intermediate input production systems possible for a larger array of crops, data from IIASA (2002) on a country level are used to estimate the percentage of change in yield levels and land suitability areas between the different production systems for these crops which are not covered by the database from Fischer (2004). This percentage of change on a country level is used to convert the NUTS-3 region database for the high input rain-fed production system to a database for the low input and intermediate production system.

2.2.2.4. High input and advanced technology production system

In the 'high input and advanced technology production system' very high quality standards and advanced management practices are applied. The increase in yields in the past decades has been the result of a combination of factors such as better crop varieties, availability of cheap and improved fertilizers and herbicides, and better irrigation techniques. Yield developments (FAOSTAT 2004) over the past 30 years for cereals, root and tuber crops in Europe (EU12) and the US show that yields have doubled in 30 years. Taking into consideration that large improvements in this period are achieved due to availability of fertilizers, pesticides and irrigation (the so called ''Green Revolution''), a yield increase of 30% for the HI+ system compared to the high input system or a yield increase of about 1% per year is assumed. Land suitability areas are similar to those of the HI production system.

It is assumed that a farmer is able to change in a short time period from a low to intermediate or high input management system on condition that consultancy and money is available for him at that moment. The change from a high input to a high advanced management system is a more gradual development, as main stimulations for this change are technical developments and research over time.

Table 2: Main features of the production systems used in the different scenarios.

Production system	Input level	Level of mechanization	Availability of varieties
Current agricultural production system (CUR)	Some to limited use of fertilizers and pesticides, but not in a quantity that can guarantee maximum yields	Current technical means are available or available to a certain limit. Use of mechanical tools is sometimes restricted. Farmers make use of mechanical weed control. Conventional tractors and seeding machines are available. Alternatives are using animals for weeding or harvesting.	High productive varieties are available to a certain extent.
Ecological production system (ECOL)	No chemical fertilizers and biocides are applied. Nitrogen is introduced into the plant/soil system through biological fixation. No mineral potassium and phosphorus fertilizer are applied; other substrates (e.g. algae) are used for this purpose	Best current technical means are available, use of advanced mechanical tools.	Productive varieties are available. Principally no Genetic Modified Organisms (GMO) are used in this scenario.
High input production system (HI)	Nitrogen, potassium and phosphorus availability to crop sufficient to reach high yields. No restrictions in biocide use. Effective methods of weed and pest control available.	Best current technical means are available, e.g. modern seeding machines and tractors.	High productive varieties are available. Using Genetic Modified Organisms (GMO) is possible.
High input and advanced technology production system (HI+)	Fertilizer and pesticide inputs are optimally used, nitrogen, potassium and phosphorus supply of the crops is optimal.	Future (i.e. 2030) technical means are used. Examples are satellite spotting, improved irrigation techniques and machines (e.g. harvest loss is minimized).	Best varieties available in future (i.e. 2030) are selected, including GMO.

Irrigation is practised on a large scale in CEEC, especially in the more southern countries. Therefore, it is realistic to include the practise of irrigation in the agricultural production systems. There are no sources available that provide information about the size of irrigated areas on a NUTS-3 region level. Therefore a calculation was carried out, based on information available for rain-fed production systems by using different data sources (see table 1). The global map of irrigated areas (Siebert *et al.* 2002) was enlarged to the scale of Europe and individual Eastern European Countries and, after indicating the location of the NUTS-3 regions into these country maps, the percentage of irrigated area per NUTS-3 region was estimated. IIASA (2002) provides information about land suitability and yield levels for a high input and intermediate irrigated production system on country level for the CEEC. These data provide information about: (1) the impact of irrigation on the size of the area of suitable land available for a crop, (2) the possibility for irrigation in a region, and (3) the impact of irrigation on yields. Data from Roman (2004), Raconczga (2004a) and FAOSTAT (2004) were used as background information.

2.2.3. Forest productivity

The total required roundwood is translated into the total required removals on country level for different scenarios. The total removals are defined as 'the volume of all trees, living or dead, that are felled and removed from the forest, other wooded land or other felling sites' (Schelhaas *et al.* 2004). The databases and publications from Schelhaas *et al.* (2004), UN-ECE (2000) and UN-ECE (1996) provide a relevant database on forest production in Europe. As the methodology behind the data collection is consistent for all CEEC, this database was used as starting point for forest productivity data. The ratios of felling per ha and removals per ha can be used as indicators for forest productivity. These data are given by Schelhaas *et al.* (2004) on country level for the base scenario, as described in Schelhaas *et al.* (2004), and are translated into the scenarios used in our model. The agricultural model is fed with the output from the forest model. That means in case extra land is required to meet wood production, this land is subtracted from the total available suitable land for all crops.

2.3. Allocation procedures

Basically, the allocation procedure has three main steps, which influence the results on available land for energy crop production. The first step reserves for some scenarios a certain amount of land that is reserved for extra growth in urban areas, forest areas or for energy crop production (see table 3). This reserved land is subtracted from the total available suitable land for all crops. The remaining total available suitable land for all crops, which is different per scenario, is used for further allocation in the procedure. A second input in the database is the amount of suitable land per individual crop and their related yield levels, which is also differentiated per scenario.

The total required food production and the required production per crop, combined with the data about yield levels on available suitable land, serve as the starting points for the further allocation procedure. The next step is the distribution of the required food production over the available land in a region X. An allocation choice here is the selection of the geographical size of region X. It is possible to allocate the required food production on country level, CEEC level or over a smaller region, which has its impact on the efficiency level of food production in a region.

The next step is explained by the example of the allocation procedure for very suitable (VS) land. In the model, the required production is distributed over the VS land for all crops individually. As the total area of VS land needs to be distributed over a wide range of crops, this procedure takes place in six allocation steps per land suitability type. There are 24 allocation steps in the model to come to the final result, which is the available land for energy crop production in a region. The methodology of this allocation procedure is explained in more detail in Smeets *et al.* (2007). However, it must be considered that both the yield levels and the amount of available land for each individual crop and for all crops in total is different for each defined agricultural management system, which has its impact on the results coming from the allocation procedure.

2.4. Cost–supply curves

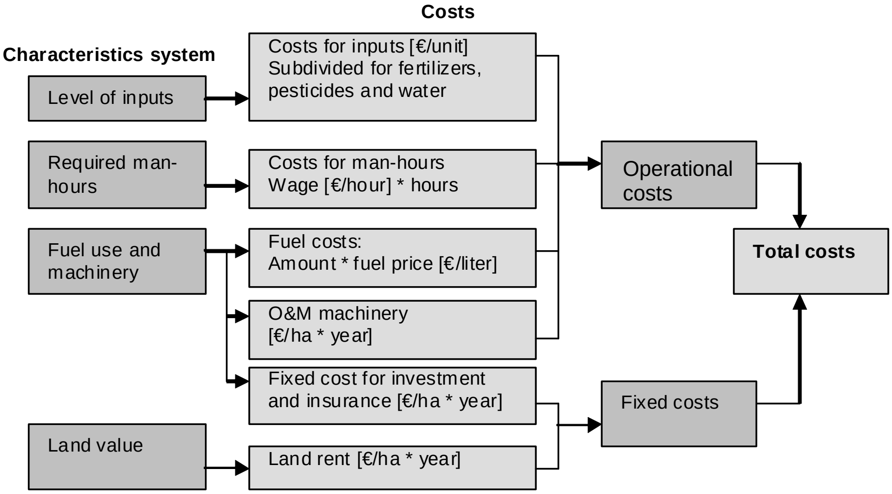
The production costs are estimated based on the level of technology and the selected agricultural production system applied to produce the bioenergy. Production costs for biomass are collected for different land suitability types and production systems. Final deliverables are the cost–supply curves. Figure 4 shows an example of the procedure to calculate production costs of bioenergy.
As figure 4 shows, the production costs are divided in two different variables:

- Fixed costs: the costs are independent from production levels in the short run;
- Operational costs: the costs are dependent from production levels in the short run.

For this study, every NUTS-3 region contains a dataset of cost variables for different production systems, subdivided to different land suitability classes, both for the present situation and for the future selected scenario. The implementation of this approach requires sufficient cost data in a region or country.

The methodology requires for each selected energy crop a database on the costs of various production factors such as pesticides, fertilizers, labour, fuels, land, depreciation of machinery, etc. Table 1 shows the sources for the different cost data used. This database is compiled in this project based on data of energy crop production in the CEEC (see table 1 for references) and projections concerning future developments of costs, yields and developments.

Figure 4: Methodology and data requirement for the calculation of biomass production costs, related to results of biomass potential assessment. Example shows the cost requirements for bioenergy production with production system X on VS land.



3. Scenarios

The scenarios used for the regional biomass potential assessment characterize the main current and future drivers in Europe related to agriculture and land-use. These drivers are translated into quantitative parameters (for example level of trade, management practice, labour and land costs, level of self-sufficiency, yield levels, etc.). These parameters are used in the analysis of the regional biomass potential assessment. The time frame considered is 2030. The following set of scenarios is defined:

- *V1 scenario:* There is a liberalization of trade; no market barriers exist between the EU and the world market for agricultural products. The EU specializes in products, which are competitive on the world market. There is a strong increase in import and export flows. The scenario is characterized by a rationalization of agriculture and adoption of the most efficient management practices;
- *V2 scenario:* Policies are regionally orientated. There is an uneven economic development in Europe. Trade barriers exist between the Western and Eastern European market. The agriculture in CEEC has difficulties to compete with agriculture in WEC;
- *V3 scenario:* There are no internal trade barriers in the EU. Trade between the EU and the world market is based on the current situation (1997-1999). CEEC have completely adopted the EU legislation and can compete fully with WEC agriculture. CAP regulates agriculture in the EU. CAP reforms (e.g. reduction of support levels in agriculture compared to current levels) in Europe are in full implementation;
- *V4 scenario:* There are no internal trade barriers within Europe. Europe protects its own internal market strongly. EU strives for self-sufficiency in its own food and energy need. Internal trade has increased. External trade of products on the world market is limited.
- *V5 scenario:* EU (WEC and CEEC) has a priority for sustainable development and nature conservation. Biodiversity, protection of rural areas and maintenance of the vitality of forest and grassland areas has a high concern. There is a tendency of greening of agriculture. A certain level of protection (trade barriers) is needed.

Table 3 gives an overview of the most relevant indicators used in the scenario analysis. The indicators refer to the main variables mentioned by Hoogwijk *et al.* (2005) and Smeets *et al.* (2007) that have an impact on the cost levels and final biomass potential in a region, in specific derived from energy crop production.

Table 3: Main indicators for scenario analysis in the regional biomass potential assessment of CEEC.

Indicators	**SCENARIOS**				
	V1	**V2**	**V3**	**V4**	**V5**
Food consumption	Based on FAO projections, increase in meat consumption	Based on FAO projections, decrease in meat consumption	Based on FAO projections	Based on FAO projections	Based on FAO projections, decrease in waste from food
Food trade	Products that can be produced cheaper elsewhere in the world are imported into Europe	Conform current situation in CEEC	CAP reforms are implemented	Import is reduced. Domestic products replace products with high import rates in Europe.	CAP reforms are implemented
Livestock production system	High-tech advanced, 30% higher share of fodder from feed crops	Current efficiency levels	High input management system, 15% higher share of fodder from feed crops	High-tech advanced, 30% higher share of fodder from feed crops	Underlying assumption is 20-30% organic agriculture, based on FAO projections
Agricultural production system	High input and advanced technology production system	Current agricultural production system	High input production system (current state-of-the-art in Western Europe)	High input and advanced technology production system	Ecological production system
Reservation of land in allocation procedure	1% land reserved for urban areas	-	2% of agricultural land reserved for set-aside land which can be used for energy crop production	1% land reserved for urban areas	-
Allocation: geographical scale	Required food production is allocated over the CEEC	Required food production is allocated on country level	Required food production is allocated on country level	Required food production is allocated on NUTS-2 region level	Required food production is allocated on country level
Land rents	International open market, no subsidies, land rents are remarkably lower than current average EU-15	Current CEEC cost levels for land rents	Land rents are lower than current average EU level due to CAP measurements	Land rents are comparable to current land rents in France	Competition in land increases. Land rents are comparable to current land rents in EU-15
Labour costs	Increase in wages due to strong economy and high level of technological developments	Current wages in CEEC	Average EU labour costs	Increase in wages due to strong economy and high level of technological developments	Average EU labour costs

4. Results of biomass potential assessment in CEEC

Basically, there are three types of results from the biomass potential assessment in the CEEC, which will be shown in the following order:
- The availability of land for energy crop production in the CEEC;
- The biomass potential in the CEEC;
- The cost–supply curves.

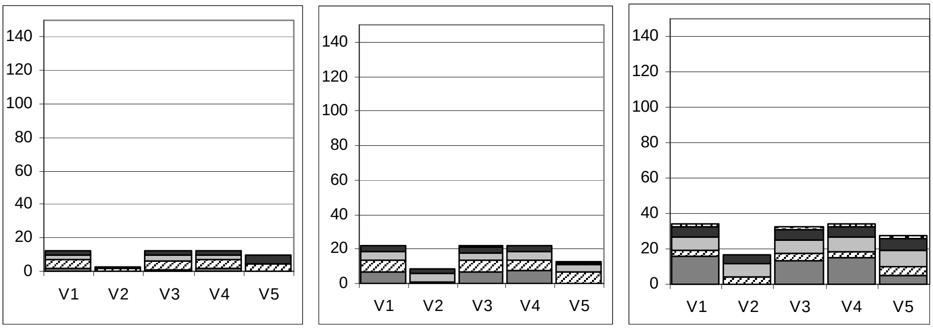
The results are produced on a NUTS-3 level for eight selected energy crops. More information on the selection of energy crops can be found in Dam *et al.* (2005). Here, the results for the whole CEEC region are presented, combined with illustrations of specific results by the example of Poland.

4.1. Available land for energy crop production in CEEC

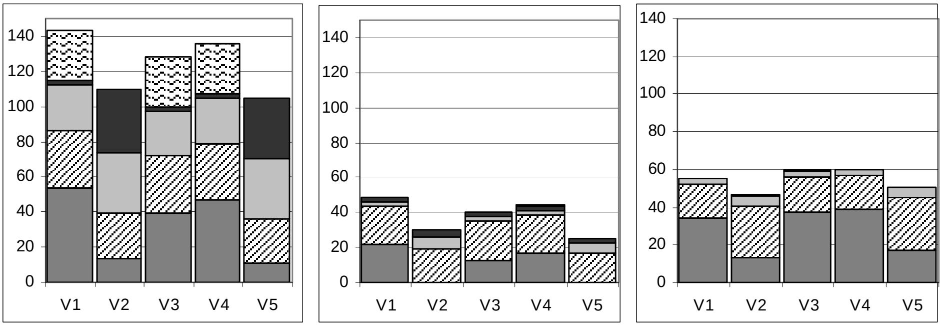
The amount of available land for energy crop production results from the allocation procedure that distributes the required food and feed production over the available suitable land for food and feed production. Figure 5 shows the results of available land for energy crop production for the set of scenarios (described in Section 3) on a country level. The results show that under the V1, V3 and V4 scenario there is generally most land available for energy crop production.

Figure 5a-i: Amount of available land in $1*10^5$ ha in CEEC on country level for energy crop production under selected scenarios to 2030.

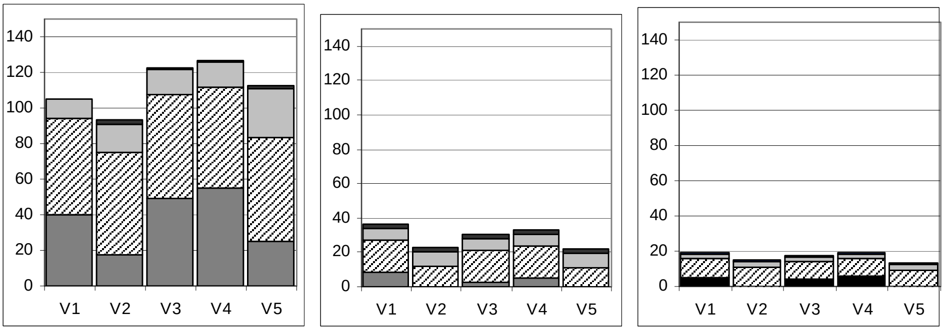
■ VS land ▨ S land □ MS land ■ mS land ▩ Extensive land



5a: Estonia **5b: Latvia** **5c: Lithuania**



5d: Poland **5e: Hungary** **5f: Bulgaria**



5g: Romania **5h: Czech Republic** **5i: Slovakia**

Table 4: Biomass potential (in EJ) in 2030 from energy crops, agricultural residues, forest residues and surplus forest for the sum of all Central and Eastern European Countries.

Selected energy crop in scenario	Scenarios VIEWLS				
	V1	V2	V3	V4	V5
Lignocellulosic crops					
Willow	11.65	4.86	8.65	10.67	5.47
Poplar	10.27	4.35	7.63	9.25	4.85
Miscanthus	10.93	5.71	9.08	10.03	6.28
Conventional crops					
Rapeseed (whole crop)	9.94	5.28	9.18	9.00	5.67
Sunflower (whole crop)	5.95	3.46	5.24	4.97	3.49
Sugar beet (beet)	8.32	3.55	6.42	7.27	3.59
Potato (tuber)	6.06	2.03	4.65	4.94	2.06
Sweet Sorghum (whole crop)	7.20	2.56	5.81	6.64	2.94

There is not only a differentiation in the quantity of available land for energy crop production per scenario, but also in the quality of land that is available. This is for example shown in Figure 5d for Poland. Here marginally suitable land appears under the scenarios V2 and V5, but almost disappears under the scenarios V1, V3 and V4. For some scenarios (mainly with an intensive production system) more land can be considered as available for energy crop production if a production system, which is less extensive than defined under the scenario, is performed on this land. This is mainly the case for the Northern European countries where irrigation plays a marginal role in agriculture. To reflect this extra available land, the land class ‘extensive land’ is introduced in Figure 5. This is land that is available for energy crop production if managed under an extensive production system.

The main underlying factors that determine the results of available land for energy crop production are the area required for food and fodder production, the allocation procedure and the selected agricultural production system, as can be shown by the following examples:

- In the example of the V5 scenario the surplus land availability for energy crop production is low. Here, larger areas than in other scenarios are needed for the production of fodder crops with low protein content because the meat production comes from an extensive livestock production system;
- The allocation procedure of the required food demand over the total available land is differentiated per scenario. This means for example that allocation in the V1 (‘‘open trade’’) scenario takes place over the complete CEEC region, while allocation in the V4 (regionally oriented) scenario takes place within a NUTS-2 region level. The allocation over the whole area of CEEC sets more land free for energy crop production because there are more possibilities to allocate the crops to areas with good eco-physiological conditions for performing high yields;
- The V1 scenario is defined by an advanced production system characterized by high yield levels. The V2 scenario, on the other hand, is defined by the current agricultural production systems, that generally results in low yield levels. This means that in the V1 scenario, with high yields, less land area is needed for the same food production than under the V2 scenario.

4.2. Biomass production potential in the CEEC

The total biomass production potential, including agricultural residues, biomass derived from energy crops, forest residues and surplus forestland, for all CEEC countries is shown in Table 4. Note that biomass potentials of energy crops are shown for the whole crop and based on the data sources as indicated in Table 1. The model shows in general good potentials for the lignocellulosic crops (willow, poplar and miscanthus) in the CEEC. Among these crops, willow gives the best results. Rapeseed and sugar beet show good potentials as well. The different performance of energy crops is due to differences in land suitability and in genetic yield potentials of the crops.

Table 5a: Yield potential for selected energy crops shown for current agricultural and high input production systems, CEEC and land suitability classes (VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable) in t dm/ha per year.

	Current agricultural production system											
	Willow				Miscanthus				Sugar beet (whole crop)*			
	VS	S	MS	mS	VS	S	MS	mS	VS	S	MS	mS
EE	9.1	6.7	4.8	1.9	0.1	0.1	0.1	0.1	10.9	9.0	7.4	3.7
LT	10.1	7.5	5.0	2.4	4.2	3.1	2.3	1.7	12.5	10.2	7.1	3.4
LV	9.7	7.2	4.8	2.3	1.7	1.2	0.9	0.7	12.5	10.0	7.8	3.5
PL	10.6	7.9	5.3	1.8	12.1	9.0	6.6	1.8	20.2	16.7	11.6	5.4
RO	10.2	7.7	5.2	2.0	14.1	10.9	7.8	4.1	13.7	10.6	7.4	4.2
BG	11.0	8.0	5.3	1.4	13.7	10.6	7.5	4.1	14.2	10.2	7.9	4.6
HU	10.4	8.0	5.3	1.9	14.4	11.3	8.0	3.8	18.9	16.0	12.9	7.6
CZ	9.1	7.7	5.1	2.0	12.2	9.0	6.8	2.9	19.9	15.6	11.4	5.4
SK	9.6	7.8	5.3	2.0	12.3	9.8	7.0	2.8	16.7	16.6	11.2	5.0
	High input production system											
	Willow				Miscanthus				Sugar beet (whole crop)			
	VS	S	MS	mS	VS	S	MS	mS	VS	S	MS	mS
EE	12.9	9.6	6.9	2.7	0.1	0.1	0.1	0.1	0.1	19.1	15.0	3.1
LT	14.5	10.7	7.1	3.4	0.1	0.1	0.1	2.4	26.9	22.1	16.3	3.4
LV	13.9	10.3	6.9	3.3	0.1	0.1	0.1	1.0	25.8	18.8	15.8	5.7
PL	15.1	11.2	7.6	2.5	17.3	12.8	9.5	2.6	30.2	24.6	17.3	8.2
RO	14.5	11.0	7.5	2.9	20.2	15.5	11.1	5.9	24.3	23.9	17.2	9.0
BG	15.7	11.5	7.5	2.1	19.5	15.1	10.7	5.9	20.7	20.8	15.1	5.6
HU	14.8	11.4	7.6	2.7	20.6	16.1	11.5	5.5	25.0	22.7	16.6	8.8
CZ	12.9	10.9	7.3	2.9	17.4	12.9	9.8	4.2	29.5	23.8	17.1	8.3
SK	13.7	11.2	7.6	2.8	17.5	14.0	10.0	4.1	24.6	24.1	17.2	8.6

For crops like willow, sugar beet and rapeseed large areas of suitable land are available in the CEEC. The climatic conditions for the energy crops sweet sorghum and sunflower, that are adapted to warmer climates, are not suitable in the Baltic States, Poland, Czech Republic and Slovakia. They can mainly be grown in Romania and their overall potential in all CEEC is therefore low. Energy crops have different genetic yield potentials. Table 5 shows the yield levels for the selected energy crops on a country level for the various agricultural production systems. In Table 5, yield levels are shown for the whole crop of sugar beet. Sugar beet is a comparatively powerful crop with total average biomass yields of about 18 tdm (of which 35% are leaves) compared to willow with about 10 tdm (values for Germany, sources from (Quade 1993; Kauter *et al.* 2003). Conventional crops, however, contain components that are generally not collected for biomass production, due to their low efficiency, as they are difficult to collect or have no good properties for energetic use. This is for example true for the leaves of sugar beet and potato.

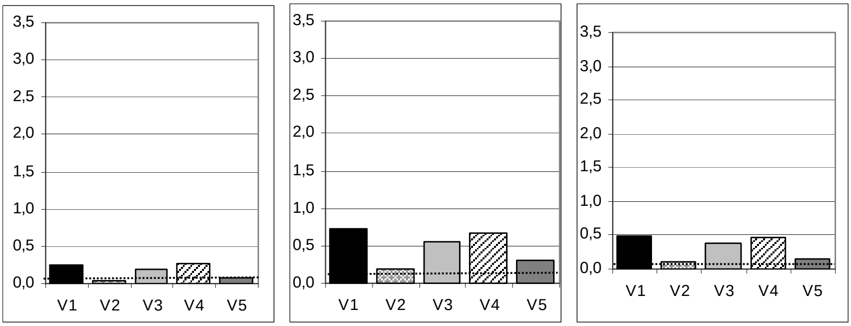
Table 5b: Yield potential for selected energy crops shown for ecological and high input , advanced production systems, CEEC and land suitability classes (VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable) in t dm/ha per year.

	Ecological production system											
	Willow				Miscanthus				Sugar beet (whole crop)			
	VS	S	MS	mS	VS	S	MS	mS	VS	S	MS	mS
EE	10.4	7.7	5.5	2.1	0.1	0.1	0.1	0.1	15.8	13.1	10.8	5.2
LT	11.6	8.6	5.7	2.7	0.1	0.1	0.1	0.1	18.7	15.4	11.3	5.5
LV	11.1	8.2	5.5	2.7	0.1	0.1	0.1	0.1	18.4	15.2	11.2	4.9
PL	12.1	9.0	6.0	2.0	13.8	10.2	7.6	2.1	20.7	16.7	11.6	5.4
RO	11.6	8.8	6.0	2.3	16.1	12.4	8.9	4.7	20.3	15.8	11.6	5.6
BG	12.6	9.2	6.0	1.6	15.6	12.1	8.6	4.7	22.4	18.5	15.9	9.1
HU	11.8	9.1	6.1	2.2	16.5	12.9	9.2	4.4	21.2	16.0	12.9	7.6
CZ	10.4	8.7	5.1	2.3	13.9	10.3	7.8	3.3	20.9	15.6	11.3	5.4
SK	11.0	8.95	6.1	2.3	14.0	11.2	8.0	3.3	20.7	16.6	11.2	5.0
	High input and advanced technology production system											
	Willow				Miscanthus				Sugar beet (whole crop)			
	VS	S	MS	mS	VS	S	MS	mS	VS	S	MS	mS
EE	16.8	12.5	9.0	3.5	0.1	0.1	0.1	0.1	0.1	24.8	19.5	10.6
LT	18.8	13.9	9.2	4.5	6.7	5.0	3.7	2.7	34.9	28.7	21.1	10.9
LV	18.0	13.4	8.9	4.3	2.7	2.0	1.5	1.1	33.5	24.4	20.5	8.7
PL	19.7	14.9	9.8	3.3	19.4	14.4	10.7	2.9	39.2	31.6	22.5	10.7
RO	18.9	14.2	9.7	3.7	22.7	17.5	12.5	6.6	31.5	31.1	22.3	11.7
BG	20.4	14.9	9.8	2.7	22.0	17.0	12.1	6.7	26.9	27.0	19.6	8.6
HU	19.3	14.8	9.9	3.5	23.2	18.1	12.9	6.1	32.5	29.9	21.6	11.5
CZ	16.8	14.2	9.5	3.7	19.6	14.5	11.0	4.7	38.4	30.9	22.2	10.7
SK	17.7	14.6	9.9	3.7	19.7	15.8	11.2	4.6	32.0	31.3	22.4	11.2

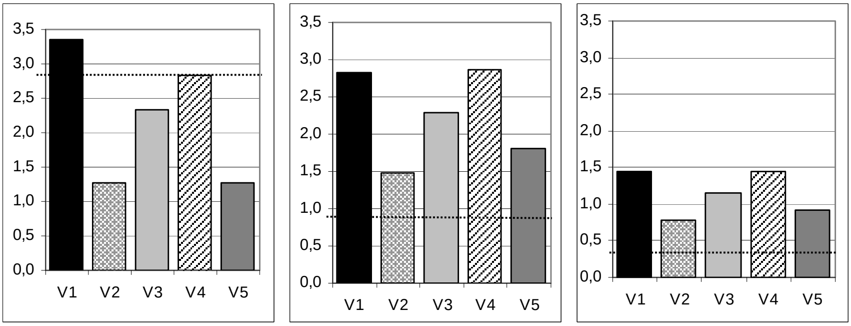
*After calculation of total available biomass for sugar beet and potato (based on yield levels of whole crop) a conversion factor (ratio leaves: beet) is used to come to the available biomass for the beet only.

Figure 6a-i: Biomass potential in CEEC for selected scenarios to 2030 on country level (in EJ). The total potential is the sum of residues, surplus forest and energy crop production. The selected energy crop is willow derived from VS, S, MS and mS land on country level. The line in the graph shows the current final energy consumption on country level in EJ for the year 2000, received from DG TREN (2003).

6a: Estonia **6b: Lithuania** **6c: Latvia**



6d: Poland **6e: Romania** **6f: Bulgaria**



6g: Czech Republic **6h: Slovakia** **6i: Hungary**

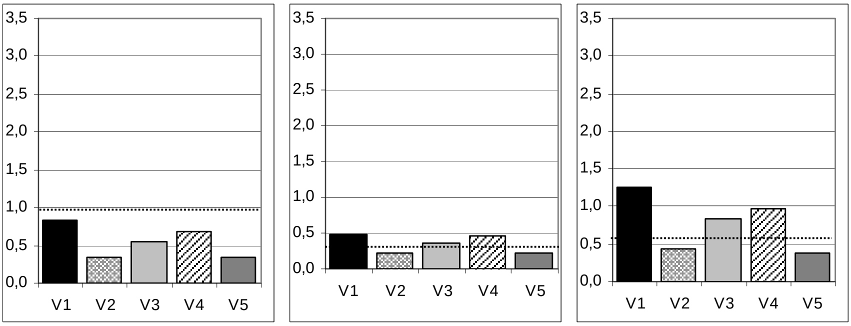


Figure 6 shows per country the total biomass potential results from the energy crop willow. The potentials vary strongly between different scenarios. These differences reflect the influences of the indicators that were used to describe the assumptions and story lines of the scenarios. A scenario assumption is, for example, that sugar beet production for food decreases in the V1 scenario due to free trade of sugar and a strong decline in financial support for this crop in Europe. The result of this scenario assumption is that more suitable land is available for sugar beet production for bioenergy in the V1 scenario than in the other scenarios. Other influences of the scenario assumptions become visible by the example of the total biomass potential (based on the energy crop rapeseed) for the NUTS-2 regions in Poland for the scenarios V1 2030 and V5 2030 (see figures 7a and 7b).

There are not only differences in the total biomass potential between the two scenarios, but also in the sources of the biomass potentials. In the ecological (V5) scenario, a large percentage of the agricultural residues remain in the fields for reasons of soil conservation and management of nutrients. That limits the economic availability of residues in this scenario (see low amount of agricultural residues in figure 7b). Biomass potentials derived from forestry residues and surplus forestland are relatively high in the V4 scenario due to a decrease in international trade of wood, which leads to an increased productivity in the forest sector in the CEEC. The availability of biomass from forest residues and surplus forestland are, on the other hand, relatively low in the V5 scenario due to ecological limitations.

Figure 7a: Total biomass potential in PJ for NUTS-2 regions in Poland for selected energy crop rapeseed, scenario V1 2030.

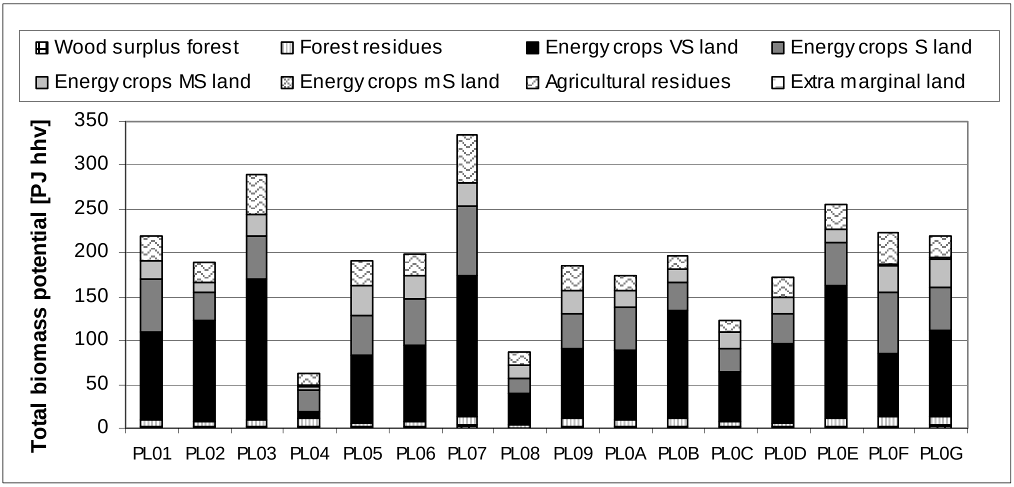
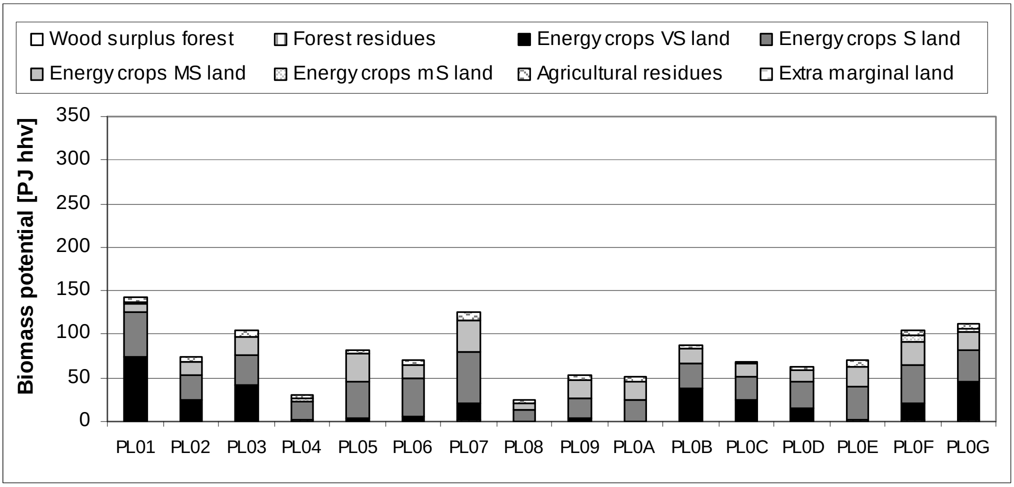


Figure 7b: Biomass potential in PJ for NUTS-2 regions in Poland for selected energy crop rapeseed, scenario V5 2030.



Biomass from energy crops is the sum of the available land for energy crop production multiplied by the yield factor of the energy crop itself. The scenarios produce different results in the total surplus of available land for energy crop production in the CEEC. Beside this, yield levels for energy crops vary between scenarios as the scenarios contain—as one of the indicators—different agricultural production systems. These two factors result in different outcomes for the biomass potential assessment per scenario.

4.3. Production costs in the CEEC for the selected scenarios

The biomass potential for conventional crops is calculated for the whole crop. This means that the total costs (in €/ha) are divided through the biomass yield of the whole crop to come to the final cost estimation in €/GJ. As also mentioned in Section 2.4, the methodology for the cost calculation of biomass production is a bottom–up approach that requires a data input for a wide range of cost items. Table 6 shows information about the land rents in €/ha/yr used for the different countries and scenarios on a country level. Table 7 shows the information used for wages in €/hour. The assumed wages in €/hour, for the different scenarios, are based on current wages for farmers in different countries in the EU. In scenario V2 the current wages in the CEEC are used. Table 8 gives an example for the range of data included for the cost calculation for biomass production, here for rapeseed production in Poland for the V2 scenario. Figures 8–11 shows the cost supply curves for the four selected energy crops willow, miscanthus, sugar beet and rapeseed for the CEEC as a whole.

Table 6: Land rents in €/ha per year for different scenarios used in biomass potential assessment and for the different land suitabilities (VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable).

Land suitability	VS	S	MS	mS
V2 scenario: Current cost level in CEEC				
Estonia	€ 27, -	€ 23, -	€ 19, -	€ 15, -
Lithuania	€ 42, -	€ 32, -	€ 22, -	€ 12, -
Latvia	€ 44, -	€ 35, -	€ 26, -	€ 17, -
Poland	€ 113, -	€ 35, -	€ 29, -	€ 10, -
Romania	€ 74, -	€ 60, -	€ 46, -	€ 32, -
Bulgaria	€ 58, -	€ 41, -	€ 28, -	€ 20, -
Hungary	€ 48, -	€ 45, -	€ 32, -	€ 18, -
Czech Republic	€ 38, -	€ 32,-	€ 16, -	€ 10, -
Slovakia	€ 13, -	€ 11, -	€ 8, -	€ 3, -
Other scenarios in model:				
V1	€ 88, -	€ 74, -	€ 59, -	€ 44, -
V3	€ 110, -	€ 92, -	€ 74, -	€ 55, -
V4	€ 132, -	€ 110, -	€ 90, -	€ 66, -
V5	€ 178, -	€ 149, -	€ 127, -	€ 104, -

Table 7: Wages in € per hour for different scenarios used in the biomass potential assessment.

Scenarios	Countries included in biomass potential assessment								
	EE	**LT**	**LV**	**PL**	**RO**	**BG**	**HU**	**CZ**	**SK**
V1	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6
V2	€ 1.3	€ 1.4	€ 1.2	€ 2.52	€ 0.67	€ 0.59	€ 1.46	€ 1.78	€ 1.28
V3	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2
V4	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6	€ 14.6
V5	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2	€ 12.2

The cost levels in €/GJ (for the whole crop!) vary per scenario. In general, the curve starts with the supply of agricultural and forest residues as these sources have the lowest production costs in €/GJ. Subsequently, the curve continues with the supply from energy crop production, starting with the biomass that can be produced cheapest (generally on VS land) and ending with the most expensively produced biomass. Figure 8 shows, for example, that the bulk of the costs are generally closer situated at the minimum cost level than at the maximum cost level.

Biomass production costs vary not only between scenarios, but also between regions within a country. This is shown in table 9 for the energy crop willow. Two factors, the regional level of crop yields and the regional cost levels, cause these regional differences. To give an example on cost differences, wages in Romania are at this moment 29% of the wages in Poland. This difference in cost items also appears in costs per inputs or costs for land. As the cost–supply curves show, among the crops, biomass from willow and other lignocellulosic crops is relatively competitive.

Table 8: Cost items included per crop for calculation, here as example for the crop rapeseed in €/ha per year for country Poland for V2 scenario 2030.

	VS	S	MS	mS	Based on:
General data:					
Interest rate in %	4	4	4	4	(Kunikowski *et al.* 2004)
Input fertilizers in kilos:					
Nitrogen (N)	55 * yield in t dm / ha *1.1				(Kaltschmitt *et al.* 1997; Falkenburg *et al.* 2004; Zdenek *et al.* 1998; Lewandowski 2004)
Phosphorus (P_2O_5)	7.9 * yield in t dm / ha *1.1				(Kaltschmitt *et al.* 1997; Falkenburg *et al.* 2004; Zdenek *et al.* 1998; Lewandowski 2004)
Potassium (K_2O)	8.3 * yield in t dm / ha *1.1				(Kaltschmitt *et al.* 1997; Falkenburg *et al.* 2004; Zdenek *et al.* 1998; Lewandowski 2004)
Other inputs:					
Seeds in kg per ha	5	6	7	8	(Poostchi 2001; Falkenburg *et al.* 2004)
Chemicals in AI[a] in AI / ha	2.1	2.1	2.1	2.1	(Falkenburg *et al.* 2004)
Fuel use in litre / ha	82.4	82.4	82.4	82.4	(Falkenburg *et al.* 2004)
Labour input in hrs / ha	4.8	4.8	4.8	4.8	(Falkenburg *et al.* 2004)
Cost in € per unit					
Seeds in € / kilo	€ 2.7	€ 2.7	€ 2.7	€ 2.7	(Falkenburg *et al.* 2004)
Chemicals in AI in € / AI	€ 10.9	€ 10.9	€ 10.9	€ 10.9	(Falkenburg *et al.* 2004)
Fuel in € / litre	€ 0.72	€ 0.72	€ 0.72	€ 0.72	(World Bank 2002)
Nitrogen (N) in € / kilo	€ 0.44	€ 0.44	€ 0.44	€ 0.44	(FAOSTAT 2004; Falkenburg *et al.* 2004)
Phosphorus in € / kilo	€ 0.56	€ 0.56	€ 0.56	€ 0.56	(FAOSTAT 2004; Falkenburg *et al.* 2004)
Potassium in € / kilo	€ 0.25	€ 0.25	€ 0.25	€ 0.25	(FAOSTAT 2004; Falkenburg *et al.* 2004)
Others:					
O&M machinery (€ / ha)	€ 84.2	€ 84.2	€ 84.2	€ 84.2	(Falkenburg *et al.* 2004)
Land rent in € / ha	€ 113, -	€ 35, -	€ 29, -	€ 10,-	(Kunikowski *et al.* 2004)
Fixed costs in € / ha	€ 106	€ 106	€ 106	€ 106	(Falkenburg *et al.* 2004)

[a] AI: active ingredients in chemicals.

Because of its high whole crop yields sugar beet also shows comparatively low biomass production costs in €/GJ HHV (see figure 11). Sweet sorghum turns out to be very expensive in those countries where the climatic conditions and low land suitability do not allow for high yields. The scenarios in the model contain a set of indicators that influence the total production costs in €/ha/yr and in €/GJ HHV for a selected energy crop, as can be shown by the example of production costs for willow biomass in Poland. Figure 12a shows that the V5 scenario has the highest production costs in €/ha/yr, followed by subsequently the V4, V3, V2 and V1 scenario. The high cost levels for V5 scenario can be explained by, among other things, the high costs for land in this scenario (see table 2) and the higher machinery and fixed costs that arise from the smaller scale production of energy crops in this ecological scenario.

Figure 12b shows the costs for willow production in Poland in €/GJ HHV. The biomass production costs in €/GJ HHV are still highest for the V5 scenario. However, although the V4 scenario has higher production costs in €/ha/yr than the V2 and V3 scenario, this scenario manages to achieve lower production costs in €/GJ HHV than V2 and V3. This difference can be explained by the impact of the agricultural production systems in the different scenarios (see table 2). Under the 'high input and advanced technology production system' in the V4 scenario, high yields are attained. This means that, although production costs are high in €/ha, costs in €/tdm are lower compared to the V2 and V3 scenarios because more biomass per hectare is harvested. High production costs in both €/ha/yr as well as in €/tdm in the V5 scenario are due to the lower yields under the ecological production system.

Figure 8: Cost-supply curve for all CEEC countries, based on willow as selected energy crop for current situation and for scenarios V1 to V5 for year 2030. Cost levels are average production costs, based on the % of available potential per individual CEEC country.

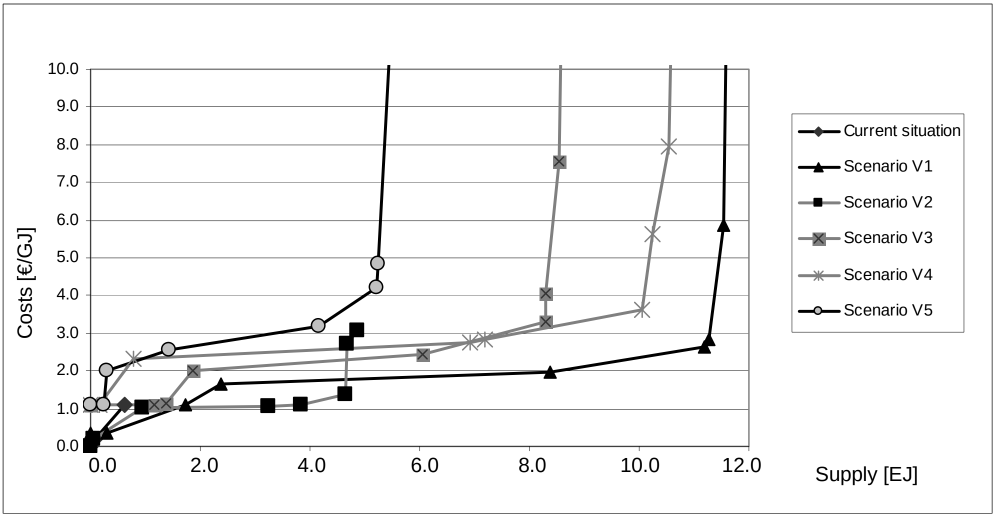


Figure 9: Cost-supply curve for all CEEC countries, based on miscanthus as selected energy crop. Cost levels are average production costs, based on the % of available potential per individual CEEC country, shown for current situation and for scenarios V1 to V5 in year 2030.

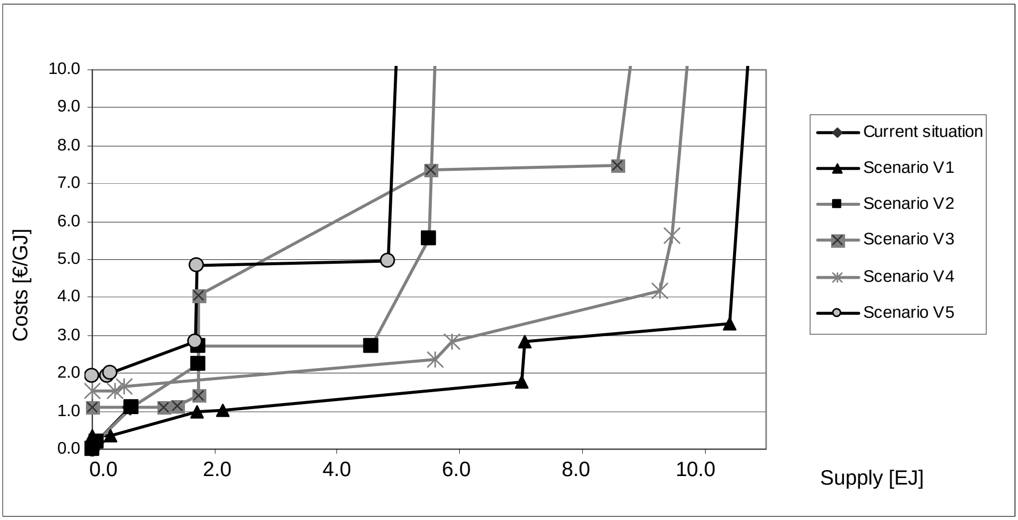


Figure 10: Cost-supply curve for all CEEC countries, based on rapeseed as selected energy crop. Cost levels are average production costs, based on the % of available potential per individual CEEC country, shown for current situation and for scenarios V1 to V5 in year 2030.

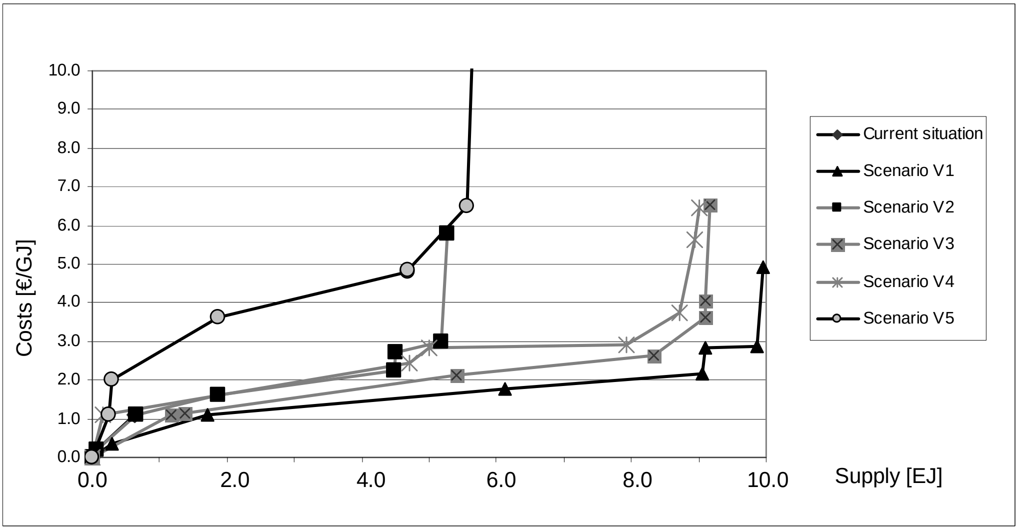


Figure 11: Cost-supply curve for all CEEC countries, based on sugar beet as selected energy crop. Cost levels are average production costs, based on the % of available potential per individual CEEC country, shown for current situation and for scenarios V1 to V5 in year 2030.

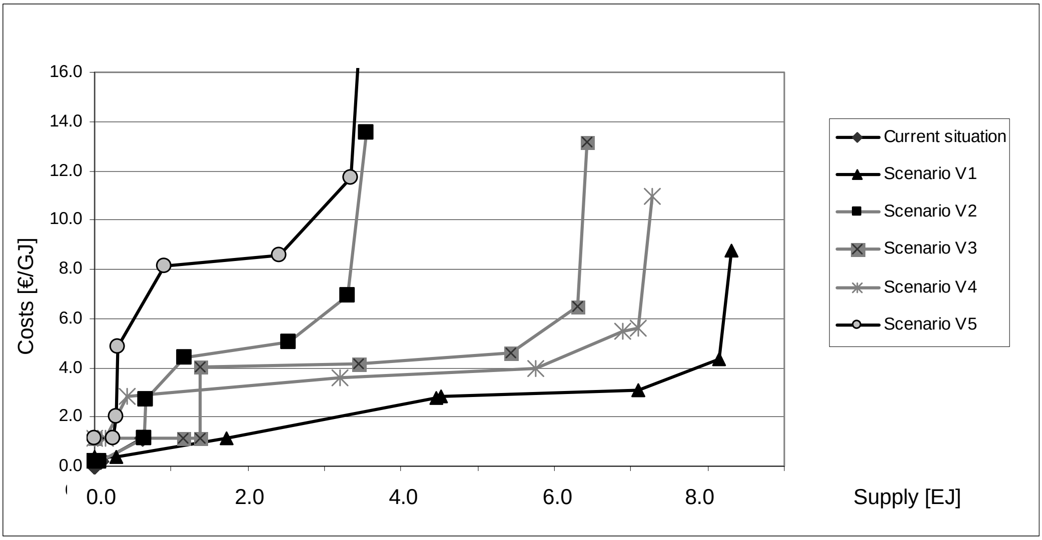


Table 9: Range of biomass production costs in CEEC countries in € per GJ for selected energy crop willow, shown for a set of scenarios.

Selected energy crop willow	V1-2030 Min	Max.	V2-2030 Min	Max.	V3-2030 Min	Max.	V4-2030 Min	Max.	V5-2030 Min	Max.
EE	1.8	6.2	1.1	4.0	2.2	8.0	2.5	8.2	2.9	11.3
LT	1.7	4.9	1.1	3.1	2.0	6.3	2.3	6.7	2.6	8.8
LV	1.7	5.1	1.1	3.3	2.1	6.5	2.4	6.9	2.7	9.1
PL	1.6	6.5	1.0	3.0	2.0	8.5	2.3	8.9	2.5	11.9
RO	1.7	5.8	1.0	3.4	2.0	7.5	2.3	7.9	2.6	10.5
BG	1.6	8.0	0.9	4.5	1.9	10.3	2.2	10.8	2.5	14.5
HU	1.7	6.2	1.0	4.1	2.0	8.0	2.3	8.4	1.8	4.4
CZ	1.8	5.8	0.4	1.1	2.2	7.5	2.6	7.9	2.9	10.6
SK	1.7	5.9	1.0	3.7	2.1	7.6	2.4	8.0	1.8	4.2

Figure 12a: Total production costs, differentiated to cost items, in Poland for willow production in €/ha per year for different scenarios and land suitability types.

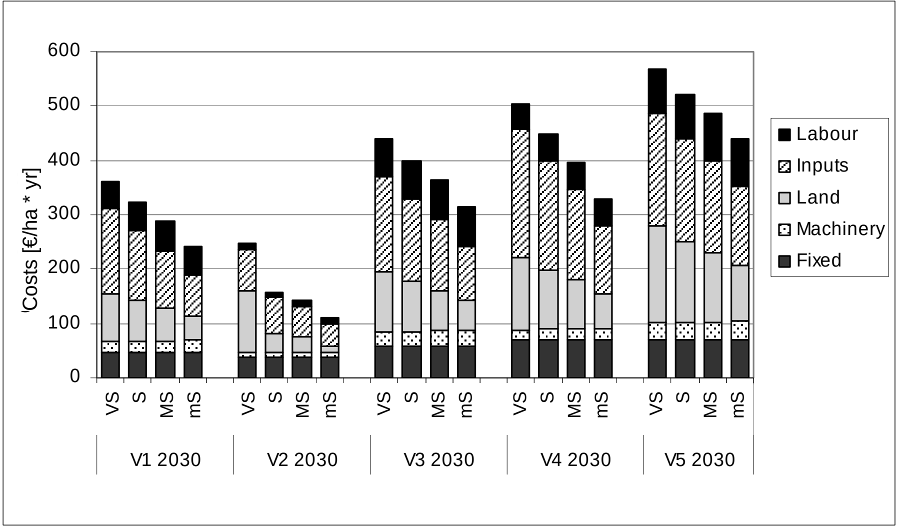
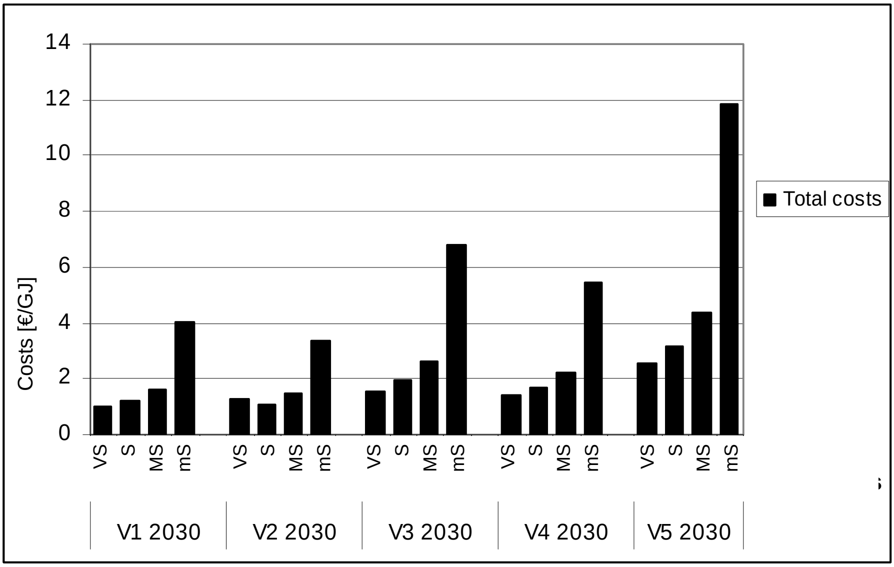


Figure 12b: Total production costs for willow in Poland in €/GJ HHV for different scenarios and land suitability types[4].



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[4] Total production costs for willow in Poland based on HHV= 18.4 GJ/ tdm. Table 5 provides information about yield levels for willow in Poland for different land suitability types.

5. Discussion and conclusions

The methodology applied here only allows modelling the production of one biomass crop on all areas available for biomass production in the CEEC. An optimization of biomass production will require that for every region the most suitable crop (in yield level and cost performance) needs to be selected. The model does not include restrictions to the share of one crop with other crops in rotation schemes. For sugar beet and rapeseed, both are already produced in large scale, such restrictions (due to phytosanitary constraints they can only appear every third year in the rotation and are therefore limited to a third of the agricultural area) can limit the biomass potential of these crops. These constraints have to be taken into consideration in further development of the model.

An uncertainty in the assessment of land availability for the production of energy crops is the demand for land for food and feed production. FAO predictions for the expected food and feed demand in the CEEC were used to estimate the amount of land needed in the future for food and feed production in the CEEC. This estimate does, however, only reflect a situation in which the food and feed demand within the studied region is included and not with regard to (optimizing) global food and feed demand. Therefore, land demand for food and feed production stays an uncertainty in the prediction of land availability for energy crop production.

In the approach taken here based on the IIASA approach, see also (Smeets *et al.* 2007), it is assumed that all land area minus forestry and urban land would be available for agricultural production. The presence of nature reserve areas, which do not include forest, or grassland areas or abandoned mining or industrial areas, are also subtracted from the area of available land. This means that the model contains a large area of agricultural land available in CEEC. In reality, the actual use and availability of agricultural land areas in the CEEC is expected to be lower. This can be partly explained by the large areas of current abandoned and unused land areas in the CEEC.

Specific data on these kinds of land areas are missing or hidden in the statistics. As part of these abandoned lands might be planned or reserved for nature conservation areas, there might be an overestimation in the biomass potential results for some regions. In future analysis, a larger amount of land area for planning nature conservation might be required. The countries with the biggest land areas, Poland and Romania, have the highest potentials for biomass energy production. Also on NUTS-3 regional level, there is a clear correlation between the amount of arable land and the potential for biomass production. Apart from large land areas also favourable eco-physiological production conditions, like fertile soils, can characterize a region with high biomass potential. This is not only true in terms of potentials, but also for costs. The results of the cost analysis show that the biomass production costs (per tonne or GJ) decrease with increasing land quality. The reason for this is that with the same production system, higher yields can be achieved on better land. Therefore regions with good quality land, which are often already today important agricultural production areas (e.g. PL03 or R003), can in the future also become important biomass production areas, assuming that food and feed demand is fulfilled and land-use competition is avoided. Also, the biomass potential in such regions can further increase as more areas of agricultural land can become available by intensification and rationalization of agriculture.

Future developments on land-use, cost and productivity levels in the CEEC are difficult to predict. Some expectations can be extrapolated from the experiences that were made in the WEC, like a rationalization of agriculture in the EU and increases of land prices and labour costs. To deal with these uncertainties and to be able to identify and analyse the factors with major impact on biomass potentials, different scenarios were formulated of which some were extrapolated to extreme situations. This is especially true for the V1 scenario, which assumes full rationalization and the application of highly advanced and efficient agriculture in all CEEC. Due to several constraints, the realization of such a scenario is hardly to be expected (FAO 2003). The same is true for scenario V5, which assumes that ecological agriculture will prevail in the EU. Presently organic agriculture has a share of about 3.5% (5.6 million ha) in the EU 25 and only slight increases of this area are recorded in the WEC (Organic-Europe 2005). Scenario V2, which assumes maintenance of status quo with low productivity levels, is unlikely, too. We expect scenario V3, which assumes the full implementation of CAP reforms and agricultural production systems in CEEC, which develop towards the standards presently applied in WEC, to be the most realistic scenario. Although some of the scenarios appear extreme, they helped to generate results from which important conclusions can be drawn.

The biomass potential in the CEEC is dominated by the potential from energy crops and therefore strongly depends on the amount of land that is available for their production. The availability of land for the production of energy crops depends on the land demand for food production. Policy, and in particular agricultural and trade policy, clearly has a strong influence on the demand and availability of land for food and biomass production. This is shown by the example of the V1 scenario.

Future agricultural production in CEEC will rationalize. Therefore in the near future the amount of land needed for food production will significantly decrease, as has been shown in the scenarios V1, V3 and V4, which employ advanced agricultural production methods. The results of the analysis done here do not only show the high biomass potentials in the CEEC, but also the possibilities for production alternatives on the large agricultural areas that are likely to become available in the CEEC in the near future due to ongoing changes in agricultural production and production methods in those countries.

The results of the V5 scenario showed a conflict between the extension of ecological agriculture and large-scale biomass production. Reasons are the lower yields that are obtained with ecological production methods, which lead to a higher demand of land for the production of food and fodder crops. This results in lower availability of land for energy crops, higher land-use and consequently higher biomass production costs. A support of productive agricultural management systems, with the optimal use of agricultural inputs, modern varieties and efficient technologies, will also support the options of large-scale biomass production.

Biomass can be produced at lower costs in the CEEC than in WEC (De Wit *et al.* 2009a). Bulk of the biomass in the CEEC could be produced at costs lower than 2 €/GJ and therefore become available at lower costs than fossil oil. High potentials for bioenergy production and its competitiveness with bioenergy produced in the WEC or fossil fuels indicate a significant biomass/ biofuel export potential for the CEEC. The costs for biomass production depend on the kind of energy crop chosen. Perennial lignocellulosic biomass crops have—in the order of willow, poplar, and miscanthus—the lowest biomass production costs, followed by sugar beet and rapeseed. Main cost components of energy crop production are labour, land-use and input costs. The production costs of perennial crops could significantly be decreased when better and cost efficient methods for establishment are developed. Because little experience with the production of perennial crops, especially miscanthus, has been made, a decrease of production costs can be expected by the establishment of pilot projects or large-scale plantations.

The production costs for willow and sugar beet range in the order of 200 to 550 and 700 to 1200 €/ha/yr, respectively. This indicates that low subsidies levels can easily support energy crops in the transition phase. The comparison of different energy crops under different scenarios showed clearly that the production of perennial lignocellulosic crop is to be given preference when high biomass potentials, low biomass production costs and environmental benign production methods are to be combined. The production of perennial crops adds ecological value to agricultural areas because of their low demands for inputs (especially fertilizer and pesticides), their contribution to biodiversity, their positive impacts on soil fertility and carbon sequestration and their potential to avoid erosion and nutrient leaching (EEA 2006; Hope *et al.* 2003). Perennial crops have manifold characteristics that make them suitable for the establishment of multiple land-use systems that deliver ecological (e.g. enhancement of biodiversity) or other services like the cleaning of wastewater or soils. Producing biomass in multiple land-use systems contributes to the reduction of biomass production costs and to more efficient land-use. Although there is a high potential for the production of sugar beet and rape seed, too, it has to be seen that these crops have higher demands towards land quality, require high to very high input intensities (especially pesticides) and can lead to soil erosion.

The bulk of the biomass potential (83–94%, depending on the scenario chosen) comes from energy crops. To realize the high biomass production potential large areas of land, in the most extreme case, e.g. up to 78% of the current agricultural area or up to 43% of the total land area, could be used for the production of energy crops, while at the same time food demand is met and forest and nature areas are preserved. The introduction of these alternative crops and the development of new markets will have major socio-economic implications for the CEEC with positive effects on employment options and the development of the agricultural sector and rural areas.

The potential analysis showed that, under a scenario with intensive, advanced agricultural production methods and optimal land allocation within the CEEC, nearly 12 EJ could be produced from biomass in the CEEC. In most CEEC, the production potentials are larger than the current energy use in the more favourable scenarios (such as V1). Combined with the low cost levels, this gives CEEC major export opportunities for the European and perhaps global market.

Acknowledgements

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Chapter 3: Large-scale bioenergy production from soybeans and switchgrass in Argentina - the potential and economic feasibility for national and international markets[5]

Abstract

This study focuses on the economic feasibility for large-scale biomass production from soybeans or switchgrass from a region in Argentina. This is determined, firstly, by estimating whether the potential supply of biomass, when food and feed demand are met, is sufficient under different scenarios to 2030. On a national level, switchgrass has a biomass energy potential of $99*10^6$ (1.9 EJ) to $243*10^6$ tdm (4.5 EJ) per year depending on the scenario. Soybean (crude vegetable oil content) production for bioenergy has a potential of $7.1*10^6$ (0.25 EJ) to $13.8*10^6$ tdm (0.5 EJ) per year depending on the scenario. The most suitable region (La Pampa province) to cultivate energy crop production is selected based on a defined set of criteria (available land for bioenergy production, available potential for both crops, proximity of logistics and limited risk of land-use competition). The available potential for bioenergy in La Pampa ranges from $1.2*10^5$ to $1.8*10^5$ tdm per year for soybean production (based on vegetable oil content) and from $6.3*10^6$ to $18.2*10^6$ tdm per year for switchgrass production, depending on the scenario. Bioenergy chains for large-scale biomass production for export or for local use have been further defined to analyse the economic performance. In this study, switchgrass is converted to pellets for power generation in the Netherlands or for local heating in Argentina. Soybeans are used for biodiesel production for export or for local use. Switchgrass cultivation costs range from 33-91 US$/tdm. The production and transportation costs of pellets are 58-143 US$/tdm for local use and 150-296 US$/tdm up to delivery at the harbour of Rotterdam. Total conversion costs for electricity in the Netherlands from switchgrass pellets range from 0.06-0.08 US$/kWh. Heating costs in Argentina from switchgrass pellets range from 0.02-0.04 US$/kWh. Soybean cultivation costs range from 182-501 US$/tdm. Biodiesel production costs are 0.3-1.2 US$/liter for local use and 0.5-1.7 US$/liter after export to the Netherlands. Key parameters for the economic performance of the bioenergy chains in La Pampa province are transport costs, cultivation costs, pre-processing and conversion costs and the costs of fossil fuels and agricultural commodities.

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[5] Accepted for the journal Renewable and Sustainable Energy Reviews on March 12, 2009. Co-authors: Andre Faaij (Utrecht University, the Netherlands), Jorge Hilbert (Instituto Nacional de Tecnología Agropecuaria INTA, Buenos Aires, Argentina), Horacio Petruzzi (Instituto de Tecnología Agropecuaria INTA, Anguil, La Pampa, Argentina) and Wim Turkenburg (Utrecht University, the Netherlands).

1. Introduction

Many energy scenarios and policy objectives indicate a growing increase in the production and use of biomass as an energy source (IEA 2007). Without further development of biomass energy resources (e.g. through energy crop plantations and better use of residues) and a well functioning biomass market to assure a reliable and lasting supply, the often ambitious targets for bioenergy use may not be met (IEATask40 2006).

Several studies (Hoogwijk *et al.* 2005; Smeets *et al.* 2006) show that there are some key regions in the world that have a short and long-term underutilized potential for bioenergy production. These regions show a technical potential for using residues as well as possibilities for bioenergy production using dedicated plantations. One of these key regions is the MERCOSUR which includes Argentina. On the other hand, there are countries, like the Netherlands, that have insufficient land to meet its projected bioenergy demand. In this case, the development of truly international markets for biomass is essential to meet the country's demands. New trade flows may offer multiple benefits for both exporting and importing countries. For example, exporting countries may gain an interesting source of income and an increase in employment from sustainable biomass production. To be able to realize a well functioning biomass market with a reliable and lasting supply, it is important to determine the economic feasibility of biomass production on the short and longer term in a sustainable manner.

Argentina is in this study chosen as biomass producing country, first, because of its favourable climate and soil conditions for growing biomass. Second, low land and labour costs are beneficial for achieving low bioenergy production costs. In addition, Argentina's existing infrastructure and human resources facilitate the production and transportation of bioenergy. The Netherlands is selected as importing country in this case study. Biomass is the most important source of renewable energy in the Netherlands (Faaij *et al.* 2006). A 30% contribution of biomass (around 1000 PJ of primary energy) to the national energy and material supply is expected after 2030 (Faaij *et al.* 2006), which requires imports from abroad (Cramer *et al.* 2006).

The study focuses on two different energy crops: soybean and switchgrass. Large-scale cultivation of these crops is based on current and more advanced production technologies. Soybean, as an annual crop, is currently the principal crop and the main export product in Argentina (ACSOJA 2007). Several experts in Argentina (Rosetto 2007; Kaloustian 2007; Ganduglia 2007; Hilbert 2007) confirm that soybean is one of the more promising crops in Argentina for bioenergy production. In this study, soybeans are converted to biodiesel for export to the Netherlands or for local use. Switchgrass, a C4 perennial grass, is the second energy crop selected for this study and largely unknown in Argentina as energy crop. Switchgrass is mainly used in Argentina for forage production for livestock (INDEC 2006). The potentially high yields and high contents of lignin and cellulose, generating a high heating value, makes switchgrass attractive for bioenergy production (Lewandowski *et al.* 2003a). Combined with the fact that 77% of the agricultural land in Argentina is dedicated to permanent pasture (FAOSTAT 2007), it suggests that this grass can be an interesting option for bioenergy production in Argentina too. In this study, we consider switchgrass conversion to pellets for export and use for power generation in the Netherlands, or for the local market using switchgrass pellets for heating.

The economic feasibility for large-scale export of biomass or biofuels from soybeans or switchgrass from a region in Argentina is determined firstly by estimating whether the potential supply of biomass, when food and feed demand are met, is sufficient under different scenarios. Beside the biomass potential, other factors such as logistics also play a role in the feasibility of large-scale export of biomass pellets or fuel. Therefore, in this study a promising region of Argentina is selected that show the best potentials to develop large-scale biomass production. After the selection of a promising region, the bioenergy chains for large-scale export (and for comparison local use) of the biomass fuels are more precisely defined to allow an investigation of the economic performance. Consequently, the economic feasibility is determined for large-scale biomass production from soybeans and switchgrass in the selected region in Argentina.

2. Key characteristics of Argentina

Argentina is the second largest country of Latin America with a total land area of 273 million hectares. The country is divided into 23 provinces and one autonomous city, the capital city Buenos Aires (Wicke 2006). The total population of Argentina is around 36 million people (2001), of which almost 90% are living in urban settings. Despite the economic crisis of 2001/2002, Argentina's economy (with a GDP of 182 billion US$ in 2005) is one of the largest in Latin America (CIA 2006). While agriculture contributes only 8% to the national GDP in 2007, around 55% of the value from export originates from the agricultural sector (U.S. Department of State 2008). Soybean and soybean derivatives represent the majority (51% in 2003) of the Argentine agricultural export (Berkum *et al.* 2006).

2.1. Land-use characteristics and agriculture in Argentina

Due to a high variety in soils, temperature and rainfall in Argentina, there is a wide variety of eco-regions, each one having its own characteristics in crop suitability (Garbulsky *et al.* 2006). Of the 273 million hectares of land, Argentina has 128 million hectare of agricultural land, of which 99 million are permanent pastures, 28 million are arable land and 1 million are permanent crops (FAOSTAT 2007). The fertile plains of the centre and the northeast of the country represent the core of Argentina's agricultural production (80% of all agricultural crop production and 75% of the national livestock production takes place in this region). The main agricultural crops in Argentina are soybeans, maize, wheat and sunflower (FAOSTAT 2007). 90% of the soybean production comes from genetically modified crops (Wicke 2006). Application of direct seeding and no-till cropping systems has become the dominant production system by 2005. No till farming has reached more than 70% of the extensive agriculture crops (Hilbert 2008a). Fertilizer input has increased in recent years, although it is still significantly lower than in North America or Europe, due to the fertility of the agricultural land in Argentina (FAO 2004). Currently, the main problem are the high harvest losses (Asal *et al.* 2005).

The traditional soybean production areas are located in Las Pampas containing parts of Buenos Aires, Córdoba, Santa Fe and Entre Ríos (Dros 2004). In recent years, however, agriculture (primarily soybean production) has extended to less fertile and more remote areas in the northeast and -west of Argentina (Berkum *et al.* 2006). This trend has driven livestock production into less fertile lands since soybean production generates more income (Dobson W.D. 2003). Soybean production in Argentina increased from $12*10^3$ tons in 1995 (FAOSTAT 2007) to $47*10^3$ tons in 2006/07 (SAGPyA 2007).

Livestock production in Argentina is primarily based on a pastoral feeding system with direct grazing from natural grasslands and cultivated pasture (Rearte 2007). Concentrated feed is added to this diet in short periods of the year only for fattening the animals (feed lot) or when there is a shortage of nutrients coming from the grasslands. Argentina has various agro-ecological livestock regions that differ in their potential of production and quality of forage. For this reason, a distribution of livestock activities over the country can be noticed. Currently, there are no agricultural subsidies in Argentina, neither at national nor at local level. The export tax for agricultural products is on average around 20% of the export value. The tax is supposed to ensure local food supply and to keep food prices on a stable level (Lamers 2006). Taxes for soybean products contribute to around 12,5% of the federal government budget of Argentina (Berkum *et al.* 2006). Early 2008, export taxes were revised and taxes for soybean increased from 35% to 45% (LaNacion 2008). In Argentina, meat prices are regulated and decoupled from international market prices.

2.2. Energy use in Argentina and the promotion of biomass for renewable energy and biofuels

Argentina uses mainly petroleum products (41%) and natural gas (40%) for its final energy consumption (OECD/IEA 2007). Natural gas is used primarily by the industrial sector to generate electricity. At a lesser extent, it is used in households. Diesel accounts for the largest percentage of local petroleum demand and is mainly used in the transport sector. The road transport fuels used in Argentina are diesel, petrol and Compressed Natural Gas (CNG). From these three, diesel is the main transport fuel. At present, Argentina is a net natural gas and oil exporter. The energy market in Argentina is still distorted as energy subsidies on electricity and fuel consumption continue to prevail. Combined with a significant lack of investments in the energy sector, and a strong increase in energy demands, this resulted in energy shortages in recent years (Lamers 2006). Consequently, from 2002 onwards, Argentina had to import diesel and fuel oil (Hoff 2007). In 2005, 3.1% of the annual diesel consumption was imported (Lamers 2006).

Argentina has a framework that regulates and promotes the production and use of renewable energy. Law 26.190, established in 2007, sets an 8% target for renewable energy consumption in the period of 10 years and mandated the creation of a Trust Fund whose resources will be allocated to pay a premium for electricity produced from renewable sources (Balenstrini *et al.* 2007). The Biofuels Law from 2007 established a 5% mandatory use of biodiesel and bioethanol in all diesel oil and gasoline consumption, beginning January 1, 2010 (Hoff 2007). Until the beginning of 2008, biodiesel export was taxed with 5% and a 2.5% tax deduction. However, this tax has changed to 20% with a 2.5% tax deduction (Infocampo 2008). Although the difference between the export tax of soybean oil for food and feed on the one hand and biodiesel on the other hand is still attractive for Argentine biodiesel producers, it also shows that export taxes can possibly change drastically having an impact on biodiesel export prices.

To comply with the Biofuels Law, it is estimated that about 700 million liters of biodiesel and 250 million liters of ethanol will be needed in 2010 (Hoff 2007). End of 2007, there were 9 biodiesel companies having a total technical production capacity of 585.000 tons, from which only 180.000 tons was effectively used. It is expected that this number will increase to a production capacity of 1.424.700 tons end of 2008, realised by 18 different companies (CAER 2008). In February 2008, Argentina exported 47.634 tons of biodiesel from which 77% was exported to the USA, 13% to the Netherlands and 10% to France (Infocampo 2008). Soybean oil is currently the main feedstock for biodiesel production in Argentina. Beside, there are several small plants using recycled vegetable oil, sunflower and rapeseed oil. Corn, sugar cane and molasses are currently the main feedstocks for ethanol production in Argentina and there is interest in using sorghum (Hoff 2007). There are 15-16 small producers of bioethanol serving the beverage, food and pharmaceutical industry in Argentina.

3. Assessment of the potential of biomass for energy production

The potential of biomass for energy production in Argentina is assessed by investigating the availability of land. Next, the potential is assessed on a provincial level in Argentina for various land-use scenarios. Soybeans and switchgrass are the energy crops investigated.

3.1. Scenario development to assess national and provincial biomass potential for energy

In this study, a scenario is used as an imagined possible future situation placed in a defined time set. The scenarios used to assess the national biomass for energy potential characterize drivers in Argentina related to agriculture, energy and land-use. The drivers are translated into quantitative parameters (see table 1) and used in the assessment (Dam *et al.* 2007). They are also used to evaluate the economic performance. The time frame considered is 2030. Three main trends can be determined, based on different levels of production and trade, productivity and environmental awareness, reflecting different story lines. The dimension 'production and trade' reflects the trends in trade balance, domestic consumption and national welfare for different scenarios.

Estimations for the current situation (CUR) present the biomass potential and economic performance of the bioenergy chains on the short term. Scenario A reflects the baseline scenario for the development of the economy. Scenario B and C are characterized by a stronger economic growth. Between them, scenario C is more export oriented, while scenario B is more environmental friendly and oriented on developing domestic markets.

3.2. Methodology national and provincial biomass potential assessment

A bottom-up approach, based on the studies from (Smeets *et al.* 2006; Dam *et al.* 2007), is used to assess the biomass potential for energy on a national and provincial level in Argentina. For each scenario, the domestic demand for food and feed is fulfilled. A certain area of agricultural land will be needed to meet this demand. The size of this area depends not only on the demand for food and feed, but also on the productivity of the agricultural production system and the allocation procedures. The allocation procedures define the land most suitable for each crop based on individual requirements. This means that crop preferences of farmers based on (inter-) national price tendencies are not taken into account. The current land, excluding forest areas and protected areas, minus the required land for food, feed and livestock production gives the surplus land for biomass production that can be available energy crop cultivation. The amount of total biomass from this land is calculated by multiplying the available land (in ha) with the productivity (ton/ha) for energy crops on this land.

Soybean generates crude oil for biodiesel (20% incl. waste) and pellets for feed (80%). Only the crude soybean oil can be used for bioenergy production. An extra allocation step is therefore made to calculate the usable biomass potential from crude soybean oil for bioenergy. The possibility to use the generated soybean pellets again as input in the model to meet required feed demand, providing in return extra land for bioenergy production, is analyzed.

Table 1: Input parameters for assessment of potential for biomass for energy in Argentina for current situation (CUR) and for scenarios, A, B and C in year 2015 and 2030.

Parameter	CUR - Scenario A	Scenario B	Scenario C
GDP (in US$/capita)	CUR: 1997-99: 8085, 2002: 2711 Scenario A: 2015: 3882, 2030: 6503	Rise in economy 2015: 4571, 2030: 8351	Strong rise in economy 2015: 4995, 2030: 10610
GDP growth rate in % per year	1997-99 to 2015: 2.8% 2015 to 2030: 3.5%	1997-99 to 2015: 4.1% 2015 to 2030: 4.1%	1997-99 to 2015: 5.15% 2015 to 2030: 5.15%
Population growth in % per year	Scenario A: 1997-99 to 2015: 1.3% 2015 to 2030: 0.9%	Rise in economy results in slowing down population growth. 1997-99 to 2015: 0.86%, 2015 - 2030: 0.49%	Strong rise in economy results in strong slowing down population growth. 1997-99 to 2015: 0.56%, 2015 - 2030: 0.3%
Population in 10^7 inhabitants	CUR: 1997-1999: 3.72, 2002: 3.99 Scenario A: 2015: 4.72 2030: 5.39	2015: 4.46 2030: 4.79	2015: 4.29 2030: 4.48
Total food consumption in 1000 tonnes	CUR: 1997-1999: 31616, 2002: 28659 Scenario A: 2015: 36647, 2030: 44473	2015: 37306 2030: 41725	2015: 38068 2030: 41600
Food distribution pattern	Based on FAO outlook Argentina (FAO 2003)	Food distribution pattern 2030 is based on distribution pattern Argentina 1997-1998 (FAO 2003). 2015: 3013 cal/cap/day, 2030: 3032 cal/cap/day	Food distribution pattern is based on pattern USA (2003) for year 2030 (FAO 2003) 2015: 3185 cal/cap/day 2030: 3213 cal/cap/day
Total domestic use excluding feed (other uses) in 1000 tonnes	CUR: 1997-1999: 78743, 2002: 80186 Scenario A: Rise of Other Uses in line with the growth of total food consumption in 2002-2015 and for 2015-2030. 2015: 107393 2030: 146308	Growth in line with the growth of total food consumption. Rise of high value agricultural products leads to 2.5% growth in food manufacturing in 2002-2015 and in 2015-2030 compared to scenario A. 2015: 111788, 2030: 131944	Growth in line with growth of total food consumption. Strong rise of high value agricultural products leads to 5% growth in food manufacturing in 2002-2015 and in 2015-2030 compared to scenario A. 2015: 116852, 2030: 126539
Net trade in 1000 tonnes	CUR: 1997-1999: 33550 2002: 37072 Scenario A: 2015: 50007, 2030: 64376	Trade scenario is based on data main agricultural products 2015: 53575, 2030: 74962	2015: 56125 2030: 75050
Main agricultural export crops in %	CUR: 97-99: cereals (63%), oil crops and vegetable oils (20%) 2015: cereals (57%), oil crops and vegetable oils (30%), meat and milk (4%) 2030: cereals (57%), oil crops and vegetable oils (30%), meat and milk (4%)	Stronger increase in trade of meat and egg products. 2015: cereals (53%), oil crops and vegetable oils (23%), meat and milk (4%) 2030: cereals (56%), oil crops and vegetable oils (22%), meat and milk (5%)	Strong increase of trade in high value products as meat, milk, fruit, vegetables and vegetable oils. Decrease in trade cereals. 2015: cereals (46%), oil crops and vegetable oils (24%), meat and milk (8%) 2030: cereals (45%), oil crops and vegetable oils (20%), meat and milk (14%)

Databases on food and livestock demand in Argentina are available from INDEC (2006), FAOSTAT (2007), SAGPyA (2007), FAO (2003), FAO (2007), IMAGE (2001), WRI (2007a), WRI (2007b) and OECD-FAO (2007). In our assessment, it is assumed that forest production and forest land remains constant over time. Consequently, changes in the demand of forest products are not included in the assessment.

Databases on the productivity and land suitability of individual crops for an intermediate, mixed input and high input agricultural production system (all rain-fed) are available from IIASA (2007) on country level and converted to provincial level with data from SAGPyA (2007). The assumption behind is that the current production of an individual crop takes place on the land that is most suitable for this crop. A description of the selected agricultural production systems is presented in IIASA (2007) and Batidzirai *et al.* (2006) and summarized here:

- Intermediate production system, rain-fed: some use of fertilizers, pesticides, improved seeds or breeds, animal health care and mechanical tools;
- High input production system, rain-fed: full use of all required inputs and management practices as in advanced commercial farming at present found in the USA and the EU;
- Mixed input production system, rain-fed: high level of technology on very suitable to suitable soils, medium level on moderately suitable areas and low level on moderately to marginally suitable areas.

In total, in Argentina more suitable land for agricultural production is available for the high input and mixed input system than for the intermediate production system according to data from IIASA (2007). It is assumed that the current agricultural production corresponds to the intermediate production system. Note that the biomass potential calculated in this study does not include wood from surplus production forest, agricultural and forest residues.

3.3. Results required food and feed production and land availability for biomass for energy

The required food and feed production is calculated for each scenario on a national and provincial level. Some results are shown in figure 1. Scenario (A2030) and (B2030) have higher levels of required crop production due to higher demands for food consumption and feed and lower levels of the Feed Conversion Efficiency (FCE).

The amount of land that is available for bioenergy production, subdivided to different land suitability classes, is calculated on provincial level by allocation (see also 3.2). Table 2 shows the sum of the total available land for bioenergy production from soybean. Limited amounts of land for soybean production are available in scenario (A2030).

Figure 1: Estimated crop production in $1*10^6$ t dm per year (minus required feed from natural grasslands and required production for tomatoes, onions and other vegetables) on country level for current situation and for scenarios A, B and C for the years 2015 and 2030.

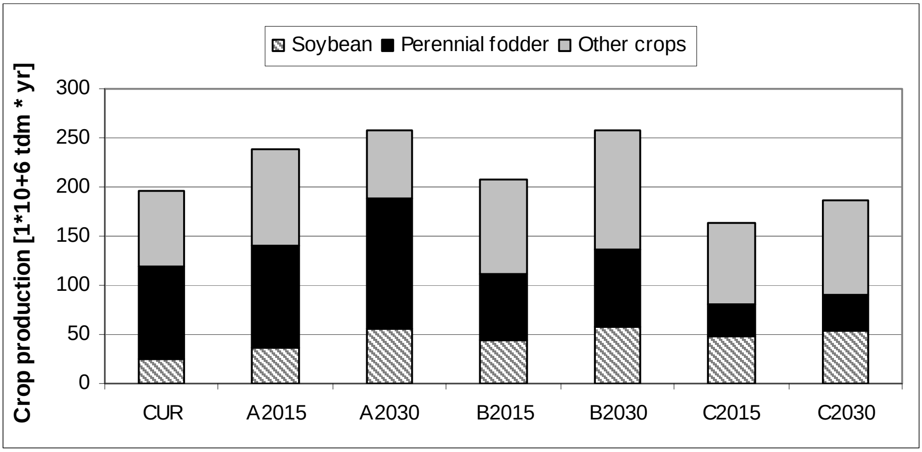


Table 3 shows the sum of total available land for bioenergy production from switchgrass. Again, a limited availability of land for bioenergy production is found in scenario (A2030).

Soybean pellets (80% of whole crop) are currently largely used for export in Argentina. The pellets, produced on land for soybeans for bioenergy production, can also be used to meet national feed demand. This generates consequently extra land for bioenergy production. The extent of extra available land is calculated for scenario (C2030), characterised by a high-input production system. When the pellets are used to replace other feed crops, an extra $66*10^5$ ha becomes available, from which $65*10^5$ ha is very suitable (VS) land. Only limited amounts of this land (5000 ha of S land) are suitable for soybean production and the remaining extra available land can be used for other purposes. In case the pellets are used to replace fodder from grasslands, an extra $21*10^5$ ha becomes available from which $88*10^4$ ha of S land is suitable for soybean production.

Table 2: Available land for bioenergy production from soybeans in 1000 ha on national and on provincial level for current situation (CUR) and for scenarios A, B, and C for 2015 and 2030.

	CUR	A 2015	A 2030	B2015	B2030	C 2015	C2030
Total land	*33338*	*27993*	*17995*	*32073*	*28357*	*24181*	*25019*
Buenos Aires	10505	9506	5468	12613	11490	7775	7940
Catamarca	126	118	92	132	134	87	89
Córdoba	9599	8490	5263	10107	8370	7960	8066
Corrientes	24	23	18	25	26	17	17
Chaco	1200	718	626	648	643	672	895
Chubut	0	0	0	0	0	0	0
Entre Ríos	2291	2007	1239	1093	1786	1711	1742
Formosa	28	26	21	29	29	19	19
Jujuy	4	4	2	5	5	3	3
La Pampa	399	374	289	417	424	275	282
La Rioja	0	0	0	0	0	0	0
Mendoza	0	0	0	0	0	0	0
Misiones	10	9	7	10	11	7	7
Neuquén	0	0	0	0	0	0	0
Río Negro	0	0	0	0	0	0	0
Salta	971	943	636	617	892	781	787
San Juan	0	0	0	0	0	0	0
San Luis	189	177	137	197	200	130	133
Santa Cruz	0	0	0	0	0	0	0
Santa Fe	6026	4385	3121	4961	3345	3424	3551
Santiago del Estero	1305	803	759	733	615	938	955
Tierra del Fuego	0	0	0	0	0	0	0
Tucumán	661	408	317	487	388	381	532

3.4. Results national and provincial assessment of the potential for biomass for energy

For switchgrass, the total potential of biomass for energy production on a national level is, depending on the scenario, $995*10^5$ to $243*10^6$ tdm per year. Figure 2 shows the estimated switchgrass production for bioenergy production on surplus land for each selected scenario. The five provinces with the highest potential of biomass for energy from switchgrass under different scenarios are: Buenos Aires, Córdoba, Corrientes, La Pampa and Sante Fe.

For soybean, the total potential of biomass for energy production on a national level is, depending on the scenario, $353*10^5$ to $690*10^5$ tdm per year for the whole crop. This generates yearly $706*10^4$ to $138*10^5$ tons of crude soybean oil.

Table 3: Available land for bioenergy production from switchgrass in 1000 ha on provincial level for current situation and for scenarios A, B and C for 2015 and 2030.

	CUR	A2015	A2030	B2015	B2030	C2015	C2030
Total land	*15851*	*15038*	*10311*	*16648*	*15917*	*17046*	*17413*
Buenos Aires	4385	4231	3116	5197	5098	5638	5632
Catamarca	52	52	52	42	42	52	52
Córdoba	3251	3157	1400	3685	3651	3895	3894
Corrientes	2570	2552	2361	2642	2648	2537	2537
Chaco	515	193	192	179	174	204	464
Chubut	7	7	7	6	6	7	7
Entre Ríos	771	753	310	273	846	878	879
Formosa	23	23	23	39	38	54	54
Jujuy	40	40	40	32	32	41	41
La Pampa	837	791	650	1121	1061	1270	1269
La Rioja	21	21	21	17	17	21	21
Mendoza	85	85	85	69	69	86	86
Misiones	155	151	135	177	175	186	186
Neuquén	5	5	5	4	4	5	5
Río Negro	35	34	35	28	28	35	35
Salta	207	207	207	167	167	209	209
San Juan	25	25	25	20	20	25	25
San Luis	307	306	307	248	248	304	304
Santa Cruz	3	3	3	3	3	3	3
Santa Fe	2095	1943	874	2326	1217	1127	1240
Santiago del Estero	302	302	302	244	244	306	306
Tierra del Fuego	0	0	0	0	0	0	0
Tucumán	160	160	160	129	129	162	162

When the soybean pellets on land for bioenergy production are used to replace fodder from grasslands (see 3.3), an additional $542*10^3$ tons of crude soybean oil in scenario (C2030) is produced. Only $10*10^3$ tons of extra crude soybean oil is produced when the pellets replace other feed crops.

Figure 4 shows the estimated crude soybean oil production from soybeans for bioenergy production on surplus land for each selected scenario. The five provinces with the highest biomass potential from soybeans under different scenarios are: Buenos Aires, Córdoba, Entre Ríos, Salta and Santa Fe. The biomass potential for soybean and switchgrass, subdivided to land suitability type, from surplus land available in the identified provinces is shown in figure 4 and 5. The figures show that most biomass production for bioenergy comes from a combination of S and MS surplus land for both crops. It is concluded that the available potential for biomass energy production is substantially higher for switchgrass production than for soybean production.

Figure 2: Biomass potential for energy production in 1*10^6 tdm per year from switchgrass on provincial level for current situation (CUR) and for scenarios A, B and C to 2030.

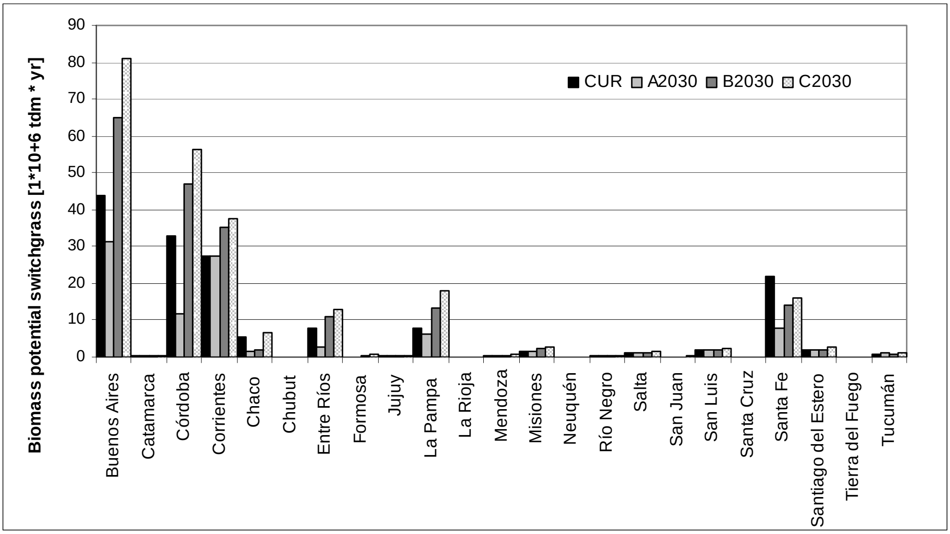


Figure 3: Biomass potential from energy production from crude oil production from soybeans (20% of whole crop) in 1*10^5 tdm per year on provincial level for current situation and for scenarios to 2030.

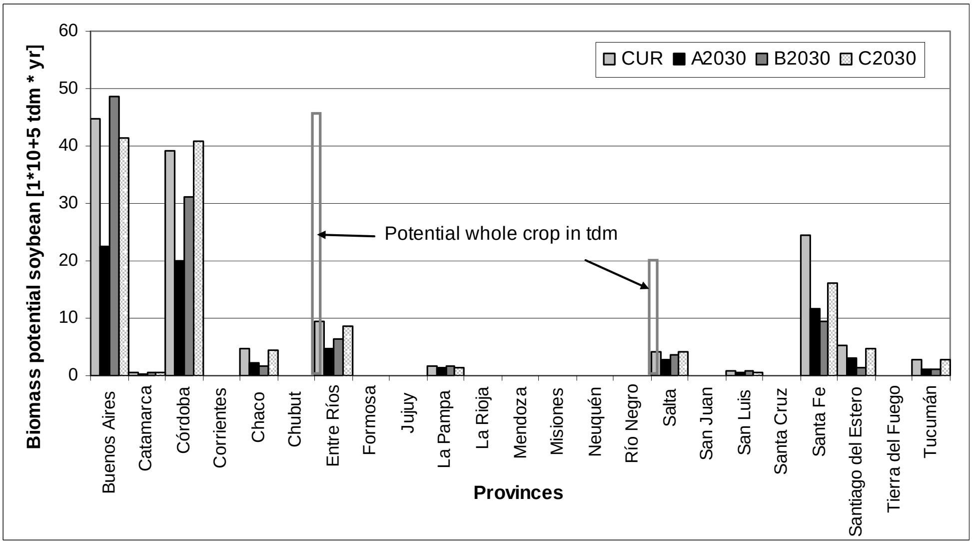


Figure 4: Biomass potential from energy production from crude oil production from soybeans in $1*10^5$ tdm per year for provinces with highest potential, per land suitability type for current situation and for scenarios A, B and C to 2030.

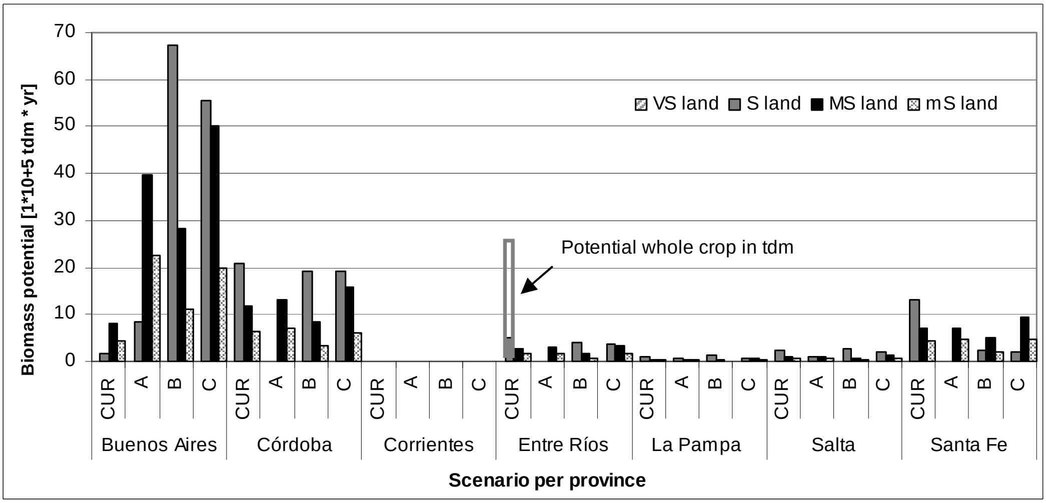
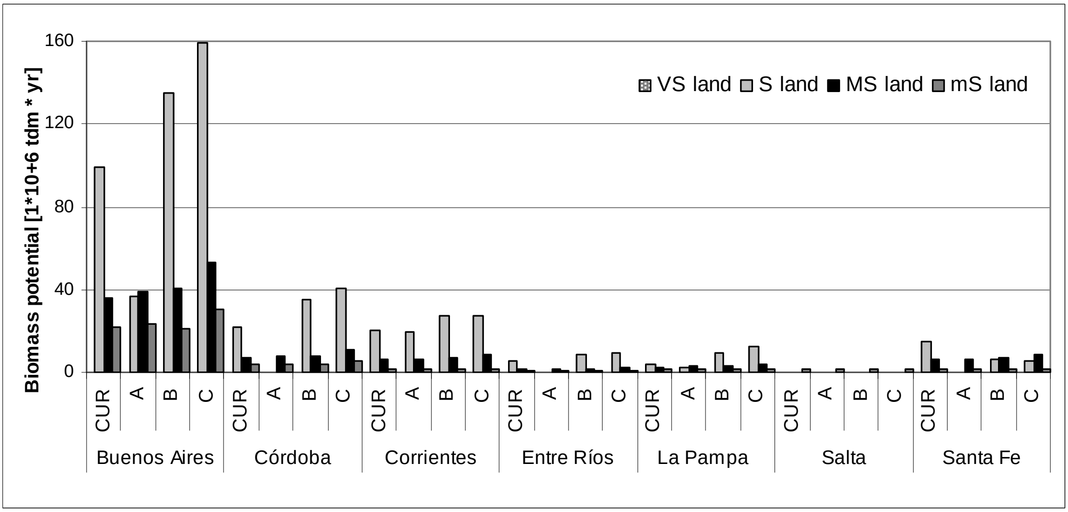


Figure 5: Biomass potential for energy production from switchgrass in $1*10^6$ tdm per year for provinces with highest potential, per land suitability type for current situation and for scenarios A, B and C to 2030.



4. Defining the region for large-scale bioenergy production in Argentina

The selection of a suitable region for large-scale bioenergy production in Argentina is based on the following set of criteria:

1. Sufficient land availability for bioenergy production under different scenarios;
2. The production potential for both selected energy crops in the defined region;
3. Limited risk for competition between land for bioenergy production and land for food or feed production;
4. Proximity of logistic infrastructure.

After identification of a suitable region, the available area to produce biomass can be further characterized.

4.1. Selection of suitable region for large-scale bioenergy production in Argentina

Based on the results in 3.3 and 3.4, seven provinces have been identified showing sufficient surplus land and a good potential for bioenergy production from both switchgrass and soybean production for the selected scenarios. These provinces are Buenos Aires, Córdoba, Corrientes, Entre Rìos, La Pampa, Salta and Santa Fe. Buenos Aires and Córdoba show the best results for both soybean and switchgrass production. Corrientes, Santa Fe and La Pampa show good results for switchgrass production for the scenarios, while Salta and Entre Rìos show, compared to the other provinces, a lower potential. Entre Rìos, Salta and Santa Fe show a good biomass potential for soybean production, while La Pampa and Corrientes show compared to the other provinces, lower outcomes.

To be able to analyze the economic performance of the selected energy crops, the second criterion requires that both soybean and switchgrass can grow and have a production potential in the selected region. Data from (SAGPyA 2007) show that current soybean production in Corrientes is limited, while the current perennial fodder production is limited to zero in Salta.

The main eco-regions dominating the provinces with the best biomass potential results are the Pampas, the Espinal and Chaco Seco eco-region, each one having its own ecological characteristics (WWF 2001). The Pampas eco-region (occupying the plains in the east of Argentina) is the most fertile region in Argentina and can be identified as most suitable for soybean production because of its optimal conditions (between 20-33°C and an average rainfall between 600-1500 mm (Ecocrop 2007). Switchgrass can grow on a wider variety of land types. Because of competition of land, less fertile eco-regions (as the Chaco and Espinal eco-regions) are preferred for bioenergy production. Growing switchgrass for bioenergy in the Espinal eco-region or in the erosion sensitive sandy areas in the Las Pampas eco-region is also recommended by Petruzzi (2008a). To select a suitable region for biomass for energy production, an area on the fringe of the Pampas and Espinal / Chaco eco-region would be most preferred for both crops.

Avoidance of competition in land-use between land-used for bioenergy production and land-used for food or feed is an important criterion for sustainable large-scale biomass production, although less relevant for soybeans providing pellets for feed as one of its outputs. An indicator for competition in land-use is its price. In Argentina, there is a large variation in land price within a province depending on the sub-region and the indicated land-use (Margenes 2006a). Another indicator for competition in land-use is the population density, which is highest in the urban centres of Buenos Aires, Córdoba, Rosario and Mendoza where 90% of the population lives.

Finally, the economic feasibility of large scale biomass production for export is related to the proximity of infrastructure and other logistical facilities like harbours. Road and railway infrastructure is available in all selected provinces (CNRT 2007; Viajeaargentina 2007) although there is a difference in the density of these networks. Important for railway and truck transport is the required transport distance of the produced biomass to the nearest harbour or processing facility. The location (approximately, on provincial level) of available and planned processing units in Argentina such as crushing facilities, biodiesel plants and pelleting plants, are indicated in figure 6.

Table 4 gives an overview of the performance of the selected provinces in relation to all criteria and indicators identified. From this table, it is concluded that the most suitable region for biomass production would be the north-east of La Pampa province / south of Cordoba, bordering the north-west of Buenos Aires and south-east of San Luis. In our regional analysis, we will focus on La Pampa province.

Figure 6: Location of main harbour areas and location of existing and planned processing plants in Argentina related to the soybean and switchgrass bioenergy chain.

Table 4: Performance of seven provinces, selected based on their high biomass potential for switchgrass and soybean production for bioenergy in the short and long term, on defined set of four criteria (as listed below) with as objective to select a promising region for biomass for energy in Argentina (++ is good, + is medium, 0 is low performance).

Criteria and performance indicators	Provinces						
	Buenos Aires	Córdoba	Corrientes	Entre Rìos	La Pampa	Salta	Santa Fe
1) Sufficient land available for bioenergy production							
Biomass potential from soybean	++	++	0	+	+	+	+
Biomass potential from perennial grass	++	++/+	++/+	+	+	0	+
2) Production potential for selected energy crops							
Current soybean production in the province	++	++	0	+	+	+	+
Current perennial grass production in the province	+	+	+	+	+	0	+
3) Limited risk for competition in land-use							
Availability of Las Pampas / Espinal eco-region	0	++	0	++	++	0	++
Land price	0	++ (north)	+	+ (north)	++	++	++ (north)
Population density in the area	0 (north-east)	0 (east)	++	+	++	++	0 (south)
Recent expansion soybean production	++	++	+	0	+	0/-	++
4) Proximity of logistical infrastructure							
River infrastructure	++	+	++	++	+	0	++
Proximity harbour	++	+	+	++	+	0	++
Railway network	++	++	+	+	+	+	++
Road infrastructure and distance to harbour	++	+	+	++	+	0	+
Availability pelletizing plant or in planning	0	0	++	+	0	0	0
Availability crushing facility	0	0	0	++	0	0	++
Availability biodiesel plant or in planning	++	0	0	0	0	0	++

4.2. Socio-economic characteristics of La Pampa province

The province La Pampa has a surface area of 143.440 km^2. Its capital is Santa Rosa (Verna *et al.* 2007). The average population density is 2.27 habitants / km^2 in 2006. The eastern part of the province is more densely populated (around 3 habitants / km^2). The urban population is 81.3% in 2001 (Verner 2005).

4.2.1. Land-use characteristics of La Pampa province

The eastern part of the province is dominated by crop production. More to the west, land is mainly used for grazing areas for cattle, which are more extensively managed to the west (Iturrioz 2005). Important cereals in the province are wheat and maize. Sunflower and soybean are dominating oil crops. The seeded area for soybean cultivation in the province is still relatively small, although the area increased 373% from 1993 to 2001. In the same period, cattle production for beef decreased while dairy production (being more intensive) increased (Iturrioz 2005). There is no or very limited irrigation in the selected region. The reason is that deeper soils contain salt water causing salinization of soils when pumped up (Petruzzi 2008b). The contribution of the agricultural sector to total gross domestic product of the province decreased from 26% in 1993 to 19% in 2006. The livestock sector contributed 65% to the gross domestic product of the agricultural sector in 1993 compared to 54% in 2006 (Verna *et al.* 2007). Most of the agricultural land in La Pampa province is privately owned (Petruzzi 2008b). The number of agricultural units has decreased with 10% between 1998 and 2002. 77% of the exploitations have an area of 50-5000 ha. In the period 1998-2002, the number of agricultural units with a small area size decreased while the number of units with a large area size increased (Iturrioz 2005).

4.2.2. Specifying the biomass for energy potential results for La Pampa province

The assessment of the biomass for energy potential shows the amount of land that is available for soybean and switchgrass production (in 1000 ha) for various scenarios (see table 5). For both crops and for all scenarios, no very suitable (VS) land is available for bioenergy production. Depending on the scenario, switchgrass has a regional potential of $627*10^4$ (A2030) to $182*10^5$ (C2030) tdm per year. The potential for soybeans (whole crop) in the selected region ranges from $615*10^3$ (C2015) to $893*10^3$ (B2030) tdm per year in La Pampa province for the various scenarios, generating yearly $123*10^3$ to $179*10^3$ tons of crude soybean oil.

Table 5: Amount of available land in 1000 ha for bioenergy production from soybean and from switchgrass in La Pampa province per land suitability type* for current situation and for scenarios A, B and C for the year 2015 and 2030.

Scenarios	Soybean production				Switchgrass production			
	VS	S	MS	mS	VS	S	MS	mS
CUR	0	236	103	61	0	347	278	212
A2015	0	211	103	61	0	301	278	212
A2030	0	125	103	61	0	161	278	212
B2015	0	201	142	74	0	690	260	171
B2030	0	238	122	64	0	630	260	171
C2015	0	117	114	44	0	757	299	214
C2030	0	122	115	45	0	756	299	214

* VS = very suitable land, S = suitable land, MS = moderately suitable land, mS = marginally suitable land

Maps about the current potential of crop production in La Pampa province (Hilbert 2008a; LaPampa 2008) show that soybean production is limited to the eastern part of the province. The VS land in the east of the province changes over short distance to less suitable land in the west of the province. The suitable land for extensive grazing and grassland covers a larger area in La Pampa province. This shows that switchgrass can be grown on land where soybean production is not feasible. It must be noted that, according to the methodology used (IIASA 2007), the land suitability types of various crops are not located per definition on the same geographical location. In other words (as an example) MS land for soybean production can still be S land for switchgrass production.

Figure 7: Historical yields in La Pampa province and on national level for soybean production for bioenergy in tdm/ha per year, based on S land, and related yield expectations in scenarios A, B and C to 2030.

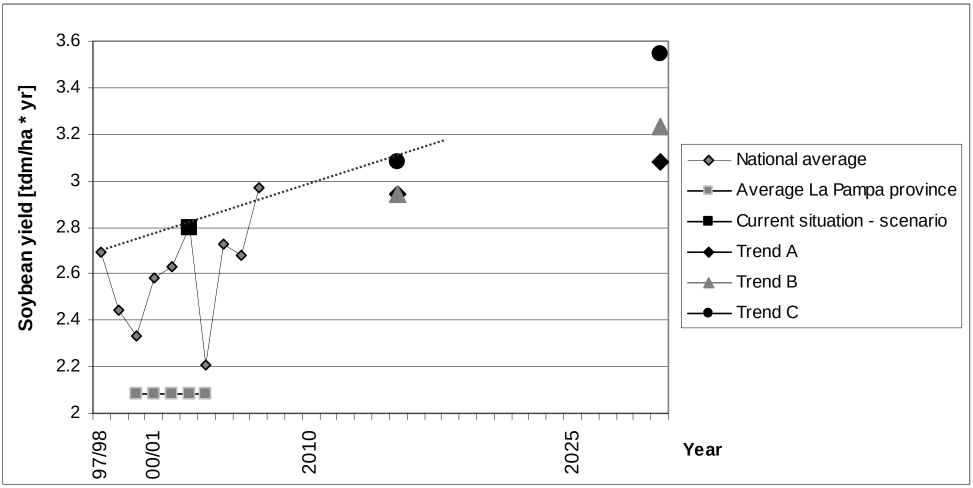
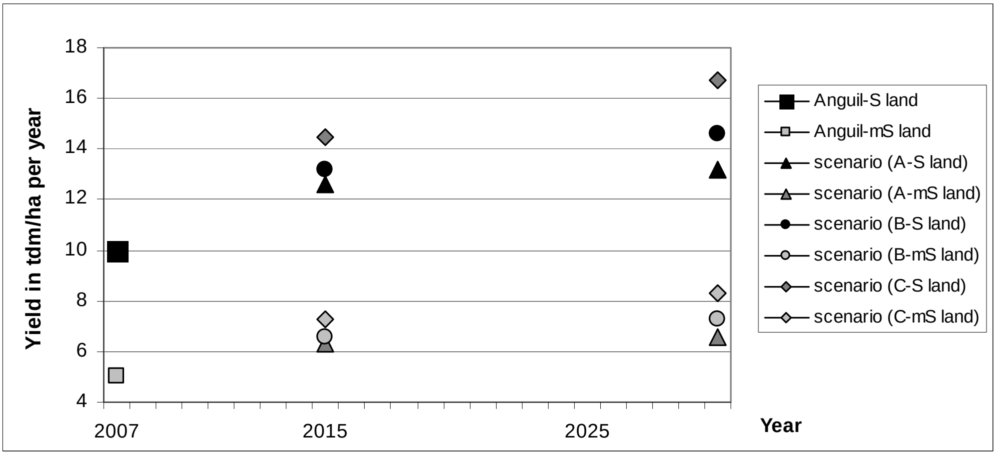


Figure 8: Current switchgrass yields for biomass energy potential assessment in tdm/ha per year for mS and S land, measured in Anguil (La Pampa province) and yield expectations in scenarios A, B and C to 2030.



Soybean yields used in the assessment of the biomass for energy potential for the scenarios till 2030 are shown in figure 7. An average yield level of 2.8 t/ha for S land (IIASA 2007) is assumed for the current situation. The national historical trend in soybean yield (SAGPyA 2007) is in line with scenario C. Soybean yields vary, however, strongly within the country and the average soybean yield in La Pampa province (2.08 t/ha) is currently lower than the national average (SAGPyA 2007; Verna *et al.* 2007). A 50-70% yield increase to 2030 in the province is therefore required to meet the yield levels in scenario (C2030), when looking at the yield levels for S land, which is equivalent to an annual increase of 40-60 kg/ha. Scenario A requires the lowest yield increase while scenario C requires the highest yield increase till 2030.

Data about current switchgrass yield are more limited available for Argentina. An estimated yield level for switchgrass of 10 tdm/ha per year is given by Petruzzi (2007a) for the area around Anguil in good years. This figure is used as reference for suitable land to produce switchgrass in the current situation. Years with drought and climate limitations have shown annual yields of 3.9-5.2 tdm/ha (Petruzzi 2008c). A yield of 5 tdm/ha per year is used as reference for mS land for the current situation (see figure 8). Future yields are based on the data used in the assessment of the biomass for energy potential. The scenarios suggest a 32-67% yield increase to 2030 compared to the current situation.

4.2.3. Transport, processing facilities and energy supply in and around La Pampa

National highways are available throughout the country and in La Pampa province. Railways run from Santa Rosa, Telén and Arizona to Rosario or Bahía Blanca (CNRT 2007). The western part of La Pampa province has no availability of railways. The majority of the train lines were privatized in 1992-1993, which means that the maintenance of the railway is largely the responsibility of private companies (BCR 2007). Although the train is more efficient for large scale transport, most of the transport takes place via truck due to infrequency of train transport in the region (Molina *et al.* 2008).

There are several inland ship transport routes in the country such as Río de la Plata and its tributaries (Wicke 2006). Ship transport is, however, not an option for La Pampa province. The province has limited superficial water sources: The Rio Colorado forms the southern border of the province and the second main river (Salado-Chadileuvú) goes from north to south in the western part of the province. In Argentina, there are two main harbour areas for transport (Bergero 2007). The first area are the harbour terminals from the Up River (terminals for oceanic transport centred in Rosario, San Lorenzo, Villa Constitución). This is a 90 km strip located south and north of Rosario, on the left side of the river Paraná. The second main area for oceanic transport is the harbour terminals south of Buenos Aires, centred in the custom harbours of Bahía Blanca (BB) and Necochea. The available capacity per transport is 66.000 ton based on a Panamax ship. Ships leaving from harbour terminals further up the River Paraná leave with a cargo of around 48.000 ton of grains based on a Panamax ship (Bergero 2007).

Rosario is the area with the largest concentration of oil crushing plants in the world. Its feedstock is almost exclusively soybean oil. The current oil milling capacity reaches $154*10^3$ tons per day (Lamers 2006). 85% of the installed milling capacity is divided among 6 major companies (Lamers 2006). Biodiesel plants (in development) are located in Buenos Aires and Santa Fe (EVD 2007). Large pelletizing facilities are limited in Argentina. At this moment, only one pelletizer is working in Corrientes. There are five more projects in development, all with sawdust input and with a capacity ranging from $30*10^3$ ton/yr to $100*10^3$ ton/yr (Kingston 2007). Electricity in La Pampa province is delivered by hydro plants and by natural gas fired power plants.

Table 6: Input parameters for economic performance bioenergy value chains from switchgrass and soybeans for current situation and for scenarios A, B and C for year 2030 for suitable (S) land and for marginally suitable (mS) land.

Parameter	CUR		Scenario A		Scenario B		Scenario C	
Available land for bioenergy soybeans in 1000 ha	S: 236	mS: 61	S: 125	mS: 61	S: 238	mS: 64	S: 122	mS: 45
Available land bioenergy from switchgrass in 1000 ha	S: 347	mS: 212	S: 161	mS: 212	S: 630	mS: 171	S: 756	mS: 214
Agricultural production system	Intermediate agricultural production system		Intermediate agricultural production system		Mixed agricultural production system.		High input agricultural production system	
Agricultural production system switchgrass	No irrigation Lifetime plantation: 15 yrs Seeding: 3 kg, seeds are imported Fertilizers: 50 kg N / yr for S land, 14 applications. Herbicides: in 1st and 2nd year of establishment with common herbicides Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Lifetime plantation: 15 yrs Seeding: 3 kg, seeds are imported Fertilizers: 50 kg N / yr for S land, 14 applications. Herbicides: in 1st and 2nd year of establishment with common herbicides Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Lifetime plantation: 20 years Seeding: 3 kg needed, available in country Fertilizers: 50 kg N / year and 25 kg P / year for S land, 28 applications. Herbicides: in 1st year of establishment, herbicides specified for switchgrass Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Advanced developments in seed technology to improve yields and weather resistance. Lifetime plantation: 17.5 years Seeding: 3 kg needed, available in country Fertilizers: 50 kg N / year and 25 kg P / year, in total 28 Herbicides: in 1st and 2nd year of establishment, herbicides specified for switchgrass. Harvesting: twice a year No-tillage mS land requires lower inputs fertilizer and agrochemicals	

Table 6 (continued): Input parameters for economic performance bioenergy value chains from switchgrass and soybeans for current situation and for scenarios A, B and C for year 2030 for suitable (S) land and for marginally suitable (mS) land.

Parameter	CUR		Scenario A		Scenario B		Scenario C	
Agricultural production system soybean	Direct seeding in combination with rotation of crops. Transgenic seeds are used. Use of fertilizers and herbicides Reduced tillage mS land requires lower inputs fertilizer and agrochemicals		Conventional cropping system (no direct seeding) Reduced tillage mS land requires lower inputs fertilizer and agrochemicals		Use of fertilizers and herbicides (organic if available). GM seeds for soybean production are used, further development is not promoted. Direct Seeding in combination with other conservation measures to improve sustainability No tillage mS land requires lower inputs fertilizer and agrochemicals		Advanced developments in seed technology to improve yields and weather resistance. Use of fertilizers and herbicides. Direct Seeding Reduced tillage mS land requires lower inputs fertilizer and agrochemicals	
Soybean yield in tdm/ha	S: 2.1	mS: 1.3	S: 3.1	mS: 1.9	S: 3.2	mS: 1.0	S: 3.5	mS: 2.3
Switchgrass yield in tdm/ha	S: 10.0	mS: 5.0	S: 13.2	mS: 6.6	S: 14.6	mS: 7.3	S: 16.7	mS: 8.3
Reference land-use	S: crop production (C) mS: degraded grassland (D)		S: crop production (C) mS: degraded grassland (D)		S: non-degraded grassland (G) mS: degraded grassland (D)		S: crop production (C) mS: degraded grassland (D)	
Environmental and economic priorities	Average environmental awareness.		Average environmental awareness due to economic constraints. Protection of the internal market is considered a priority.		High environmental awareness. Diversification of landscape and renewable energy sources is promoted.		Low to average environmental awareness. Economic growth and competition on the internal market is considered a priority.	
Economic trends and costs	Current situation		Continuation of current trend economy. Energy and fuel prices remain subsidized to keep prices low. Renewable energy sources do not have a key priority. Biodiesel remains an export product. Labour costs increase slowly		Rise in economy Focus on main agricultural products High environmental awareness leads to promotion of renewable energy sources, both for export and local use, and to an increase in the fuel price Increase in labour costs		Strong rise in economy Focus on high value end-products Increase in energy and fuel prices according to international market. Biodiesel is strongly promoted Strong increase in labour costs	
Technology level applied	Current situation		Processing plants (e.g. pellet plants) are used on a small scale.		Making use of larger processing plants available in the Latin American region.		Up-scaling of processing plants (state-of-the-art technology in the world).	

5. Defining the bioenergy chains

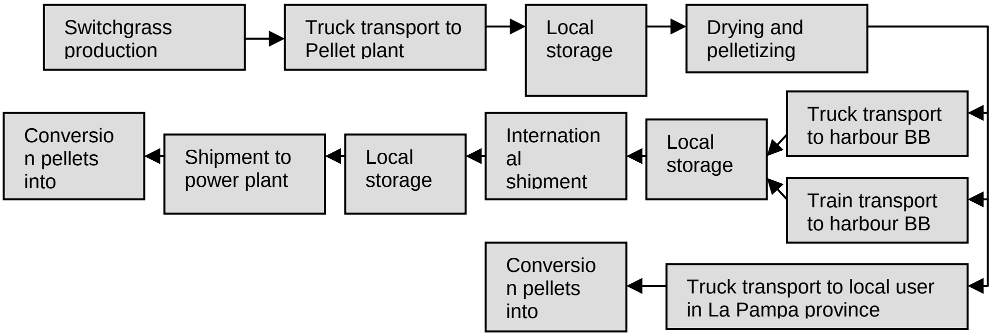
The bioenergy value chains for switchgrass and soybean production can be further specified based on the previous sections. Quantitative parameters shown in table 6 (only shown for CUR and for the year 2030), relevant for calculating the economic performance of the bioenergy chains in each scenario, are added to the parameters presented in table 1.

5.1. Defining the bioenergy chain for switchgrass production

The bioenergy production chain for switchgrass is shown in figure 9. After the harvest, the product is transported to the closest pellet plant. The pellets are exported to Rotterdam to be converted into electricity in a power plant in the Netherlands or used in the local market. Information from Smeets *et al.* (2008b) about the management of switchgrass for one production cycle forms the basis for specifying the applications of the switchgrass plantation in this case study. The information is further specified to the Argentinean situation by using information from a 13 year old test of using switchgrass for bioenergy production from INTA based in Anguil in La Pampa province (Petruzzi 2008c). Input parameters are diversified for the different scenarios (see also table 6). In this study, we assume a lifetime of the switchgrass plantation from 15 to 20 years depending on the scenario, based on Lewandowski *et al.* (2003a), Petruzzi (2008b) and Smeets *et al.* (2008b).

Based on experiences from Petruzzi (2008c), October and November are considered optimal seeding months as the risk for frost is limited. Results show however, that lack of rainfall and the occurrence of severe drought in the first months after seeding can have a great influence in the survival of the attained plants.

Figure 9: Defined bioenergy production chain from switchgrass, produced in La Pampa.



Economically viable crop yields require fertilization rates between 50-100 kg/ha/yr. The effect of N fertilizer, however, can be site specific. On more fertile sites, effects have typically been negative or neutral (Lewandowski *et al.* 2003b). N fertilizer can increase yields if there is sufficient rainfall in that year (Petruzzi H. 2008a). Test results show that the use of P-fertilizer and calcium is not needed in INTA Anguil but P-deficiencies are recorded in some other regions in La Pampa province (Petruzzi 2008a). Weeds can be an obstacle for switchgrass establishment. In the first year after seeding, herbicides may be needed to control weeds (Lewandowski *et al.* 2003a). This is confirmed by Petruzzi (2008a), recommending the use of herbicides in the 1st and / or 2nd cycle of the crop. Once a good stand is established, the use of herbicides is no longer needed.

Stands are typically not harvested during the first growing season. There after, the highest yield per hectare can be obtained when switchgrass is harvested once or twice per year (Lewandowski *et al.* 2003b). Data from Petruzzi (2008c) show that differences in total yield are small for one or two harvests per year when no fertilizer is applied. The appropriate harvesting date in La Pampa province is still being examined, but is expected to be around April-July (Petruzzi 2008b). In this study it is assumed that the grass is harvested and turned into bales. A mounted big baler machine, conform the study from Smeets *et al.* (2008b), is used for harvesting. The moisture content from Switchgrass after harvest is 15% (McLaughlin *et al.* 1996). The bales are directly transported to the nearby pellet plant for storage. The removal of the plantation includes two times of rotary cultivating and one time of spraying (Smeets *et al.* 2008b).

5.2. Defining the bioenergy chain for soybean production

The bioenergy production chain for soybean is shown in figure 10. After harvesting, the product is transported to Junín for oil extraction. This is the closest processing unit for soybean production in the region (Molina *et al.* 2008). In Argentina, only larger agricultural companies will directly export the soybean to the oil extraction companies. The smaller to medium sized producers sell their soybean in practice via cooperatives or stocking companies spread in the country, who take care of the merchandise and send it to industry or to the harbour, where it is commercialized via the stock market (Prone 2008a). After oil extraction, the crude soybean oil is transported to Rosario to be converted to biodiesel. This end-product is exported to Rotterdam or used in the local market.

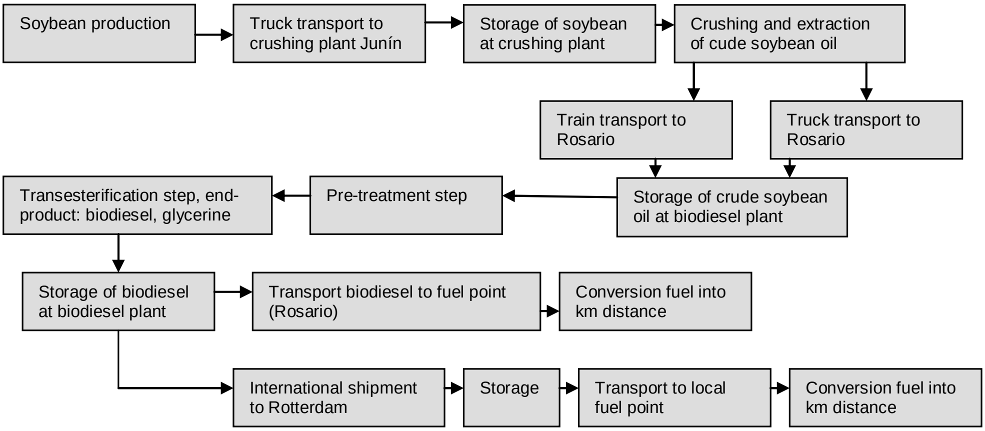
Almost all soybean production in Argentina is seeded with GM seeds. The so-called “Roundup Ready” (RR) soybean is resistant against the herbicide glyphosate: the soybean is not affected when surrounding weeds are eradicated. Around 80% of the Argentinean farmers combine the use of RR-seeds with the practice of ‘direct seeding’ (Hilbert J. 2007). According to Hilbert (2008a), Negri *et al.* (2008) and Michelena (2008), direct seeding in combination with a rotation system is the dominating agricultural system for soybean production in La Pampa province. The cultivation of transgenic soybeans is profitable for Argentinean farmers due to higher yields and reduction of costs.

There is only a small surcharge for the use of transgenic soybean seeds (Berkum *et al.* 2006). In the scenarios, green manure seeds (only for scenario B) and RR-seeds are used as inputs with a rate of 80 kg/ha, differentiated to the various production systems (AACREA

2007). Data about required agrochemicals input per scenario are based on AACREA (2007) and Margenes (2007a).

Often, soybean is grown in crop rotation patterns. In case of double cropping (in rotation with wheat), seeding takes place in the months October (‘Soja Primera’) or January (‘Soja Segunda’) and harvesting in the months March to June (Berkum *et al.* 2006). In La Pampa province, most of the soybean comes from so-called ‘Soja Primera’. As water is a limiting factor, the second cultivation only takes place if there is enough water available (Chessa 2008a). P and N input for soybean production are not needed for the current situation in La Pampa province according to Negri (2008). However, data from AACREA (2007) give an input of 80 kg/ha monoamonico phosphate for the conventional and direct seeding (with fertilization) system and data from Panichelli (2007) give a fertilizer input of 7.5 kg/ha triple superphosphate and 18 kg/ha monoamonico superphosphate for the direct seeding system during 1st cultivation. Due to the current imbalance of nutrients in crop cultivation in Argentina (Dam *et al.* 2008) and expected intensification of agriculture, an increase of fertilizer is assumed for the future scenarios. Less fertilizer input is assumed for scenario B due to an increased use of environmental friendly methods.

Figure 10: Defined bioenergy production chain from soybeans, produced in La Pampa province.



At the start of the crushing process, the soybean has a moisture content of 10-10.5%. After the crushing process, 17% of the final output is oil, 80% sub-products (soybean pellets) and 3% waste (Donato *et al.* 2007). The current oil milling capacity reaches $154*10^3$ tons per day (Lamers 2006). Soybean and sunflower absorb 99% of the available crushing capacity (Panichelli 2006). The technology applied for the production of oil from soybean on large scale is solvent extraction (Panichelli 2006).

The production process of biodiesel is relatively simple. After extraction, the oil is usually filtered in a pre-treatment step to remove water and other contaminants. In the actual biodiesel production step, the transesterification step, the oils are blended with an alcohol (usually methanol) and a catalyst. This leads to the breaking of oil molecules, which reforms into esters (biodiesel) and glycerine (Lamers 2006).

6. Economic feasibility of selected bioenergy chains in La Pampa province

6.1. Methodology

The costs for bioenergy production for the two defined chains are calculated for the scenarios. Cost data, collected from 2007 to the beginning of 2008, are used as a basis for the current situation. The conversion of cost data from € to US$ (or vice versa) is based on February 2008. Future costs and market prices are based on the main characteristics of the different scenarios to 2030 (see table 1 and table 6). Unless indicated else, the prices for 2015 are the average between the price or cost for 2030 and the current situation. General cost and price items used in the calculations for the soybean and switchgrass bioenergy chain are shown in table 7.

6.1.1. Cultivation on the land for biomass production

The cultivation costs are the sum of the cost for land rent, fertilizer, agrochemicals, seeds, labour and machinery, harvesting costs and operation and maintenance (O&M) and depend on the required inputs (as explained in 4.1 and 4.2) and the assumed price level per input required. Table 8 shows the main cost and price items for biomass cultivation.

Input data for the current scenario of soybean cultivation are based on a cost analysis from Negri *et al.* (2008) for a 'direct seeding' production system for the 1st cultivation situated west of Buenos Aires province.

Table 7: General cost and price items for the soybean and switchgrass bioenergy chain for current situation and for the defined scenarios A, B, and C in 2030.

General Cost and price items	Unit	Scenarios				References
		CUR	A2030	B2030	C2030	
Interest rate (IR)	In %	8% (ARG), 6% (NL)	12%	2%	4%	(Prone 2008b; Margenes 2007b; FXStreet 2008)
Soybean oil R'dam (FOB)	US$/ton	1511	1587	1587	1587	(SAGPyA 2008a)
Soybean pellets R'dam (FOB)	US$/ton	455	455	466	479	(SAGPyA 2008a)
Soybeans BA (FOB)	US$/ton	540	567	540	554	(SAGPyA 2008a)
Soybean pellets BA (FOB)	US$/ton	385	385	431	404	(SAGPyA 2008a)
Soybean oil BA (FOB)	US$/ton	1390	1460	1523	1587	(SAGPyA 2008a)
Glycerine price	US$/ton	50	5	20	10	(Lamers 2006; Fear 2006; Miller-Klein 2006)
Price free fatty acids	US$/liter	0.05	0	0.05	0.1	(Lamers 2006; Negri *et al.* 2008; Panichelli 2006; Delgado 2002)
Pellet price	US$/ton	183	229	275	238	(Junginger 2008; Douglas 2007; Peksa-Blanchard *et al.* 2007)
Diesel price ARG	US$/liter	0.5	0.7	1.1	0.9	(GTZ 2007)
Diesel price NL	US$/liter	1.3	1.3	1.3	1.1	(GTZ 2007)
Labour cost manufacturing ARG	US$/hour	2.2	4.0	8.7	13.4	(LABORSTA 2008)
Labour cost manufacturing NL	US$/hour	33.3	33.3	33.3	36.1	(Smeets *et al.* 2008b; CBS 2007)
Labour cost agriculture ARG	US$/hour	3.2	5.9	8.7	13.4	(Margenes 2007c)
Natural gas price	US$/m^3	0.1	0.2	0.4	0.2	(Negri *et al.* 2008; Metrogas 2005)
Electricity price ARG (La Pampa)	US$/kWh	0.02	0.05	0.08	0.05	(MECON 2000; EIA 2008)
Electricity price NL	US$/kWh	0.15	0.15	0.15	0.13	(CBS 2007; ECN 2008)
Land rent Switchgrass S land	US$/ha*yr	130	195	124	111	(Petruzzi 2008a; Chessa 2008)
Land rent Switchgrass mS land	US$/ha*yr	110	110	121	110	(Petruzzi 2008a; Chessa 2008)
Land rent Soybean S land	US$/ha*yr	150	225	150	225	(Petruzzi 2008a; Chessa 2008)
Land rent Soybean mS land	US$/ha*yr	130	130	130	195	(Petruzzi 2008a; Chessa 2008)
(Cooling) water industry ARG	US$/ton	0.09	0.1	0.15	0.13	(Asal *et al.* 2005; Palermo 2008a; OPS 2008)
(Cooling) water industry NL	US$/ton	0.17	0.17	0.2	0.19	(Lenntech 2008; VEWIN 2007)
Price for heat / steam ARG	US$/kWh	0.006	0.01	0.014	0.02	(Negri *et al.* 2008; Thek *et al.* 2004)
Price for heat / steam NL	US$/kWh	0.009	0.01	0.02	0.02	(Thek *et al.* 2004)
Export tariff biodiesel	In %	17.5	20	10	15	(Petruzzi 2008b)
Export tariff vegetable oil	In %	41	40	30	15	(Petruzzi 2008b)
Export tariff pellets	In %	10	15	5	15	(Petruzzi 2008b)

Table 8: Cost data for biomass for energy cultivation in La Pampa province in Argentina for the current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				References
		CUR	A2030	B2030	C2030	
N fertilizer Urea	US$/kilo	0.5	2.0	1.7	1.4	(AACREA 2007; Margenes 2007a; ERS 2008; Margenes 2006b; ABIOVE 2008)
P fertilizer (Superphosphate)	US$/kilo	0.5	1.9	1.6	1.3	(AACREA 2007; Margenes 2007a; ERS 2008; Margenes 2006b; ABIOVE 2008)
P fertilizer (monoamonico)	US$/kilo	0.6	2.4	2.0	1.6	(AACREA 2007; Margenes 2007a; ERS 2008; Margenes 2006b; ABIOVE 2008)
Agrochemical Atrazina (1)	US$/unit	2.9	6.4	4.6	3.6	(AACREA 2007; Agromercado 2008a; Margenes 2008a; SAGPyA 2008b; Ferrell *et al.* 2008)
Agrochemical Roundup Max	US$/unit	17.8	40.1	29	22.3	(AACREA 2007; Agromercado 2008a; Margenes 2008a; SAGPyA 2008b)
Agrochemical Cipermetrina	US$/unit	5.6	12.6	9.1	7.0	(AACREA 2007; Agromercado 2008a; Margenes 2008a; SAGPyA 2008b)
Agrochemical Inoculante	US$/unit	3.7	8.3	6.0	4.6	(AACREA 2007; Agromercado 2008a; Margenes 2008a; SAGPyA 2008b)
Soybean seed RR	US$/kilo	0.2	0.2	0.2	0.1	(AACREA 2007; Benbrook 2005)
Green manure seed soybean	US$/kilo	0.5	0.5	0.5	0.4	(AACREA 2007)
Switchgrass seed	US$/kilo	15	15	10	12.5	(Petruzzi 2007a)

(1) Not all agrochemicals used for soybean cultivation are indicated in this table.

To differentiate these data to the production systems assumed for the scenarios (see table 6), economic analyses from AACREA (2007) for a conventional and a direct seeding (with and without fertilization) soybean production system are used. The required fuel and labour input for harvesting is based on data from Donato (2007). The economic analysis for soybeans (AACREA 2007) includes an assessment of the harvesting and marketing costs.

Marketing costs are the costs related to local storage, sealing, drying (3% moisture decrease), local taxes, collecting and local transport. In this study, local transport costs are not included in the marketing costs as they are calculated as a separate cost unit (see 5.1.2). The calculation of the harvesting and marketing costs for soybeans is based on price and yield levels presented in Negri *et al.* (2008) and AACREA (2007):
Formula (1) Marketing costs = 6% * (soybean price in US$/ha) * (yield in t/ha)
Formula (2) Harvesting costs = 8% * (soybean price in US$/ha) * (yield in t/ha)

In Argentina, labour and machinery costs are expressed in a unity called 'Unidad Técnica Arada' (UTA). This unity includes fuel use, maintenance and reparation of machinery, depreciation and interest, personal or manual labour and administration costs (Borga *et al.* 1997). The total 'UTA' costs for soybean production from Negri *et al.* (2008) and AACREA (2007) are differentiated to the individual agricultural activities with data from Margenes (2007c). Ultimately, the machinery and labour costs for soybean production (excl. harvesting) per agricultural activity are calculated with data from Donato *et al.* (2007) about the required labour and fuel input per agricultural activity for a defined soybean production system.

UTA costs are also provided for the implantation of pasture, which can potentially be a reference for switchgrass production. However, available data show a large variety in implantation costs according to the type of pasture planted, selected region and year (Tosi *et al.* 2001; Tosi *et al.* 2005). Due to this large data variety and the lack of required input data for various management systems, it is decided to use the input and cost data on switchgrass cultivation in Europe from Smeets *et al.* (2008b) as a basis to calculate labour and machinery costs. Labour and fuel costs are an outcome of the required input per agricultural activity (including harvesting) multiplied by the cost per input. The cost of machinery is divided into capital, operation and maintenance, fuel, labour, storage, insurance and others. The Argentinean purchase price (Margenes 2008b) is used for tractors, loaders and trailers. For the other agricultural machines, Argentinean purchase prices were not available or not specified enough. In this case, the purchase price is based on Smeets *et al.* (2008b).

Switchgrass seeds (see table 8) currently need to be imported from Texas at a cost price of 20 US$/kg. In case seeds would be produced in the country, the cost would probably be around 10 US$/kg, as seeds from similar species (Kleingrass or Digitaria) that are produced on the local market are about half the price (Petruzzi 2007b). Seeds can be easily produced by seed harvesting on the switchgrass plantation which generates seeds for future cultivations (Petruzzi 2008b).

One of the relevant costs for biomass cultivation is land rent. Current land rental prices in Argentina are high, also compared to other countries (USDA 2007), and both land rent as the value of land fluctuate strongly between land-use types, (Margenes 2007b) and expected crop prices[6] (Hilbert 2008b). The indication of land prices for S and mS land for 2007 in the selected region by various authors (Petruzzi 2008a; Chessa 2008a; Prone 2008b; Diaz 2008; Arbolave 2007) ranges from 100 to 450 US$/ha*yr depending on land suitability type, location and crop type.

6.1.2. Transport and storage of biomass products

The cost for transport is shown in table 9 in US$/tkm. Calculating the transport distance from the roadside of the field to the first processing unit is based on the approach taken by Wicke (2006) and Batidzirai *et al.* (2006). The delivery area for a processing unit is the area of land needed for meeting the energy crop demand of the processing unit. Portraying this delivery area as a circle -with the processing unit in the centre of it- and various production fields located inside, allows the calculation of the average transport distance from the roadside of an energy crop field to the processing unit as the radius of this circle. The size of the delivery area depends on the energy crop yield and the coverage of the crops (as % of the total land). Multiplying these two parameters gives the distribution density of the energy crop. It is assumed that there is a uniform distribution density within the delivery area, so that the average transportation distance from the roadside to the first processing unit is calculated using formula (3):

Formula (3): $$R = \sqrt{\frac{P}{(2 * \Pi * Y * C)}}$$

Where: R = average transport distance from roadside field to processing unit in km^2
P = Capacity processing unit in tons/yr
Y = Energy crop yield (in tons/km^2 per year)
C = coverage of energy crop (as percentage of total land area)

Distances from the 1st processing unit onwards to the next facilities are shown in table 10. Truck transport from the farm to the first processing unit is ‘dedicated’, meaning that the truck has no load on its return. Transport from the first processing unit to the next stop onwards is ‘non-dedicated’, meaning that there is new cargo for the return trip and therefore costs are calculated for a one-way trip only. Local storage costs for soybeans are included in the marketing costs (see formula 1). Storage for switchgrass bales is located at the pellet plant, stored outside the pellet plant under a plastic roof. The costs involved are based on data from Smeets *et al.* (2008b), Margenes (2007a) and RPB (2007). Storage costs of the pellets are included in the costs for pellet production. A dry matter loss of 2.5% is assumed for all scenarios, based on data from Hamelinck *et al.* (2005). As pellets are stored at the pellet plant, it is assumed that storage at the harbour is only needed for limited time.

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[6] End of 2008, soybean prices dropped substantially from 600 to 300 US$/ton. This resulted in a similar decrease in land rents for this period, showing the sensitivity of land rents to (international) crop prices.

In the current situation, the plants in Rosario load the biodiesel produced directly in the ships due to lack of storage capacity. The crude soybean oil is stored at the crushing plant in Rosario and thus closely located at the harbour. Due to large fluctuations in storage costs at the harbour areas in Argentina (Palermo 2008b; Larizzate 2008) and the expected limited storage time at the harbour for all products defined, the storage costs at the harbour in Argentina is assumed to be zero. Once the products arrive in the Netherlands, there are no storage costs as the products are directly transported to the power plant or biodiesel plant.

Table 9: Transportation costs for various transport modes used in the switchgrass and soybean bioenergy chains for the current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				References
		CUR	A2030	B2030	C2030	
Truck transport	US$/tkm	0.06	0.12	0.18	0.19	(Bergero 2007; Smeets *et al.* 2008b; López 2005; NEA 2004)
Train transport	US$/tkm	0.03	0.03	0.05	0.07	(Bergero 2007; Smeets *et al.* 2008b; López 2005; NEA 2004)
Sea ship transport	US$/tkm	0.007	0.007	0.008	0.009	(BCR 2007; Bergero 2007; NEA 2004; DIMEAGRO 2008)
Inland ship transport	US$/tkm	0.14	0.14	0.09	0.03	(Smeets *et al.* 2008b)
(Un)-loading ARG	US$/tdm	3.0	3.3	3.8	4.0	(Smeets *et al.* 2008b; Chessa 2008a)

Table 10: Transport distances (in km) for soybean and switchgrass bioenergy chains.

Distance	In km.	Reference
Pellet Plant to Bahía Blanca harbour area	327	(REGION® 2008)
Pellet plant to local user La Pampa province	50	Own estimation
Bahía Blanca to harbour Rotterdam	12024	(GoogleEarth 2008)
Harbour Rotterdam to power plant	50	(Junginger 2008)
Crushing plant Junín to Rosario by truck	208	(Henrichsen 2007)
Crushing plant Junín to Rosario by train	200	(Molina *et al.* 2008)
Rosario to harbour Rotterdam	12303	(GoogleEarth 2008)
Harbour Rotterdam to fuel point	0	Biodiesel is used in Rotterdam harbour
Biodiesel plant Rosario to local fuel plant	10	Biodiesel is used in industrial area Rosario

6.1.3. Processing and conversion facilities

Cost estimations for processing and conversion facilities are based on the required inputs and the price per input, see table 7, 11 and 12. Economies of scale, included in the cost calculations, play a role in the investment costs when the scenarios assume a larger plant scale or when it is assumed that more plants need to be installed to fulfil demand. The Producer Price Index (PPI) from (UNSTAT 2007) is used as a reference to differentiate investment costs of machinery between the Netherlands and Argentina and between scenarios, each characterised by its level of economic growth. PPI measures the average change in selling prices, received by domestic producers of goods and services over time and is used as a basis to estimate investment costs for the biodiesel and pellet plant.

Pelleting costs include fixed and operating costs. Pelleting costs for Argentina are based on Thek *et al.* (2004) and Samson (2006) where Thek (2004) provides a basic structure to analyze costs for pellet production based on wood for the Austrian and Swedish situation. Input data such as fuel, electricity and labour costs are specified for Argentina. Cost data about machinery for pellet plants in Argentina are limited although some information is provided by Molina *et al.* (2008) and Troncoso (2008).

It is assumed that pellets in the Netherlands are used to generate electricity in coal-fired plants. During co-firing, the biomass is mixed with coal. Typical co-firing ratios are up to 10% while in newer multi-fuel power plants higher shares of about 40% are possible. The lifetime of the plant is 20 years with a load factor of 6500 hours per year for all scenarios. It is assumed that pellets in Argentina will be used for district heating and for heating of larger buildings or process heat in small enterprises. Conversion takes place in an industrial, medium scale boiler with a lifetime of 20 years and a load factor of 4000 hours per year for all scenarios.

Table 11: Cost data for processing facilities included in switchgrass bioenergy chain for current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				References
		CUR	A2030	B2030	C2030	
Annual capacity pellet plant	In 10^{+3} tdm	35	45	73	100	(Peksa-Blanchard *et al.* 2007; Thek *et al.* 2004)
Load pellet plant	Hrs / yr	7884	7884	7972	8000	(Kingston 2007; Thek *et al.* 2004)
Drying machine used	Unit	Tube bundle dryer	Tube bundle dryer	Drum dryer	Superheated steam dryer	(Thek *et al.* 2004; Mani *et al.* 2006)
Storage type pellet plant	Unit	Silo	Silo	Warehouse	Warehouse	(Thek *et al.* 2004)
Capacity power plant (1)	MW(el)	10	40	40	40	(Dornburg *et al.* 2007)
Investment power plant (2)	€/kW(el)	250	250	230	230	(Dornburg *et al.* 2007)
O&M costs power plant	% inv.	38%	38%	38%	38%	(Dornburg *et al.* 2007)
Net electric ή	Mje/MJlhv0	37%	44%	44%	44%	(Dornburg *et al.* 2007)
Capacity boiler	MW (th)	2	2	2	2	(Dornburg *et al.* 2007)
Investment costs boiler	€/kW th	450	450	420	400	(Dornburg *et al.* 2007)
O&M costs boiler	% inv.	4%	4%	4%	4%	(Dornburg *et al.* 2007)
Net heat ή	MJth/MJlhv0	0.87	0.9	0.9	0.9	(Dornburg *et al.* 2007)

(1) Only capacity of electricity produced from biomass is given, (2) Investment costs for co-firing, and costs are additional costs of biomass co-firing while the basic investments for the fossil fuel power plant are not taken into account.

Table 12: Data for processing facilities in soybean bioenergy chain for current situation and for scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				References
		CUR	A2030	B2030	C2030	
Capacity crushing plant (1)	Ton oil/day	2000	4000	6000	8000	(Prone 2008a; Chessa 2008a)
Capacity biodiesel plant	Liter/day	46000	40.000	100.000	200.000	(Negri *et al.* 2008)
Load	Days/year	359	359	359	359	(Negri *et al.* 2008)
Methanol price ARG	US$/kilo	0.7	1.5	2.0	1.1	(Lamers 2006; Duncan 2003; Methanex 2008)
Methanol price NL	US$/kilo	0.8	1.7	2.0	1.1	(Lamers 2006; Duncan 2003; Methanex 2008)
Hexane price	US$/ton	1000	2875	2250	1625	(ICIS 2008; PCA 2008)
Sodium hydroxide ARG	US$/ton liq.	540	878	1148	1148	(Asal *et al.* 2005; ICIS 2008; Harriman Chemsult Ltd 2008)
Sodium hydroxide NL	US$/ton liq.	480	780	1148	1148	(Asal *et al.* 2005; ICIS 2008; Harriman Chemsult Ltd 2008)
Sulphuric acid price	US$/kilo	1.6	4.6	3.6	2.6	(Asal *et al.* 2005; PCA 2008; Meulen 2008)
Phosphoric acid price	US$/kilo	0.1	0.4	0.2	0.2	(Asal *et al.* 2005; PCA 2008; Meulen 2008)
Water treatment cost ARG	US$/l biod.	0.24	0.48	0.48	0.47	(Panichelli 2006; Haas *et al.* 2005)
Water treatment cost NL	US$/l biod.	0.48	0.48	0.48	0.47	(Panichelli 2006; Haas *et al.* 2005)

(1) Larger crushing plants are available in Argentina in the current situation. However, due to the (for some scenarios) limited availability of soybean for bioenergy production, a smaller size is selected to limit the transportation distance for delivery of the input product.

The cost to convert pellets into electricity or heat is calculated from the yearly capital and operational costs of the installation, the yearly fuel costs, the efficiency of conversion, the operation hours in a year and possible revenues from by-products using formula 4 (Dornburg *et al.* 2007):

Formula (4): $$C_e = \frac{INV * (af + OM)}{lf * 3600} + M_{by\text{-}p} * P_{by\text{-}p}$$

Where: C_e = Cost of energy production (electricity, heat) in US$/MJ
INV = Specific investment costs per output capacity (electricity, heat) in US$/MW
af = Annuity factor
OM = Yearly operation and maintenance costs as ratio of total investment in 1/year
lf = Load factor of conversion installation in hours/yr
$M_{by\text{-}p}$ = Amount of by-product in MJ_{th} or MJ_{el} per MJ_{energy}
$P_{by\text{-}p}$ = Price of by-product in US$/ MJ_{th} or in US$/MJ_{el}

The crushing facilities in Argentina are privately owned. It is therefore difficult to obtain cost data for this part of the biodiesel value chain. Indicated cost levels range from 5 to 12 US$ per ton grain (Prone 2008a; Negri *et al.* 2008; Chessa 2008b). For the current situation, we assume a cost of 8 US$ per ton grain for the crushing process. A cost breakdown of the crushing process from Larizzate (2008), excluding input costs from the grains is used in this study: 40% variable costs, 30% fixed costs including employment and 30% amortization costs. The required amount of inputs (electricity, natural gas, water, chemical inputs) for the oil extraction process is taken from Panichelli (2006). The required labour input is estimated with information from Panichelli (2006), Larizzate (2008) and Trigueirinho (2008). The calculated total crushing costs are allocated over the pellets and crude soybean oil, based on the mass balance ($97*10^3$ tons of crude soybean oil, $457*10^3$ tons of pellets for an input of $572*10^3$ tons of grains) of the output products.

In this study, the transesterification process takes place in Rosario or, alternatively, in Rotterdam. It is assumed that on each location the same plant capacity is used. The input-output balance for the biodiesel production process is based on information of the mass balance for the transesterification process from Asal *et al.* (2005), Lamers (2006), Donato *et al.* (2007) and Panichelli (2006). Input data for electricity and heat for the transesterification process are from Panichelli (2006). The required amount of labour input and data on investment costs for biodiesel plants are taken from Negri (2008). The availability of free fatty acids is estimated as 12.6% of the generated glycerine production (Negri 2008). Extra revenues from free fatty acids depend on price and demand. A price of 0.20 US$/liter is given by Negri (2008). Several studies (Lamers 2006; Panichelli 2006; Delgado 2002) do, however, not consider free fatty acids as a by-product but as a waste with no value.

Biodiesel cost estimations from Argentina do not mention an extra cost for waste water treatment, although the item is indicated by Panichelli (2006) for the extraction and transesterification process. Waste water treatment costs vary per location due to different environmental regulations (Haas *et al.* 2005). In the study from Haas *et al.* (2005), a cost for wastewater treatment of US$ 50.000 per year for a biodiesel plant of 105.000 liter biodiesel per day is used (0.48 US$/liter biodiesel per day). Water treatment costs are included for all scenarios (see table 6). New technologies reduce the amount of waste water in the system (Hilbert 2008a), which is considered for scenario B and C.

6.2. Economic analysis switchgrass bioenergy chain

Switchgrass cultivation costs (figure 11) range from 33 (A2015-S) to 91 US$/tdm (B2030-mS). For comparison, calculated switchgrass production costs in various countries in Europe range from 46 to 119 US$/tdm or 31 to 81 €/tdm (Smeets *et al.* 2008b). We can assume that switchgrass cultivation (with a cost range of 339 to 306 US$/ha per year for CUR on S and mS land respectively) is competitive with alfalfa production in the current situation as alfalfa production costs for bales in the same region (land suitability type undefined) are estimated in 2008 at 320 US$/ha per year with a margin of 176 US$/ha year (Chessa 2008a). This study has calculated purely the costs for switchgrass cultivation and profits are excluded in the analysis. Although the margin for switchgrass cultivation is not defined, depending largely on the demand of the product, a similar margin as for alfalfa production is realistic though.

For comparison, current livestock production costs in La Pampa province are estimated at 36 US$/ha with a net margin of 17 US$/ha (Iturrioz 2007), based on a price of 1300 US$ per cow (Agromercado 2008). As the margins for livestock production are considerably lower than for alfalfa production, switchgrass production is expected to be competitive with livestock production and other, similar land-uses in the region.

In all scenarios, costs for switchgrass cultivation on mS land is higher than on S land due to lower yields and relatively higher fixed costs (e.g. land rental). The contribution to total cultivation costs is, depending on the scenario, 15-39% for land-use, 36–54% for machinery and fuel costs and 3-30% for fertilizer costs. The variation of the latter is due to assumptions about fertilizer input (see section 4) and the price per unit of fertilizer in each scenario.

Figure 11: Switchgrass cultivation costs in US$/tdm for defined land suitability types (mS and S land) for the current situation and for scenarios A, B and C in 2030.

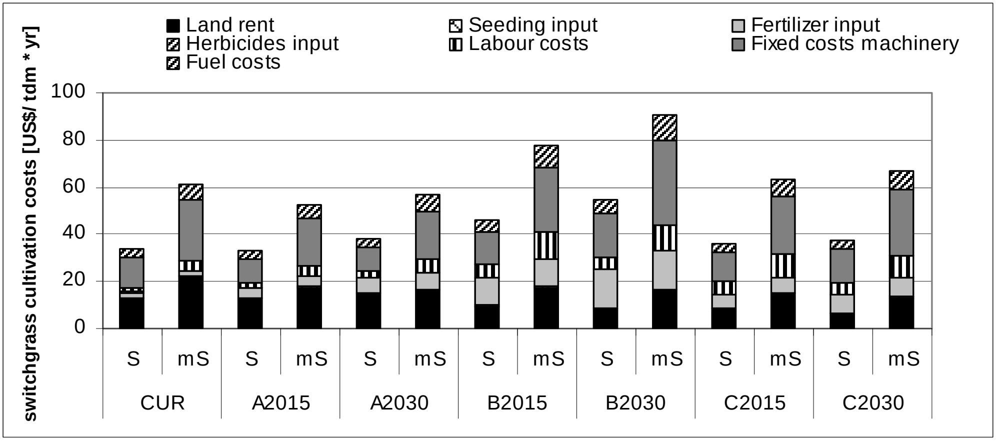


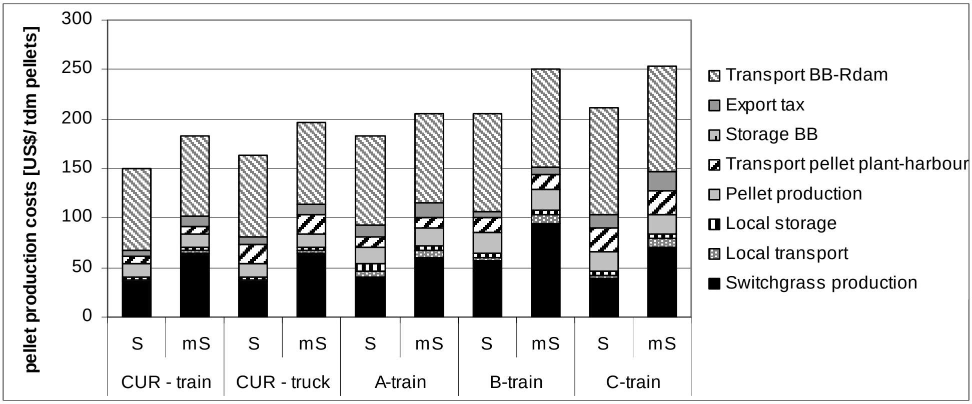
Table 13: Pellet production costs in US$/tdm delivered at harbour Rotterdam (for export chain) or at end-user in Argentina (for local use) for current situation and for scenarios A, B and C to 2030. Cost margins (assumed European pellet production costs minus calculated costs) are indicated for export chains.

Scenario	CUR		A2030		B2030		C2030	
Land suitability type	S	mS	S	mS	S	mS	S	mS
Pellet production costs Europe (low)	110	110	110	110	110	110	110	110
Pellet production costs Europe (high)	205	205	205	205	205	205	205	205
Cost pellet at harbour ROT (truck)	163	196	218	240	252	297	253	296
Margin with European pellet costs (low)	-53	-86	-108	-130	-142	-188	-143	-186
Margin with European pellet costs (high)	42	9	-13	-35	-46	-92	-48	-91
Cost pellet at harbour ROT (train)	150	184	183	214	211	282	214	270
Margin with European pellet costs (low)	-40	-74	-73	-95	-95	-141	-101	-141
Margin with European pellet costs (high)	55	22	22	0	0	-46	-6	-49
Cost pellet at end-user (local use)	58	88	80	89	100	143	80	117

Table 13 presents the calculated pellet production costs for the current situation and for the scenarios to 2030 compared to a range of estimated pellet production costs from 110-205 US$/tdm (75-140 €/tdm)) in Europe based on Thek *et al.* (2004) and Peksa-Blanchard *et al.* (2007). Pellet production costs for local use, until delivery at the end user, range from 58 (CUR–S) to 143 US$/tdm (B2030-mS). Pellet production costs for the export chain, until delivery at the harbour in Rotterdam, range from 150 (CUR-S–train) to 218 US$/tdm (B2030-mS–truck). Most scenarios show a positive cost margin when a pellet production cost of 205 US$/tdm (140 €/tdm) is assumed. Scenario (C2030) is competitive when European pellet production costs are 253 US$/tdm (144 €/tdm). Pellet production from mS land shows in general higher costs than pellet production costs from S land (see figure 11). Transport of pellets from the pellet plant to the harbour by train instead by truck reduces costs for all scenarios.

Figure 12 shows the contribution of the various cost items to total pellet production costs delivered at the harbour of Rotterdam for the selected scenarios. The contribution to total pellet production costs for the scenarios shown is 20% (C2030-S-train) to 44% (B2030-mS–train) for cultivation, 35% (B2030-mS–truck) to 55% (CUR–S–train) for oceanic ship transport, and 6% (CUR–mS–truck) to 10% (B2030–S–train) for the pelleting process. As shown in pie 1, drying and pelletisation are the main cost items for pellet production.

Figure 12: Pellet production costs in US$/tdm. Pellets are produced in Argentina and delivered at harbour of Rotterdam, using truck or train for inland transport. Results are presented for defined land suitability types (mS and S land) for current situation and for scenarios A, B and C to 2030.



Pie 1: Relative contribution in % of various cost items to pellet production costs for scenario (CUR-S).

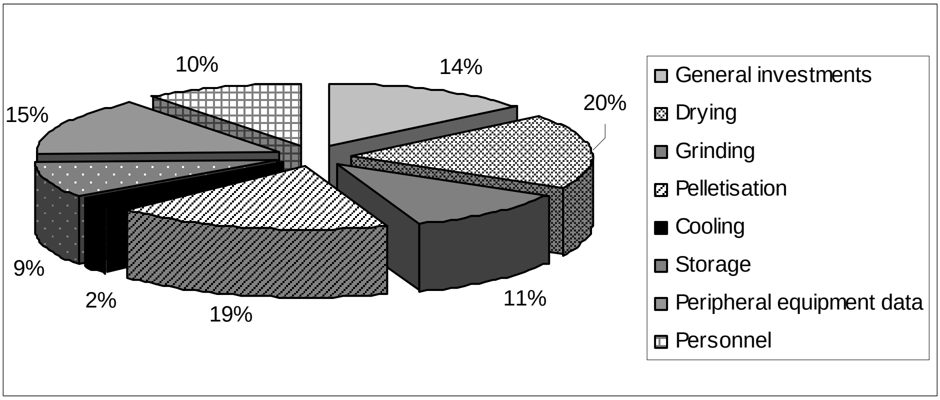


Table 14 shows the total conversion costs in US$/GJ and in US$/kWh for electricity in the Netherlands and for heating in Argentina generated from switchgrass pellets. Electricity costs for co-firing pellets in the Netherlands range from 0.06 to 0.08 US$/kWh. The chains producing switchgrass on S land with train as transport means have the best cost results. Current cost prices for electricity from coal in the Netherlands range from 0.05 to 0.09 US$/kWh, the latter including costs for carbon capture and storage (Ouwens 2006). The results in table 14 show that the electricity costs for co-firing pellets in the current situation and in scenario (A2030) are close to the electricity costs from coal when costs for carbon capture and storage are excluded. All scenarios show a positive cost margin with the electricity costs from coal when costs for carbon capture and storage are included.

Table 14: Total conversion costs and margins for heating in Argentina (US$/GJ) and electricity in the Netherlands (in US$/kWh) from switchgrass pellets for current situation and scenarios A, B and C to 2030.

Scenario		CUR		A2030		B2030		C2030	
Land suitability	Unit	S	mS	S	mS	S	mS	S	mS
Conversion costs electricity (truck) NL	US$/GJ	16.7	18.5	19.7	20.9	20.4	22.8	20.2	22.5
	US$/kWh	0.06	0.07	0.07	0.08	0.07	0.08	0.07	0.08
Margin low*	US$/kWh	-0.01	-0.02	-0.02	-0.02	-0.02	-0.03	-0.02	-0.03
Margin high**	US$/kWh	0.03	0.02	0.01	0.01	0.01	0.0	0.01	0.0
Conversion costs electricity (train) NL	US$/GJ	16.0	17.8	17.8	19.4	18.2	22.0	18.1	21.1
	US$/kWh	0.06	0.06	0.06	0.07	0.07	0.08	0.07	0.08
Margin low*	US$/kWh	-0.01	-0.01	-0.01	-0.02	-0.01	-0.02	-0.01	-0.02
Margin high**	US$/kWh	0.03	0.02	0.02	0.02	0.02	0.01	0.02	0.01
Conversion costs local heating ARG	US$/GJ	9.6	11.3	8.9	9.9	7.9	10.2	7.0	9.0
	US$/kWh	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.03
Margin (in $1*10^{-2}$)	US$/kWh	-2.2	-2.8	-0.5	-0.9	1.1	0.3	2.3	-0.5

* Based on cost price electricity for coal of 0.05 US$/kWh. ** Based on cost price electricity for coal of 0.09 US$/kWh.

Heating costs in Argentina (local use) from pellets range from 0.02 to 0.04 US$/kWh. Differences between the various scenarios are limited. The current price[7] of natural gas for heating in Argentina is 0.12 US$/m^3 or 0.01 US$/kWh (Negri *et al.* 2008), including national taxes (≈ 10-20%) but excluding provincial or municipality taxes. The price of natural gas for future scenarios is based on defined fluctuations in the electricity price (see table 7). Natural gas prices in Argentina are substantially lower than its surrounding countries (0.07, 1.47, 0.59 and 0.53 US$/m$^3{}_{2005}$ in Argentina, Brazil, Uruguay and Chile). The heating cost from switchgrass is competitive with the assumed heating price (see table 7) for scenario (B2030, C2030-mS) and close to competitive for scenario (A2030-S, C2030-mS). Based on current natural gas prices, switchgrass pellets for heating cannot compete with natural gas for heating in Argentina. Switchgrass pellets can, however, be used as alternative energy source for areas where natural gas is not available (Petruzzi 2008b), see section 7.

6.3. Economic analysis soybean bioenergy chain

Cultivation costs (figure 13) range from 182 US$/tdm (CUR-S) to 501 US$/tdm (B2030–mS). In comparison, Berkum et al. (2006) calculated a price of soybeans (CIF-Rotterdam) from Argentina and USA of respectively 225 US$/ton and 299 US$/ton including national transport to the harbour and an off-farm price of soybeans in Argentina of 145 US$/ton. The difference between the calculated off-farm prices of soybeans between this study (CUR-S) and Berkum et al. (2006) can be explained by differences in costs for herbicides and fertilizers: this is 59 US$/ton in this study compared to 23 US$/ton in Berkum *et al.* (2006). The influence of input prices on cultivation costs is further discussed in 6.4.

Cultivation costs for alternative crops in or near the same region are around 427 US$/ha for wheat and around 183-218 US$/ha for sunflower (direct costs only) (Chessa 2008a). In general, sunflower cultivation costs are slightly lower than soybean production costs but differences in net margins (249 for sunflower and 248 US$/ha for soybeans in mid 2008) are negligible (Agromercado 2008b). Soybean production for bioenergy purposes (348–440 US$/ha for CUR) is thus competitive with alternative, similar, land-uses. Beside, soybeans can be sold to various markets (food, feed, fuel), which gives a farmer selling alternatives, in case of a decreasing demand in the biofuels market.

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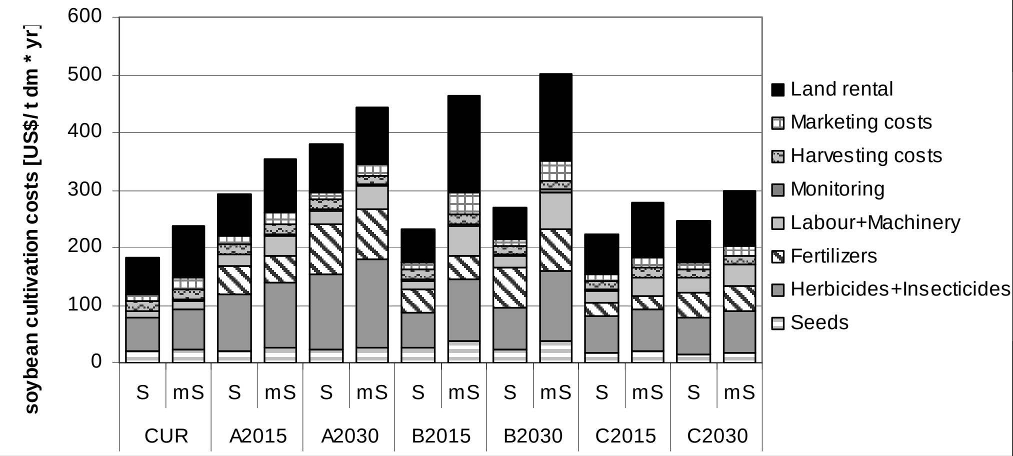
[7] Prices are used as cost estimates for heating from natural gas are not transparent in Argentina.

Figure 13: Soybean cultivation costs in US$/tdm per year for defined land suitability types (S and mS land) for current situation and for various scenarios A, B and C in 2015 and in 2030.



The contribution of cost items to total cultivation costs is, depending on the scenario, 23% (A2030–S) to 35% (CUR–S) for land rent, 20% (C2030–S) to 37% (A2030–mS) for agrochemicals and 0% (CUR) to 27% (B2030–mS) for fertilizers. The variation of the last two items can be explained by differences in costs per input (table 7) and the assumptions behind the scenarios (table 6).

Table 15 shows the total biodiesel production costs for various scenarios. Biodiesel production costs for local use in Argentina range from 0.3 US$/liter (CUR–S–train) to 1.2 US$/liter (B2030–mS–truck), which is 10 to 34 US$/GJ respectively. Train transport from the crushing plant to the biodiesel plant instead of truck transport results in a decrease in final costs for all scenarios.

For comparison, Hoff (2007) gives a biodiesel cost estimation of 0.5 US$/liter. Net production costs for biodiesel calculated by Asal *et al.* (2005) and Lamers (2006) are 0.4 US$/liter without taxes (fuel transfer tax, diesel tax, taxes on profits for crude fuels) and 0.49 US$/liter including local taxes for the year 2006. The difference in biodiesel production costs between this study and Lamers (2006) and Asal *et al.* (2005) can largely be explained by the assumption in costs for vegetable oil as input in the biodiesel production process as Lamers (2006) and Asal *et al.* (2005) use price data whereas this study uses cost data based on outcomes from previous steps in the bioenergy chain.

Table 15: Soybean biodiesel production costs and (in US$/liter) for local use and for export for current situation and for scenarios A, B and C to year 2030, specified for defined land suitability types (S and mS land) and for the possibility of biodiesel conversion in Rotterdam (ROT) or in Rosario (ROS). Also indicated is the oil price (US$/barrel) against which soybean biodiesel costs are competitive with fossil fuel costs.

Scenario	CUR		A2030		B2030		C2030	
Land suitability type	S	mS	S	mS	S	mS	S	mS
Costs for export chains in US$/liter								
Biodiesel processing in ROS – truck	0.5	0.6	0.9	1.1	0.8	1.2	0.8	0.9
Oil price (US$/barrel)	83	98	162	183	143	211	131	159
Biodiesel processing in ROS - train	0.5	0.5	0.9	1.0	0.8	1.2	0.7	1.0
Oil price (US$/barrel)	80	94	153	173	134	202	124	151
Biodiesel processing in ROT - truck	0.6	0.7	1.1	1.2	0.9	1.4	0.8	1.0
Oil price (US$/barrel)	101	118	183	207	157	238	132	160
Biodiesel processing in ROT - train	0.6	0.7	1.0	1.1	0.8	1.3	0.7	1.0
Oil price (US$/barrel)	96	113	175	199	149	229	126	153
Costs chain local use in US$/liter								
Biodiesel processing in ROS - truck	0.3	0.4	0.7	0.8	0.7	1.0	0.6	0.7
Oil price (US$/barrel)	58	70	122	139	114	176	98	121
Biodiesel processing in ROS - train	0.3	0.4	0.7	0.8	0.6	1.0	0.5	0.7
Oil price (US$/barrel)	55	67	114	131	106	168	91	115

Biodiesel production costs for export to the Netherlands range from 0.5 US\$/liter (CUR–S-train-ROS) to 1.7 US\$/liter (B2030–mS-truck-ROT). This is 13.8 US\$/GJ to 44.8 US\$/GJ respectively. In comparison, current and future estimated production costs in for biodiesel are 14.1 $\text{US\$/GJ}_{2002}$ in the US (soybean, likely export price), 17.4 $\text{US\$/GJ}_{2002}$ in EU15 (rapeseed), 13.9 $\text{US\$/GJ}_{2020}$ in the USA, 17.2_{2020} US\$/GJ in EU15 and 14.6 $\text{US\$/GJ}_{2020}$ in Eastern Europe (AEATechnology 2002).

The margins in table 15 indicate the oil price[8] (in US$/barrel) that is needed to make the costs for soybean biodiesel competitive with the costs for fossil fuel. Current costs for soybean biodiesel, exported to the Netherlands, can be competitive with fossil fuel costs with an oil price of 80 US$/barrel, when produced on suitable land, and with an oil price of 94 US$/barrel when produced on marginally suitable land. Local soybean biodiesel production costs are competitive with fossil fuel costs with an oil price of 55 US$/barrel, when produced on suitable land, and with an oil price of 67 US$/barrel when produced on marginally suitable land.

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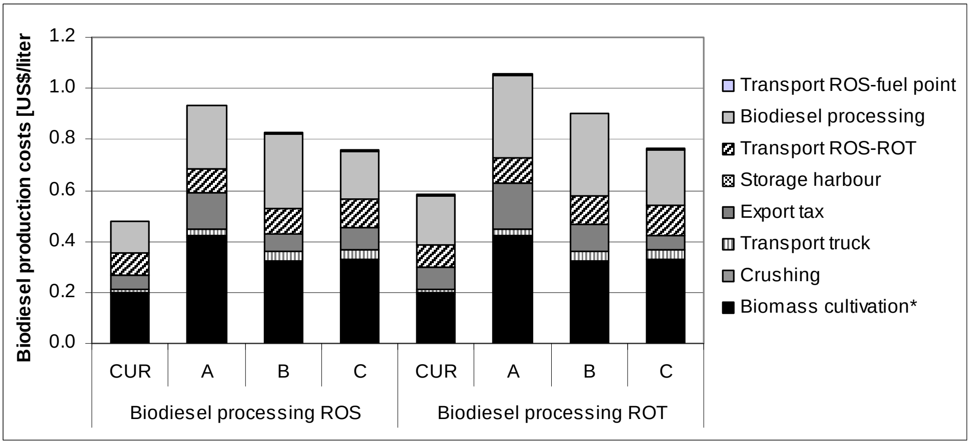
[8] Fossil fuel costs: based on oil barrel price in US$/barrel (6.38 GJ/barrel) plus 10% extra costs for refinement and transport.

Figure 14: Biodiesel production costs in US$/liter, produced from soybeans in Argentina on S land. Results are shown for export chains using truck transport for current situation and for scenarios A, B and C in 2030. Biodiesel processing is located in Rosario or in Rotterdam.

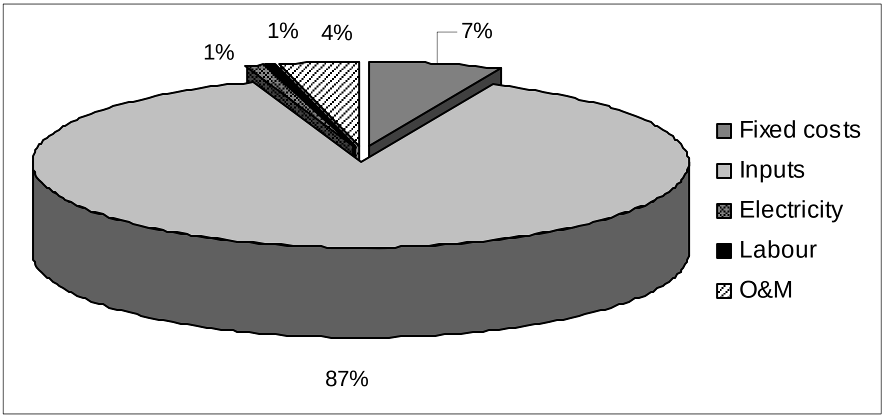


* Biomass production includes local transport in Argentina, ROS = Rosario, ROT = Rotterdam

The contribution to total biodiesel production costs (see figure 14) for the selected scenarios is 9% (A2030–ROT) to 18% (CUR–ROS) for oceanic ship transport, 33% (CUR-ROT) to 44% (A2030-ROS) for cultivation including local transport costs and 7% (C2030-ROT) to 17% (A2030-ROT) for taxes. Cultivation and transportation costs contribute together 61% to the total costs (in CUR-ROS) compared to 27% for the crushing and transesterification process in the same scenario.

It is cheaper to locate the biodiesel processing facilities in Rosario than in Rotterdam (see figure 14, table 15). Pie 2 shows the relative cost distribution of the transesterification process for a biodiesel plant in Rosario for (CUR–S) excluding the income provided by the selling of by-products. By-products in the transesterification process are glycerine and free fatty acids. The selling of these by-products reduces the biodiesel processing costs from 379 to 373 US$/ton biodiesel for (CUR–S-truck) which is around 1%. The relative cost distribution of the transesterification process for a biodiesel plant in Rotterdam shows a slightly different picture than the cost distribution shown in pie 2 for a biodiesel plant in Rosario: 83% inputs (including oil and other chemicals), 1% electricity, 10% labour, 1% operation and maintenance (O&M) and 4% fixed costs. The differences in relative cost distribution between biodiesel processing in Rotterdam and Rosario is explained by higher costs for oil input in Rotterdam (as ship transport and taxes are already included) and variations in price assumptions (table 7).

Pie 2: Relative cost distribution of transesterification process in biodiesel plant in Rosario for scenario (CUR-S-truck).

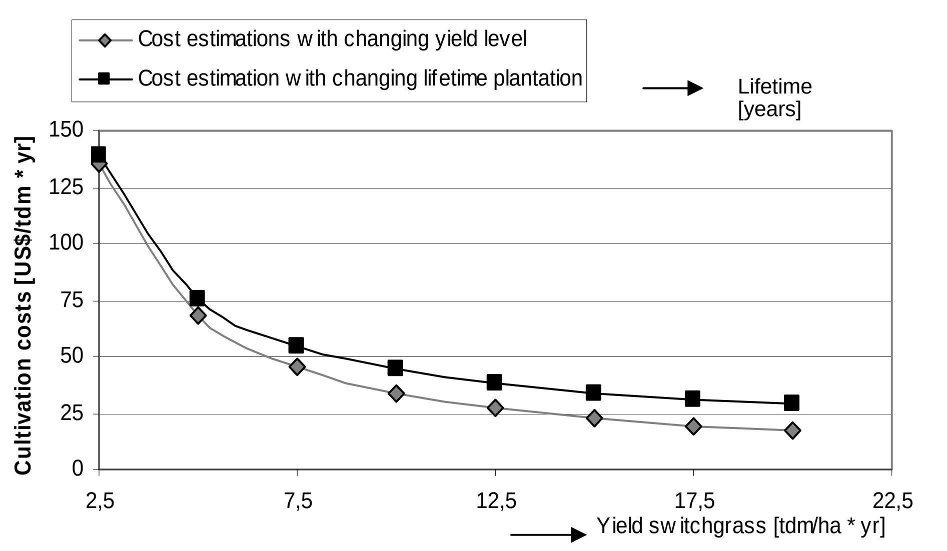


6.4. Sensitivity analysis economic results bioenergy chains

The economic analysis is based on cost data for the current situation, collected from September 2006 to August 2008. Prices in Argentina fluctuate strongly over time. For example, the price for Urea fertilizer increased from 0.5 US$/kilo in august 2007 (Margenes 2007a) to 0.73 US$/kilo in august 2008 (Agromercado 2008b) and soybean prices dropped from 600 to 300 US$/ton in one month in the 3rd quarter of 2008 (Hilbert 2008b). The cost data for (CUR) reflect therefore a snapshot of the current situation. This also explains some of the differences in cost results between various studies of soybean and biodiesel production available in Argentina. In addition, required inputs for soybean production vary strongly per region and production system, which is not specified by Berkum et al. (2006). Total direct costs for the first cultivation of soybean in August 2008 range, as an example, from 245 US$/ton in west Buenos Aires for limited tillage to 308 US$/ton in south-east Buenos Aires for conventional farming (Agromercado 2008b). The cost results of the future scenarios are based on assumptions following story lines that have a certain interpretation of a future world and should be interpreted this way.

Cultivation costs on the field are calculated for S and mS land for both energy crops. The yields are an output of the biomass potential assessment and based on a selected management system for all crops (see 3.1). Figure 15 shows for (CUR-S) the influence of yield variation (fixed lifetime) and variation of the lifetime of the plantation (fixed yield level) on switchgrass cultivation costs. The influence of these parameters increases strongly when yield levels reduce below 7.5 t dm/ha per year or when the lifetime of the plantation is shorter than 10 years. The influence of yield levels for soybean cultivation costs shows similar results, resulting in a cost range of 440 US$/tdm to 110 US$/tdm when yield levels vary from 1 to 4 tdm/ha per year for (CUR-S).

Figure 15: Sensitivity of assumed yield and lifetime plantation on switchgrass production costs in US$/tdm per year shown for scenario (CUR-S).



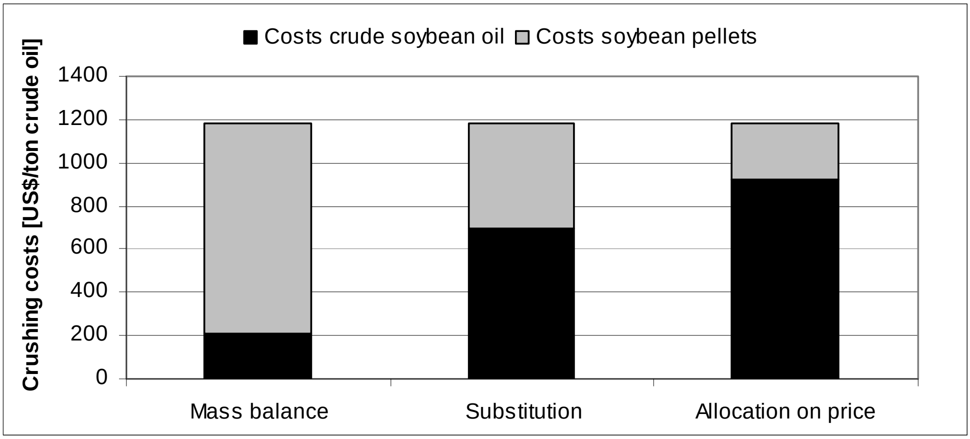
Higher yield levels can possibly be achieved in the selected region, especially for soybeans, compared to the yield levels assumed in this study for (CUR) for several reasons. First, costs are only calculated for S and mS land in this study as no VS land is available for bioenergy production in the selected region (see 4.2). In case VS land would be available (without competition), yield levels would increase and cost performances improve. Second, yield levels in the assessment of the biomass for energy potential are determined per scenario for all crops based on one management system in the country. In Argentina, some parts of the country (as the humid Pampas) apply considerably better developed agricultural management systems than other areas. This diversification within the country is also visible for individual crops as the production of some crops (especially soybeans) is more intensive and developed than others.

Cost estimations of agricultural machinery and pelletisation are based on newly purchased machinery. In reality, switchgrass and soybean cultivation can make use of existing agricultural machinery available in the region and of the common practice of sharing agricultural machinery between farmers (Chessa 2008a), which will probably reduce the calculated cultivation costs for both crops. Small pellet plants are available in La Pampa province for the production of pellets for livestock (Molina *et al.* 2008). Using these plants for relatively small amounts of switchgrass bales can possibly reduce total pellet production costs as calculated in this study.

Soybean extraction results in two outputs: pellets and crude soybean oil. In this study, the crushing cost for crude soybean oil is calculated by allocation of the total crushing costs to crude soybean oil based on the mass balance of the outputs (see also 5.1.3). However, other options are allocation based on price or energy content or the substitution of pellets by an alternative product by-products as applied in the LCA methodology (Horne 2004). Total crushing costs, including costs for grains, are around 200 US$/ton grains (CUR-S). This is 1180 US$/ton oil when no allocation or substitution is applied. Figure 16 shows the crushing costs for crude soybean oil (including input of grains) for (CUR-S), based on different allocation methodologies and substitution. In this example, soybean pellets are substituted by sunflower pellets, the latter having an economic value of 100 US$/ton (SAGPyA 2008). Allocation of price is based on the prices for soybean oil and pellets in table 7 for (CUR).

The calculated costs for crude soybean oil, based on allocation of mass, are most in line with the input prices for crude soybean oil for biodiesel production given by Asal *et al.* (2005) and Lamers (2006).

Figure 16: Crushing costs (including grain input) for crude soybean oil in US$/ton oil based on allocation by mass balance or price or based on substitution of soybean pellets by sunflower pellets.



Allocation of the crushing costs for both outputs to crude soybean oil, based on substitution or prices allocation, results in considerably higher costs for crude soybean oil and consequently, in higher biodiesel production costs. This does not seem to be realistic compared to the results of other studies. Beside, national price trends of sunflower and soybean products show large fluctuations and their relative competition strongly depends on the prices in the international market (SAGPyA 2008).

7. Discussion and conclusions

In this study, the land availability for bioenergy production from soybeans and switchgrass is calculated for different scenarios on a national and provincial level in Argentina. On a national level, $18*10^6$ ha (A2030) to $33*10^6$ ha (CUR) of land may become available for soybean bioenergy production. For switchgrass bioenergy production, $10*10^6$ (A2030) to

17*10^6 ha (C2030) of land may become available. There is a large variation in the amount of land that becomes available for biomass energy production on a provincial level, ranging for (CUR) from 0 ha (Chubut, La Rioja, Mendoza, Neuquén, Río Negro, San Juan, Santa Cruz, Tierra del Fuego) to 10*10^6 ha (Buenos Aires) for soybean bioenergy production and from 68 ha ((Tierra del Fuego) to 4*10^6 ha (Buenos Aires) for switchgrass bioenergy production.

The biomass potential on national and provincial level is calculated by multiplying the available surplus land with the productivity level of the selected energy crops. An additional allocation step is made for soybeans to calculate the amount of crude soybean oil, generated from the biomass from the whole crop. On a national level, switchgrass can reach the highest biomass energy potential of 243*10^6 tdm per year (4.5 EJ) in (C2030) compared to 99*10^6 tdm per year (1.9 EJ) in (A2030). Soybean (crude vegetable oil content) can reach biomass energy potentials of 13.8*10^6 tdm per year (0.5 EJ) in (CUR) and of 12.6*10^6 tdm per year (0.45 EJ) in (C2030) compared to 7.1*10^6 tdm per year (0.25 EJ) in (A2030). Most bioenergy production comes from a combination of suitable and moderately suitable surplus land having yield ranges from 12-22 tdm/year for switchgrass and 1.5-3 tdm/year for soybeans on a national level with strong fluctuations per province. Overall, the bioenergy potential from switchgrass is substantially higher than from soybean. The provinces Buenos Aires, Córdoba, Entre Ríos, Salta and Santa Fe have the highest biomass potential from soybeans. Buenos Aires, Córdoba, Corrientes, La Pampa and Sante Fe have the highest biomass potential from switchgrass. Possible impacts of climate change (droughts or more rain) on the biomass potential results are not taken into consideration in this study.

The selection of a suitable region for large scale bioenergy production in Argentina was based on a defined set of criteria. These are i) sufficient land availability for bioenergy production under different scenarios, ii) the production potential for both selected energy crops in the defined region, iii) limited risk for competition between land for bioenergy production and land for food or feed and iv) proximity of logistic infrastructure. The most suitable region to cultivate energy crops, based on this set of criteria, is north-east of La Pampa province and south of Cordoba, bordering the north-west of Buenos Aires and south-east of San Luis. To analyze the economic performance, the focus in this study is on La Pampa province. The available potential for bioenergy in La Pampa ranges from 1.2*10^5 (C2015) to 1.8*10^5 (B2030) tdm per year for soybean production (based on vegetable oil content) and from 6.3*10^6 (A2030) to 18.2*10^6 (C2030) tdm per year for switchgrass production.

Switchgrass production costs in La Pampa province are 33 US$/tdm (A2015-S) to 91 US$/tdm (B2030-mS). Cost estimates for soybean production in La Pampa province are 182 US$/tdm (CUR-S) to 501 US$/tdm (B2030-mS). Land-use, machinery and fuel costs, and inputs (mainly for soybean bioenergy production) are main cost components for energy crop production. Switchgrass production has in general a better cost performance (in US$/tdm) than soybean production for bioenergy.

Based on a comparison of switchgrass cultivation costs in (CUR), being 306-339 US$/ha per year, with current costs for the production of alfalfa bales (with a cost level of 320 US$/ha and a net margin of 176 US$/ha per year) and for livestock (with a cost level of 36 US$/ha and a net margin of 17 US$/ha per year) in La Pampa province, switchgrass is expected to be cost competitive with livestock production and other, similar land-uses in the region. Soybean production for bioenergy purposes in (CUR), being 348-440 US$/ha per year, is considered competitive with other, similar, land-uses as sunflower production (183-218 US$/ha per year for direct costs only) and wheat production (427 US$/ha per year).

The production and transportation costs of pellets produced in La Pampa province are 58 (CUR-S) to 143 (B2030-mS) US$/tdm for local use and 150 (CUR-S-train) to 296 US$/tdm (C2030-mS-truck) up to delivery at the harbour of Rotterdam. Electricity costs for co-firing pellets in the Netherlands, replacing coal, range from 0.06 to 0.08 US$/kWh. Current cost prices for electricity from coal in the Netherlands range from 0.05 to 0.09 US$/kWh, the latter including costs for carbon capture and storage. The electricity costs for co-firing pellets in the current situation and in scenario (A2030) are close to the electricity costs from coal when costs for carbon capture and storage are excluded.

Heating costs in Argentina from switchgrass pellets, replacing natural gas, range from 0.02 (C2015-mS) to 0.04 US$/kWh (CUR2030-mS, A2030-mS and B2030-mS). The heating cost from switchgrass is competitive with the assumed heating price per scenario (ranging from 0.012 to 0.027 US$/kWh) in scenarios (B2030, C2030-mS) and close to competitive in scenario (A2030-S, C2030-mS). Based on the current low natural gas prices, switchgrass pellets for heating cannot compete at this moment with natural gas for heating in Argentina.

Biodiesel production costs in Argentina, replacing fossil diesel, range from 0.3 US$/liter (CUR-S-train) to 1.2 US$/liter (B2030-mS-truck). Biodiesel production costs for export to the Netherlands range from 0.5 US$/liter (CUR-S-train-ROS) to 1.7 US$/liter (B2030-mS-truck-ROT). Current costs for soybean biodiesel, exported to the Netherlands, can be competitive with fossil fuel costs with an oil price of 80 US$/barrel, when produced on suitable land, and with an oil price of 94 US$/barrel when produced on marginally suitable land. Local soybean biodiesel production costs are competitive with fossil fuel costs with an oil price of 55 US$/barrel, when produced on suitable land, and with an oil price of 67 US$/barrel when produced on marginally suitable land.

This means that biodiesel is not competitive with fossil fuels, based on the oil prices in the beginning of 2009, lowering to levels of 40 US$/barrel in January 2009 (IEA 2009). IEA gives a projection for the crude oil price of 100 US$/barrel for the period 2008-2015, increasing to over 120 US$/barrel in 2030. In this projection, the fluctuations of the oil prices in 2007-2008 are taken into account. The IEA outlook (2008) indicates that “while market imbalances could temporarily cause prices to fall back, it is becoming increasingly apparent that the era of cheap oil is over” and that “pronounced short-term swings are likely to remain the norm and temporary price spikes or sharp falls cannot be ruled out”. IEA predicts an upward pressure on oil prices through to the end of the project period beyond 2015, mainly because of required investments in (additional) capacity to increase supplies

(OECD/IEA 2008a). Therefore, oil price increases are likely on the short to middle term already.

Key parameters for the economic performance of both bioenergy chains in La Pampa province are:

- *Transport costs*. Costs are reduced when favourable transport routes and transport modes are selected. It is cheaper to transport biomass inland by train than by truck;
- *Cultivation costs*. Allocation of biomass production on areas where a synergy in the potential and socio-economic performance can be obtained, is preferred;
- *Pre-processing and conversion costs*. Costs are reduced when pre-processing or conversion takes place within or near the biomass producing region, combined with an optimalization of scale and technology;
- *Prices of fossil fuels and agricultural commodities*. Fluctuations in soybean and crude soybean oil price in Argentina are for example strongly related to prices on the world market (Berkum *et al.* 2006) and its cost margins may strongly decrease with declining crop prices (UNDP 2000). As large areas of land in the country are dedicated to soybean production, this may create an economic risk on national level.

It must be realized that, as long as there is no market, the economy of scales is not working. If markets develop, it can be expected that costs decrease due to optimization of logistics, research and development, and technical learning. Improving the logistics of train transport in Argentina will make existing agricultural areas, further away from harbours, economically attractive for sustainable bioenergy production. Based on our results, it can be concluded that soybean production in La Pampa province for bioenergy has a good economic performance. As large volumes of biodiesel are needed by 2010 in Argentina to comply with its Biofuels law (Adámoli 2007), the local use of biodiesel from soybean production is recommended.

The large potential and good economic performance of the switchgrass bioenergy chain in La Pampa province, combined with an expected good environmental performance (Dam *et al.* 2008), makes it interesting to further develop the production of switchgrass in La Pampa province, especially on more marginal land areas.

Although the use of switchgrass pellets for local use is economically not competitive, when replacing natural gas, it might be worthwhile to use (part of) the switchgrass pellets for local use for:

- Contributing to the target of 8% renewable energy use for electricity production in 2016 (law 26.190);
- Stimulating incentives and promoting the development of a new market for bioenergy production;
- Reducing national GHG and energy emissions when replacing GHG intensive energy sources;
- Creating a new source of revenue for farmers while diversifying the crop area (UNDP 2000);
- Improving access of energy in the region by using switchgrass pellets for domestic heating in places where natural gas is not available (UNDP 2000);

- Replacing wood used for heating that normally comes from the natural forest (Petruzzi 2008b);
- Diversifying available energy sources within the region to back-up power shortages (UNDP 2000).

With depleting oil resources in Argentina, bioethanol production from switchgrass pellets can be an interesting alternative for heat and electricity production on the medium term. Ethanol could be produced locally for (roughly) 19 US\$/GJ_{del} on the short term to 10 US\$/GJ_{del} on the long term. Ethanol production costs further decrease from 17 US\$/ GJ_{del} on the short term to 9 US\$/GJ_{del} on the long term, when switchgrass bales are directly converted to ethanol. These cost levels can be considered competitive assuming a fossil fuel production cost of 10-26 US\$/GJ (with an oil price of 60-150 US\$/barrel). Key pre-conditions are the availability of feedstock and national demand (Lamers 2006).

As switchgrass is a relatively new alternative for bioenergy production in Argentina, the development of large-scale demonstration projects, possibly integrated with other perennial grasses for livestock production, is highly recommended.

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Chapter 4: Options of biofuel trade from Central and Eastern to Western European countries[9]

Abstract

Central and Eastern European countries (CEEC) have a substantial biomass production and export potential. The objective of this study is to assess whether the market for biofuels and trade can be profitable enough to realize a supply of biofuels from the CEEC to the European market and to estimate the cost performance of the energy carriers delivered. Five NUTS-2 regions with high biomass production potentials in Poland, Romania, Hungary and the Czech Republic were analysed for biofuel export options. From these regions pellets from willow can be provided to destination areas in Western European countries (WEC) at costs of 105 to 220 € per tonne. Ethanol can be produced at 12 to 21 € per GJ if the biomass conversion is performed at the destinations in Western Europe or at 15 to 18 € per GJ if the biomass to ethanol conversion takes place (at small scale) at the regions where the biomass is produced. Short sea shipping shows most cost advantages for longer distance international transport compared to Inland water way shipping and railway. Another reason for lower biofuel supply costs are the shorter distances between the source and destination areas. Therefore the Szczecin region in Poland, closely located to the Baltic Sea, shows a better economic performance for long distance trade of biomass production than the selected region in Hungary (‘land-locked’). It is concluded that in future key CEEC regions can supply (pre-treated) biomass and biofuels to the European market at cost levels, which are sound and attractive to current and expected diesel and gasoline prices.

1. Introduction

The EU has set ambitious targets to increase the use of Renewable Energy Sources, from which a large part has to come from biomass (DG-TREN 2001; EC 1997). In addition, the Directive on biofuels was released that recommends for an increase of the consumption of biofuels to 5.75% of the diesel and gasoline consumption in 2010 (CEC 2003). To meet these ambitious targets, a large amount of biomass resources is needed, which cannot be covered by biomass from forestry or residues alone. Several thousands km^2 of agricultural land dedicated to biomass production from energy crops would be required in the EU.

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However, the availability of good land for energy crop production is limited in Western European Countries (WEC). This means that the potential from indigenous biomass resources is not sufficient to meet the set bioenergy targets (Faaij 2006a).

At the same time, by the inclusion of the Central and Eastern European Countries (CEEC) into the EU, the agricultural area of the EU will expand significantly. Agriculture in the CEEC is characterized by comparatively low labour and land-use costs, low mechanization and input levels and low productivity compared to Western European Countries (WEC) (Pouliquen 2001). Therefore it is to be expected that agriculture in CEEC will rationalize in the future with the effect of increased productivity, less labour need and setting free of agricultural land.

A study from Dam *et al.* (2007) analysed the technical ad economic biomass production potentials in the CEEC (including the countries Estonia, Lithuania, Latvia, Poland, Romania, Bulgaria, Hungary, Czech Republic and Slovakia) based on a scenario analysis for a set of selected energy crops.

The results show that the CEEC have, especially for the scenarios with advanced, intensive agricultural production systems, a substantial biomass production potential. The potential even exceeds in some scenarios the current final energy consumption on a country level. In this study only agricultural land that is not needed to cover the demands for food and feed production and of nature protection is considered as available for energy crop production. In all CEEC up to $440*10^3$ km^2 – of which more than 75% is suitable to very suitable land – could become available in 2030 for the production of energy crops in a scenario with highest agricultural input, most advanced agricultural production techniques, high feed conversion efficiencies and optimal allocation of crop production. The corresponding bioenergy potential is 11.7 EJ, of which 85% comes from energy crops, 12% from residues and 3% from surplus forest wood. Poland could provide 29%, Romania 24% and Bulgaria 12% of these biomass sources. Thus, based on the results from Dam *et al.* (2007) it can be concluded that the CEEC have a large amount of potentially available and underutilized biomass resources. On the other hand, countries in the EU are deploying biomass in their energy mix, which cannot be met by their own indigenous biomass resources. This raises the question whether biomass trade can connect intra-European supply and demand of biofuels.

To what extent can bio-trade contribute to cost reduction of producing energy carriers from biomass? This is the key question for the development of large-scale energy crop production, infrastructure, and capacity. Setting up infrastructure for large-scale biomass production will only occur when this becomes profitable for stakeholders in both the WEC and CEEC. Therefore, an important question is whether the market for biofuels and trade can be profitable enough to realize the supply of biofuels from the CEEC to the European market.

International trade can include direct transport of biomass materials, intermediate energy carriers, or high quality energy carriers as fuels. Beside this, factors like the production method of the biomass, the transport type, and the order and choice of pre-treatment operations are of importance in the chain performance. Earlier examples (Hamelinck *et al.* 2005) have shown that intercontinental trade of biofuels and even bulk transport can be economically feasible. Main objectives of this study are therefore to:

- Estimate the cost performance of the energy carriers delivered in the WEC from the CEEC;
- Analyze the regional differences in cost performance of the energy carriers in the CEEC;
- Identify critical factors to set up a stable international biofuel trade between CEEC and WEC.

For this purpose, regions in the CEEC that are promising in terms of biomass production and export potentials are selected and described. Secondly, international biofuel transport routes that connect the biofuel producing areas in the CEEC with destination areas in WEC are identified. Thirdly the logistics and costs of the different biofuel trade chains are described and analysed. A sensitivity analysis on cost data is performed in the fourth part of the study for the biofuel trade chains before the results are finally reflected and discussed.

2. Methodology

2.1. Biomass potential assessment and selection of regions with high biomass potentials

In a previous study (see chapter 3 of this thesis), a methodology to assess the biomass potentials uniformly for all CEEC on a NUTS-3 regional level was developed (Dam *et al.* 2007). NUTS stands for 'Nomenclature of Territorial Units for Statistics' and are the statistical regions of Europe and the Accession Countries (EUROSTAT 2002). NUTS-3 regions are regional or district levels, NUTS-2 regions are county or district levels within a country. This methodology was applied to assess the biomass potentials on NUTS-2 level and to choose regions with high biomass production potentials. Five scenarios that characterize the main current and future drivers in Europe related to agriculture and land-use, are built for the regional biomass potential assessment (see table 1).

For the regional biomass potential assessment, the assumptions of the V3 scenario were used for this study because it is seen as the most realistic future scenario for 2030. The V3 scenario assumes no internal trade barriers in Europe and that the CEEC have completely adapted the EU legislation and can compete fully with the agriculture of WEC. The Common Agricultural Policy (CAP), that regulates agriculture in Europe, is fully implemented. Agricultural production systems applying high inputs and advanced technologies are used in the CEEC. Based on the results of the biomass potential assessment (Dam *et al.* 2007), five different NUTS-2 regions are selected, which look promising for large-scale energy crop production.

The following criteria were used to identify these regions:

- The region shows a large availability of land for energy crop production after food demand is fulfilled;
- The regions are more or less stable with respect to availability of land for energy crop production in all scenarios and biomass resources are relatively cheap;
- Geographical distribution of the regions with respect to main transport corridors and each other.

Based on these criteria, promising biomass production regions were selected in Poland, Rumania, Czech Republic, and Hungary.

Table 1: Set of scenarios used in regional biomass potential assessment CEEC.

Scenario	Story line
V1	There is a liberalization of trade. There are no market barriers in the world for agricultural products. EU specializes in products, which are competitive in the world market. There is a strong increase in import and export products.
V2	Policies are regionally orientated. There is an uneven economic development in Europe. Trade barriers exist between the Western and Eastern European market. The agriculture in CEEC has difficulties to compete with agriculture in WEC because of struggles as lack of investment, technology and implementation of EU policies and legislation.
V3	There are no internal trade barriers in Europe. CEEC has completely adapted the EU legislation and can compete fully with WEC agriculture. Common Agricultural Policy (CAP) regulates agriculture in Europe. The aim of CAP is that farmers can compete with world markets. CAP reforms in Europe are in full implementation.
V4	There are no internal trade barriers in Europe. Europe protects its own internal market strongly. EU strives for self-sufficiency in its own food and energy need. Internal trade has increased. External trade of products in the world market is limited.
V5	EU has a priority for sustainable development and nature conservation. Biodiversity, protection of rural areas and maintenance of the vitality of forest and grassland areas has a high concern. There is a tendency of greening of agriculture.

2.2. Assessment of the biomass distribution, availability, and production costs in the region

To determine the costs of transportation, transport requirements are related to the spatial distribution of biomass in each region. It is assumed that the distribution over an area is constant and that the biomass is transported over a marginal transport distance, that is the radius of a circle in which the biomass is spread with the given distribution density (Dornburg *et al.* 2001). Thus, for the calculation of the marginal transport distance in each region, we use information about:

- The biomass distribution density in the region in t/km^2 per year;
- The coverage of energy crops in each region in %, which is the percentage of the total land of a region that is used for the production of energy crops.

To obtain an indication for the potential surplus of biomass in each region, we consider that the selected energy crop, agricultural residues, forestry residues and surplus wood produced within the region will produce 30% of the current final energy consumption of the region and that any biomass potential larger than that is available for export outside the region. The number of 30% seems a reasonable figure given current targets for bioenergy in the EU (EC 1997; CEC 2003). A consistent set of data for final energy consumption is available on country level from DG-TREN (2003). A crude estimation of the current final energy consumption (in EJ) in the selected NUTS-2 regions is estimated by assuming that the percentage of population living in the selected region requires this percentage of the final energy consumption of the country. Population data on NUTS-2 region and on country level are available from Weger (2004), Raconczga *et al.* (2004), Rogulska *et al.* (2004) and Roman (2004) and are based on national statistics. The biomass production costs are assessed for a range of energy crops crop for different land suitability classes and production intensities. For detailed information on the cost assessment for biomass, see (Dam *et al.* 2007).

2.3. Logistics and chain selection

For chain analyses the modular spreadsheet model, developed by Hamelinck *et al.* (2005), is used. This tool enables a techno-economic analysis of a large variety of logistic long distance chains for bioenergy systems. A chain is defined by the user and processed by the model to yield results on costs and energy use. In each step along the transport chain, a biomass processing action can be selected. For each module, costs, energy use, scale effect and time (e.g. load factor, dry matter losses) are taken into account. The model processes all steps in consecutive order. After each step the results for cost and energy use are retained for an overview and new biomass characteristics are written to the next step. We limit the wide range of possible chains to three generic logistical chains for each region considered (see figure 1). All chains include willow as energy crop. Chain 1 produces pellets in the region for export, chain 2 does the same and includes the conversion of ethanol at the destination area in WEC and chain 3 includes the ethanol conversion in the biomass producing CEEC region.

Results from Dam *et al.* (2007) show that woody crops (poplar, willow) give the best potentials among all energy crops for the CEEC regions. Miscanthus, included as energy grass in the study, also shows a high potential for the CEEC regions. Information on logistical performance of energy grasses (including Miscanthus) in the CEEC can be found in Smeets *et al.* (2008b). Willow was chosen as energy crop because it showed, on average for all CEEC, a higher biomass potential than poplar.

Ethanol is selected as fuel for several reasons. Bioethanol is one of the two major biofuels produced and used today in the EU. At this moment there is a significant increase of new bioethanol plants in the EU (Hamelinck *et al.* 2005). Advantages of bioethanol are that it can flexibly be blended to a fair percentage in gasoline. Besides, bioethanol production is economically attractive with reasonable production capacities (Hamelinck *et al.* 2005). Presently, the conversion technology for lignocellulosic biomass from ethanol production is not yet commercially available. However, for 2030 we assume this technology to be commercially available. We use data from Hamelinck *et al.* (2005) and Hamelinck (2006) for expected efficiencies, costs, and scaling factors.

Hamelinck *et al.* (2005) show in the cost results for a set of logistic chains (delivering European forest residues to a power plant in the Netherlands) that there is a clear cost reduction when pellets instead of chips are transported by ship. The process of densification is important as it reduces dry matter losses and the number of international trips, especially for large distances and larger scale chains. Here, we focus on pellets or briquettes because it is a well-known and traded commodity.

The biomass production in the region (willow) is restricted to a certain harvest window, i.e. the period in which the biomass is harvested on the field of the farm. The harvest period for willow is 4 months per year (Lewandowski *et al.* 2006a) in wintertime. This period is used as a reference for all regions. For a continuous input of biomass to the logistic chain, a storage point is needed to guarantee a continuous year-round supply. Hamelinck *et al.* (2005) mention that storage is often applied at the roadside or at the farm (at the beginning of the chain) to dry the biomass. This requires the harvesting of stems or bundles at the field of the farm.

Truck transport is generally applied for relatively short distances (< 100 km.) in those areas where flexibility is required because multiple production sites have to be accessed, or where train or ship infrastructure is absent (Hamelinck *et al.* 2005). Thus, truck transport is used for local logistics in the region. Besides, storage is needed in the chain to guarantee a continuous supply. We assume a storage point in the beginning of the chain at the farm.

Generally, biomass is collected locally at small-scale production sites and subsequently transported to a Central Gathering Point (CGP), where the biomass is transferred to the main international transport corridors (Hamelinck *et al.* 2005). Truck transport generally becomes too expensive for transport of untreated, low density biomass on distances longer than 100 km. Train transport could be applied for longer overland distances (> 100 km.) and can be a serious competitor with ship transport on inland waterways for middle distance international transport, because transfer points of harbours are not needed. Sea transport is applied for longer distances. It has low variable costs and a low energy use (per t.km) compared to other transport means (Hamelinck *et al.* 2005). Based on these findings we can conclude that ship and train transport will be used for longer distances in the logistic chains. A CGP is needed to transfer from regional small-scale logistics to the main international transport routes in Europe.

Results from Hamelinck (2006) show a cost advantage for larger scale plants, which results amongst others from higher efficiency. Larger scales do not logically decrease costs further as most components reach a maximum capacity at a certain stage.

2.4. Specification of logistic chains

2.4.1. Identifying international transport routes

The biomass production source is a selected NUTS-2 region in the CEEC. For the destination area of the product, industrial areas in Europe with already main refineries and distribution points for transport fuels are selected. Transport corridors need to connect the destination areas with the source areas. Zeebroeck (2004) has studied the main transport corridors and their capacities in Europe with respect to rail and ship transport. Two different international transport chains are selected per NUTS-2 region in the CEEC. The logistic chains are assumed for the year 2030. It is expected that cost levels in the CEEC for transport have reached EU-levels in that period of time, according to the V3 scenario in 2030. This EU average is used in the calculations for all logistic chains.

2.4.2. Specifying regional logistics

2.4.2.1. On- farm logistics

For this study, we assume a moisture content of 30% for willow bundles at the field before truck transport. For the density of willow bundles we use information from the Czech Republic, assuming a density of 440 kg per m^3 dry biomass (Koutský *et al.* 2002). After harvesting and bundling of willow, the bundles are transported to the farm. Typical farm sizes in the CEEC regions are 5 to 10 ha (see table 3). Based on this information, maximum transport distances on the field are 150 m. Thus, the distance to bring willow from the field to the farm by tractor will be very limited. Because of this very small distance, we assume that tractor costs for transport on the field are included in the biomass harvest and production costs.

2.4.2.2. Conversion in the CEEC region

Pelletisation, drying, and ethanol conversion takes place within the CEEC region. Data are available from Hamelinck *et al.* (2005) and Hamelinck *et al.* (2005a). We will use these data sets as input for the model.

Pelletisation, sizing and drying:

Data from Hamelinck *et al.* (2005) are used to calculate costs and energy use for the pelletisation process. Sizing takes place on a central location close to the pellet and drying unit. The pulverising unit reduces the average particle size to 1 mm (Hamelinck *et al.* 2005) which is required for the next step: the drying process. As a reference we use data from the Stork Dryer (Hamelinck *et al.* 2005). Maximum scale for this drum is 17.8 t per hour. For pelletisation, we use the dataset for a pellet press that has a maximum capacity of 8 t per hour. The load factor is 90% (which is 7884 hours per year). A Stork Dryer can process 140 kt per year and a pellet press can process 63 kt per year. The pellet and drying unit is seen as a combined pre-processing unit. We assume an average input of 11 t per hour. Based on a load factor of 90%, the pellet and drying unit requires 86 kt per year.

Ethanol conversion in the CEEC region:

We assume that ethanol conversion in the region (source area) takes place on a smaller scale, which is 400 MW input. Data for scale factors and ethanol conversion are available from Hamelinck *et al.* (2005a) and De Wit *et al.* (2009b). The following cost data set for a 400 MW input ethanol plant is assumed: the load factor is 8000 hours per year, interest rate is 6%, and the lifetime of the plant is 20 years. The electricity output is 47.5% MW per tonne output and an electricity price of 47.7 €$_{2002}$ per MW is assumed. The efficiency (feed in / EtOH out) is 45% (De Wit *et al.* 2009b). Total investment costs in M€ are given by De Wit *et al.* (2009b) based on a cost data set from a typical input scale of 200 MW input and calculated for a 400 MW input plant. The annual fixed variable costs are calculated as a percentage (3% for maintenance, 0.5% for labour and 0.1% for insurance) of the total investment costs, based on Hamelinck *et al.* (2005a). The annual variable O&M costs are calculated as a percentage of the fixed variable costs, based on Hamelinck *et al.* (2005a). The total annual costs for conversion are the sum of the annual annuited investment costs and annual O&M costs minus income retrieved from annual electricity reimbursement.

Based on a load factor of 91%, the ethanol plant requires a yearly input of 11.5 PJ per year, which is a yearly input of 972 kt, based on a moisture content of 30% and an energy content of 15.4 GJ$_{LHV}$ per tdm. After storage on the farm, the bundles need to be transported by truck to the nearest pellet plant or ethanol plant in the region. Two important variables in this transport step are the average distance from the farm to the first processing unit and the costs for truck transport in € per t.km.

2.4.2.3. Distance from farm to first processing unit

For estimating the distance from the farm to the first processing unit the required "delivery area" (in km^2) around the pre-processing unit or plant is calculated (see formula 1).

Formula:

$$\frac{\text{(Input plant in tonne) / (yield energy crop in tonne per ha)}}{\text{Coverage energy crop in \%}} * 0.01 \qquad (1)$$

To calculate the distance from the field to the first processing unit, we use the following formula:

$$R = (\sqrt{\tfrac{1}{2} A / \prod}) \qquad (2)$$

A = required area for willow cultivation for the selected plant in km^2, see table 6.
R = radius of the circle, which presents the required distribution area.

Based on this formula, which assumes as average distance of the straight radii of the distribution area, the required distances are calculated for a small-scale ethanol plant and for a combination of drying and pelleting plant. Marrison *et al.* (1995) mention that the transport distance to a conversion or processing facility is F*r where F is a constant that accounts for the layout of the road system. For roads spreading radially from the conversion facility, F=1. Factors of F=1.25 for a square grid road system and F=1.4 for a typical agricultural region in the USA are mentioned (Marrison *et al.* 1995). Based on these factors, the average transport distance to calculate transport costs is F * (2/3) * R.

The influence of the layout of the road system on the transportation costs by truck is further discussed in the sensitivity analysis.

2.4.2.4. Costs for truck transport

Truck transport from the farm storage to the first processing unit is "dedicated", meaning that the farmer has no new load on its way back. An average speed for truck transport of 50 km per hour is used (Zeebroeck 2004). Based on data from Hamelinck *et al.* (2005), we assume a load or unload speed of 260 m^3 per hour and load or unload costs of € 0.50 per m^3. For the V3 scenario, a convergence of cost levels for truck transport in Europe of € 0.08 per t.km is used, based on current average truck transport costs in Europe. Average cost data from individual European countries are € 0.083 per t.km in France, € 0.075 per t.km in the UK, € 0.064 per t.km in Denmark, and € 0.075 per t.km in Germany, for smaller trucks, short distance (Zeebroeck 2004).

The maximum capacity of a large truck is 28 t or 100 m^3 (Zeebroeck 2004). As the weight of 100 m^3 pellets (55.2 t) is above the maximum weight (28 t) of the truck, weight is the limiting factor for truck transport of pellets. This is also true for biomass bundles with a density of 44 t per 100 m^3. Therefore, we can use the given cost data per t.km from (Zeebroeck 2004) for truck transport of fuels, pellets, and willow bundles. If volume had been the limiting factor, the cost figures should have been adapted.

2.4.2.5. Transport to the Central Gathering Point (CGP)

The distances from the first processing unit to the Central Gathering Point (CGP) are different per selected region. Truck transport from the first processing units to the CGP is "dedicated", meaning that the trucks return empty. After passing the first processing unit, pellets, or ethanol are transported to a CGP by truck. At this point, products are collected from the selected region and further transported via international transport. For calculating the distance between the processing units to the next CGP, we use formula (2) with "A" as the area of the selected region in km^2.

2.4.2.6. International transport

International transport by ship or train is "non-dedicated", meaning that the returning ships or trains bring a new load on their way back. Cost data used for international transport in the model are based on current Western European cost levels (see table 2). Data about capacities of transport modes and average speed (in km per hour) are from Zeebroeck (2004) and Hamelinck *et al.* (2005).

Table 2: Cost data and transport characteristics for international transport modes.

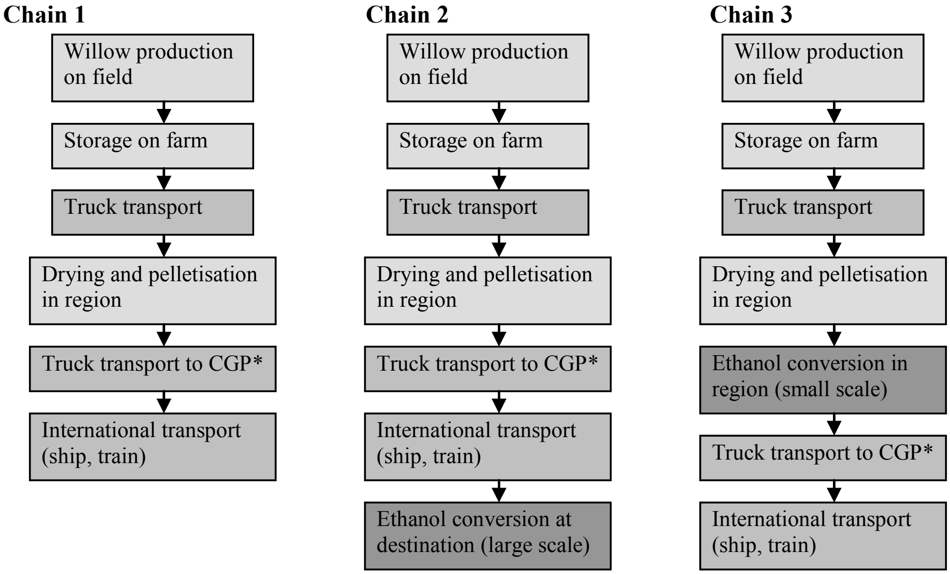
Mode	Costs	Loading / unloading		Characteristics transport mode		
	€ per t.km	Costs In € / t	Speed In t /hour	Capacity in t	Capacity in m^3	Speed in km/hour
SSS1)	€ 0.0055	€ 7,4[10]	60	2425	4062[11]	26.6
IWW2)	€ 0.022	€ 7.4	60	2000	3350[12]	10
Train	€ 0.046	€ 0.23 m^{-3}	260 m^3 / hour	1000	2500	50

1) SSS= Short sea shipping, 2) IWW = Inland water way transport

2.4.2.7. Conversion in the destination area

The cost analysis of the chains includes a comparison between chains with conversion in the source area and chains with conversion in the destination areas in Rotterdam, Duisburg or Marseille (see also figure 1). It is assumed that the large conversion plant in the destination area is a collection point for several transport chains, and the end point for the chains calculated in our analysis. We assume that ethanol conversion in the destination area takes place on a large scale, which is 1650 MW input. Data for scale factors and ethanol conversion are available from Hamelinck *et al.* (2005a) and De Wit *et al.* (2009b), see also 2.4.2.2.

Figure 1: Biofuel chains selected for analysis (CGP = Central Gathering Point).



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[10] Data are based on a small vessel from (Hamelinck et al. 2005a).

[11] Based on the ratio of cargo capacity (tonne: m^3) for a “small vessel” (capacity of 4000 tonne) from (Hamelinck et al. 2005a). We estimate the capacity for a SSS ship on 4062 m^3

[12] Based on the ratio of cargo capacity (tonne: m^3) for a ”small vessel” (capacity of 4000 tonne) from (Hamelinck et al. 2005a), we estimate the capacity for an IWW ship on 3350 m^3

Table 3: A description of the NUTS-2 regions that are selected as promising biomass production regions in CEEC.

NUTS-2 code	**PLOG**	**PL03**	**HU05**	**RO03**	**CZ03**
Name of region	West Pomerania	Lubelskie	Észak-Magyaroszág	Sud	Southern Bohemia
Location	North West of Poland	East Poland	North Hungary	South Romania	South Czech Republic
Landscape	Lowlands are dominating, many lakes	Lowland regions with heavy clay soil and upland loess with light sandy soil	hilly areas (Carpathian Mountains) in HU053 and arable flat land in HU051 and HU052	Mountains (10%) and hills (20%) in the North and fertile plains and meadows (70%) in the South	Variable topography: mountains to 1000 m as well as foot hills and lowland areas
Share agricultural area of total land area	49%	68%	n.a.	71% (80% arable land, 16% pasture)	n.a.
Share forest of the total land area	35%	22%	n.a.	19%	n.a.
Prevailing crops	74% cereals, 5% sugar beet and 5% rape seed	Very diverse, including sugar beets, rye, tobacco, vegetables, hop and fruit trees	Wheat, barley, rye, maize and vegetables in the plains, wine at the feet of mountains and pasture on hilly areas	Cereals, oil crops, fodder crops, vegetables, sugar beet	Extensively managed grasslands in the mountains, cereals (mainly wheat) and rape seed in the lowlands
Farm structure	49% small (to 7 ha) family farms, 22% of farms are between 15-50 ha	66% small (<5 ha) size agricultural households and 30% medium sized (5-20 ha) farms	Less than 1% of farms are agricultural enterprises, about 50% small private farms and 50% agricultural households	17% of farms <0.5 ha, 31% 0.5–1 ha, 38% 1–3 ha, 10% 3–5 ha, 4% 5-10 ha	More than 90% of agricultural land in holdings of more than 100 ha, holdings emerged from former co-operatives
Description region	Contains 6% of cropland in Poland, mostly good to very good soil quality	Today one of the most important centres for agricultural production and export	Very diverse crop production with specialisation in wine, tobacco and melon production	“Breadbasket” (grain production area) of Romania, realises 18% of total agricultural production in Romania	Generally extensive agricultural production with extensive cattle production (for meat) prevailing because it is triggered by subsidies

The following cost data set for a 1650 MW input ethanol plant is assumed: the load factor is 8000 hours per year, interest rate is 6%, and lifetime of the plant is 20 years (De Wit *et al.* 2009b). The efficiency (feed in / EtOH out) is 50% based on data from De Wit *et al.* (2009). The electricity output is 47.5% MW per tonne output and an electricity price of 47.7 €$_{2002}$ per MW is assumed (Hamelinck *et al.* 2005a). A cost-reduction factor based on scale-driven learning is included in the calculations to come to the total investment costs in M€ (scale factor is 0.9). Annual O&M costs are a percentage of the total investment costs (see 2.4.2.2.) assuming a scale factor of 0.25 for O&M costs for labour input, based on Hamelinck *et al.* (2005a). Calculation of the total conversion costs in €/GJ$_{\text{fuel}}$ is according to the methodology explained in 2.4.2.2. Based on a load factor of 91%, the ethanol plant requires a yearly input of 47.5 PJ per year, which is a yearly input of 4011 kt (based on a moisture content of 30%) and an energy content of 15.4 GJ$_{\text{LHV}}$ per tdm.

2.5. Performance of the sensitivity analysis

To consider the impact of the input data on the performance of the logistic chains, the sensitivity analysis considers both the minimum and maximum costs for biomass production and transportation costs for the different scenarios V1 – V5. Table 1 gives a short overview of the scenarios being used for the sensitivity analysis. As no variation is included in the conversion costs for the different scenarios (the study looks at two conversion options only, based on the best technology available), this element is not included in the sensitivity analysis. The impact of the lay-out of the transport system on transport costs is also analysed. Besides, the influence of scale on total conversion costs is considered as well.

3. Results

3.1. Biomass potentials and production costs in selected CEEC regions

The NUTS-2 regions West Pomerania (PLOG), Lubelskie (PL03), Észak-Magyaroszǽg (HU05), Sud (RO03) and Southern Bohemia (CZ03) were identified as promising biomass production and biofuel export regions in the CEEC based on results from Dam *et al.* (2007). They are described in table 3. The data on biomass potentials and production costs in the selected regions are based on assumptions and data used in the V3 scenario (for scenario assumptions see table 1). This scenario was chosen because it is considered as the most likely scenario to occur.

The availability of land for the production of energy crops varies between 34 and 50% of the agricultural land in the selected CEEC regions. The biomass yield of willow depends on the suitability of the land that is available for the production of energy crops. The average yield varies between 11.0 (RO03) and 11.9 (HU05) tdm/ha per year (table 4) for suitable land in the V3 scenario in 2030. In this scenario, yield levels are based on a high input agricultural system.

It must be noted that yield levels for these regions vary per land suitability type and scenario. For example, yield levels in the PL03 region for S land are 7.9 tdm/ha per year in the current scenario, compared to 11.3 tdm/ha per year in the V3 scenario (2030) or to 14.7 tdm/ha per year in the V1 scenario (2030). The latter is based on a high input advanced agricultural system, see also (Dam *et al.* 2007) for more information. Larger areas for the biomass supply of the drying and pelleting unit and the ethanol plant are needed in those regions that have a lower percentage of land available for the production of energy crops (table 4).

There are 4.0 to 20.0 kt biomass available for export per selected region if willow is produced as energy crop and 30% of the regional final energy consumption is covered by domestic biomass (see table 5).

Table 4: Average yield based on S land for V3 scenario 2030 and distribution density of willow as energy crop and size of areas needed to supply the drying / pelleting unit and small-scale ethanol plant with biomass in the different selected CEEC regions.

	PLOG	PLO3	RO03	HU05	CZ03
Average yield in region(tdm/ha/year)	11.19	11.34	11.04	11.93	11.1
Coverage (in %)	36%	32%	52%	34%	40%
Area for drying / pelleting unit (km^2)	145	166	90	187	219
Area for Ethanol plant (km^2)	1541	1755	956	1978	2320

Table 5: Average costs for biomass production from the energy crop willow and from residues or surplus wood and the surplus biomass potential in 1000 t in the different selected CEEC regions.

	PLOG	PLO3	RO03	HU05	CZ03
Average costs for willow production in € / tdm[13]	35.4	34.9	36.0	33.6	35.7
Biomass potential after fulfilment of 30% final energy consumption in region (1000 t per year)	8.07	8.36	20.00	3.96	4.52

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[13] The costs for willow production are given for the V3 scenario 2030 for suitable land. Production costs based on land rent costs of 55, 74, 92 and 110 €/ha per year for marginally suitable, moderately suitable, suitable and very suitable land respectively. These land rents in the V3 scenario are lower than current average EU level due to CAP measures (subsidies will decrease in 2030, which will lower land rent prices). Land rents are the average between the USA land rents (V1 scenario) and the average EU land rents (V4 scenario). The labour costs assumed in the V3 scenario are 12.22 €/hour, these are average EU labour costs. Costs for inputs are € 0.06 per seedling, € 0.82 per litre fuel, € 0.6 per kilo nitrogen, € 0.75 per kilo P_2O_5, € 0.33 per kilo K_2O, €13.40 per kilo pesticides, Level of inputs are varied accordingly to the land suitability class. Depending on the selected NUTS-3 region, cost breakdown for (in this example) suitable land is as follows: labour costs range from 17.4 to 17.6% of total costs, inputs from 37.5 to 38.2%, land from 23.0 to 23.2%, machinery from 6.7 to 6.8% and fixed costs from 14.7 to 14.9%. For more information also see Dam *et al.* (2007).

Figure 2: Cost-supply curve for region HU05 for energy crop willow for the selected scenarios in year 2030. Cost in €/GJ and supply in PJ. On Y-axis illustrated: 30% and total energy consumption in PJ in year 2030.

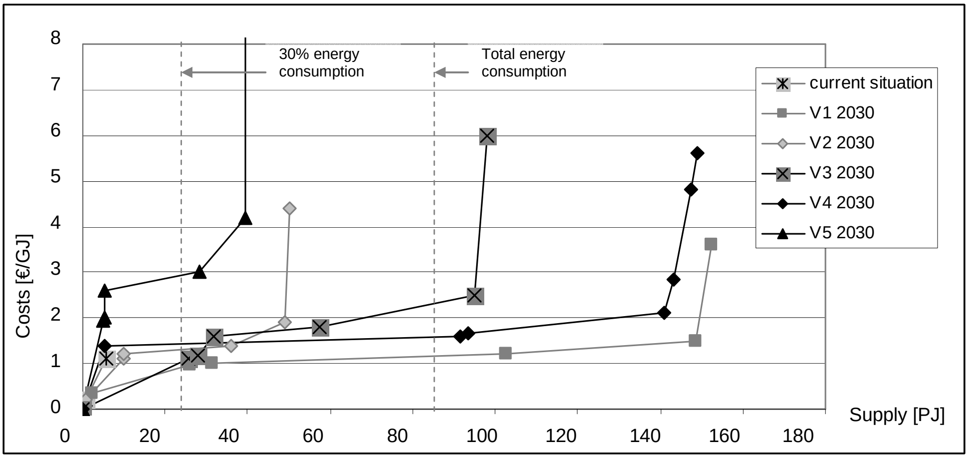
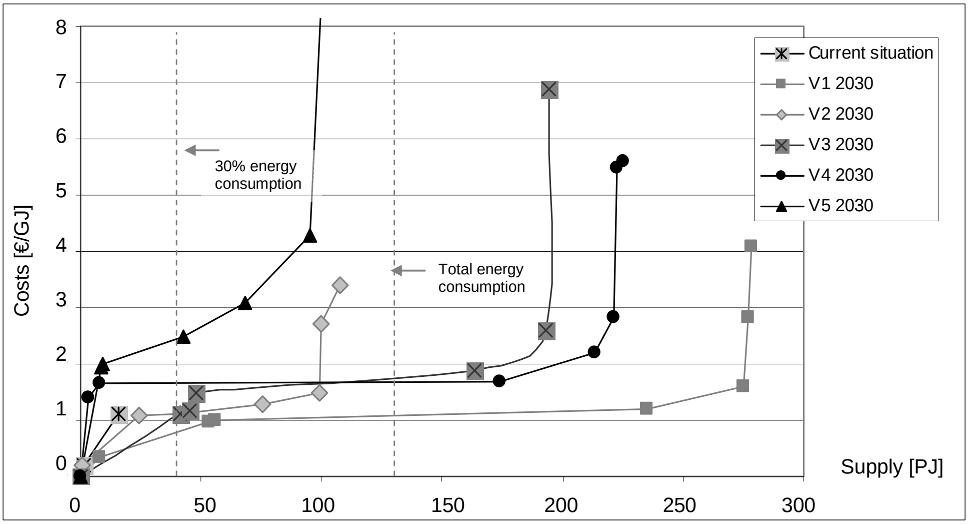


Figure 3: Cost-supply curve for region PL03 for energy crop willow for the selected scenarios in year 2030. Cost in €/GJ and supply in PJ. On Y-axis illustrated: 30% and total energy consumption in PJ in year 2030.



The assumption is that wood and residues are used for domestic consumption as well. The cost-supply curves of the regions (see figure 2 and 3) show that the larger amount of the biomass potential is in the lower cost range of the curve and that a small amount is characterized by higher costs. As we take an average cost range for biomass production into account, it must be noted that this variation is not further shown in the final calculations of the trade chains.

Figure 4: Main international transport corridors to connect destination areas with selected regions, CGP= Central Gathering Point.

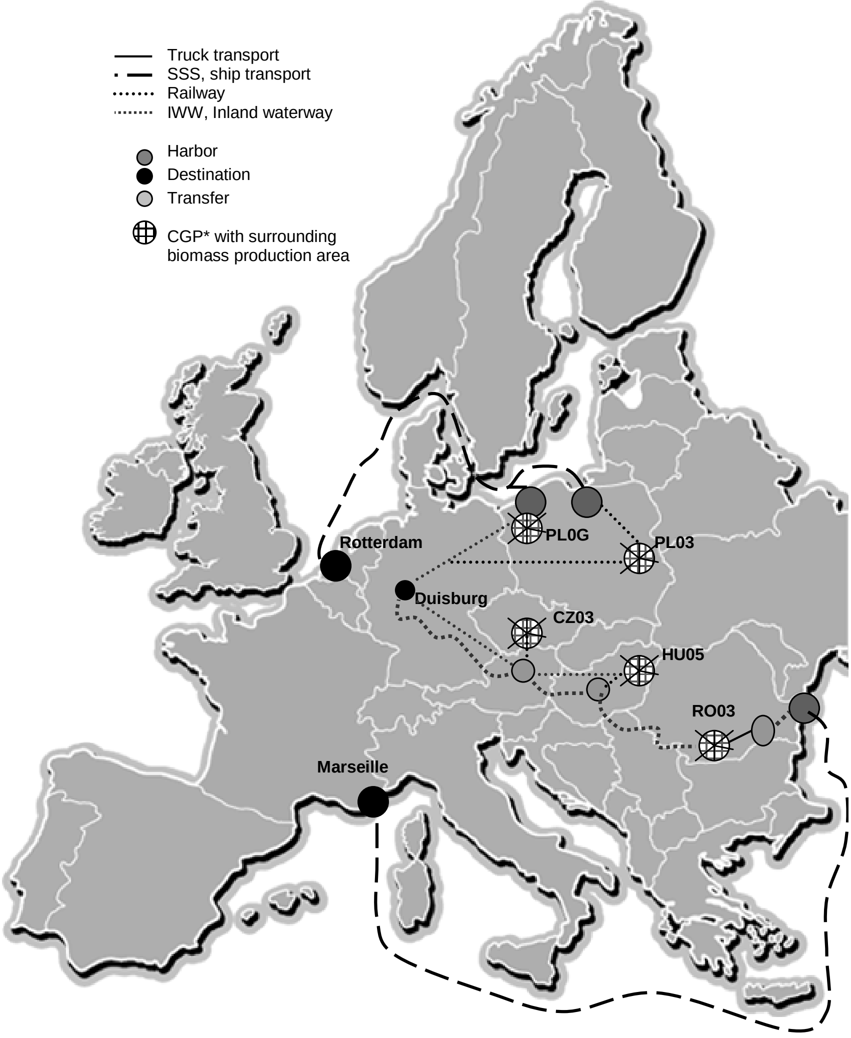


Table 6: International transport routes and their distances for two transport corridors per region (Zeebroeck 2004)[14].

Option no.	Process	Location source	Destination	Distance in km.
Region PLOG				
1)	Transport: SSS[a]	CGP Szczecin	Rotterdam	976
2)	Transport: railway	CGP Szczecin	Duisburg	702
Region PLO3				
1)	Transport: railway	CGP Warsaw	Gdansk	318
	Transport: SSS	Gdansk	Rotterdam	1226
2)	Transport: railway	CGP Warsaw	Border Poland – Germany	407
	Transport: railway	Border Poland - Germany	Duisburg	656
Region RO03				
1)	Transport: IWW[b]	CGP Calarasi	Constanta, Romania	118
	Transport: SSS	Constanta	Marseille, France	2915
2)	Transport: IWW	CGP Giurgiu, Romania	Border Romania – Hungary	857
	Transport: IWW	Border Romania - Hungary	Border Hungary – Austria	293
	Transport: IWW	Border Hungary - Austria	Border Austria – Germany	355
	Transport: IWW	Border Austria – Germany	Duisburg	675
Region HU05				
1)	Transport: railway	CGP Miskolc, Hungary	Budapest, Hungary	185
	Transport: IWW	Budapest	Hungarian – Austrian border	216
	Transport: IWW	Hungarian – Austrian border	Austrian – German border	355
	Transport: IWW	Austrian – German border	Duisburg	675
2)	Transport: railway	CGP Miskolc, Hungary	Hungarian – Austrian border	278
	Railway via Linz	Hungarian – Austrian border	Austrian – German border	368
	Transport: railway	Austrian – German border	Duisburg, Germany	736
Region CZ03				
1)	Transport: railway	CGP Budweis	Czech – Austrian border	68
	Transport: railway	Czech – Austrian border	Linz, Austria	64
	Transport: IWW	Linz, Austria	Austrian – German border	90
	Transport: IWW	Austrian – German border	Duisburg	675
2)	Transport: railway	CGP Budweis	Czech – Austrian border	68
	Railway via Linz	Czech – Austrian border	Austrian – German border	167
	Transport: railway	Austrian – German border	Duisburg	776

[a] SSS = Short sea shipping, [b] IWW = Inland water way

Biomass production costs are based on willow production on suitable land. Willow is in this case the remaining available biomass for export. The biomass production costs range between 34.9 and 36 €/tdm willow biomass. The biomass potential in two of the selected CEEC regions (region HU05 and region PL03) in EJ per year is shown in figure 2 and 3. As can be seen by the illustration of the 30% of regional final energy consumption, large amounts of biomass could be made available in every region for trade to the WEC. This is true for all the five regions that have been analysed here.

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[14] Data are based on own estimations, on www.distances.com for sea distances, and on information from the UIC for rail, see also (UIC 2004).

3.2. International transport routes

Figure 4 shows the international biofuel transport routes that have been identified as most feasible in terms of capacities and distances between the biomass production and destination areas. For the route choice, priority was given to sea transport, Inland water way transport and then railway transport in that order for reasons of costs. Furthermore, on sea and inland waterways, there is still capacity left while the rail network is confronted with several bottlenecks.

The selected destination areas for the different CEEC regions are:

- Rotterdam: destination area for PLOG and PLO3;
- Duisburg, Germany: destination area for PLOG, PLO3, CZ03, HU03 and RO03;
- Marseille, France: destination area for RO03.

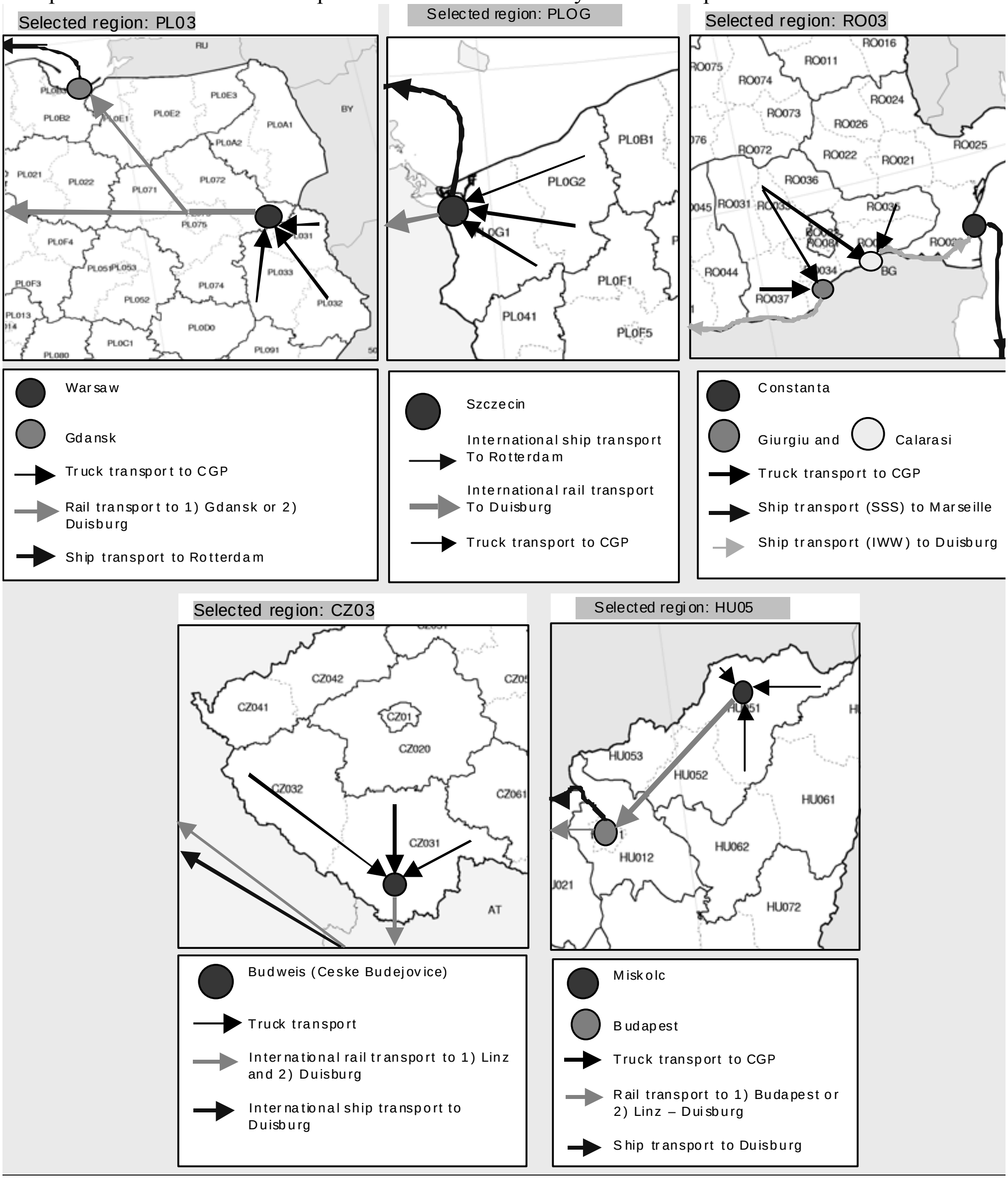
Table 6 describes transport corridors shown graphically in figure 4 and contains the international transport distances. The transport distances between the biomass producing and destination areas are largest for the Polish (PL03) and Romanian regions and can, depending on the railway route that is chosen, be shortest for the Czech region. Railway and Inland water way (IWW) transport from the Polish and Romanian regions employ shorter distances than Short sea shipping (SSS).

Figure 5 shows the regional transport modes and the connection points from the first processing unit to the CGP and the link to international transport. The transport distances between the first processing unit and the CGP are 46 to 74 km (table 7).

Table 7: Average transport distances in km from the first processing unit to the Central Gathering Point (CGP) in each region.

Region	Location CGP	Distance first processing unit to CGP in km.
Region PL03	Lublin, Poland	63.2 km.
Region PLOG	Szczecin, Poland	60.4 km.
Region RO03	Giurgiu, Romania (IWW) Calarasi, Romania (SSS)	74 km. 74 km.
Region HU05	Miskolc, Hungary	46.2 km.
Region CZ03	Budweis, Czech Republic	53 km.

Figure 5: Central Gathering Points in the regions serve as connection points from the regional transport routes to the main transport corridors in the country and in Europe.



3.3. Cost performance of the biofuel trade chains

Results about the cost performance for the selected transport chains are presented in figures 6 to 8. In case of ethanol conversion in the destination area (see figure 7), production costs are on average 16.9 € per GJ fuel. Costs range from 12.0 € per GJ fuel for region PLOG (based on SSS transport with conversion in Rotterdam) to 20.9 € per GJ fuel for region HU05 (based on train transport with conversion in Germany). On average, conversion costs are responsible for (including electricity reimbursement) 23% of the total production costs in the chain. Production costs for feedstock (biomass, processing and transport) are on average 13.2 € per GJ fuel. In case of ethanol conversion in the source area (see figure 8), production costs are on average 16.4 € per GJ fuel. Costs range from 14.84 € for region PLOG (based on SSS transport) to 17.8 € per GJ fuel for region HU05 (based on train transport). On average, conversion costs (including electricity reimbursement) contribute to 51% of the total production costs in the chain. Production costs for feedstock (biomass, processing and transport) are on average 8.1 € per GJ fuel.

Figure 6: Costs for pellets in € per tonne dry matter delivered by selected logistic chains. Destination areas are Rotterdam – the Netherlands (Rot), Marseille - France (Mars) and Duisburg in Germany (Dui).

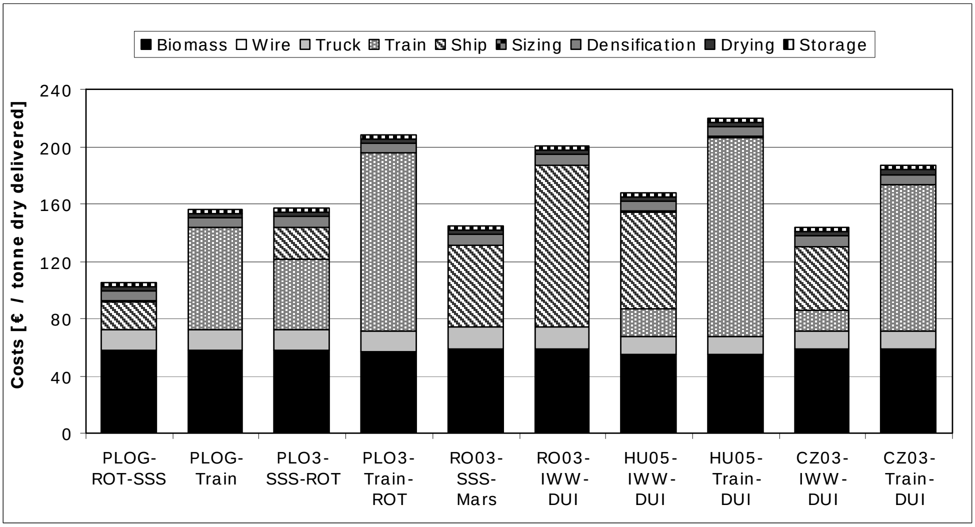


Figure 7: Costs for ethanol in € per GJ (HHV) liquids for selected logistic chains. Ethanol conversion (based on a 1650 MW ethanol plant) takes place in destination areas; these are Rotterdam – the Netherlands (Rot), Marseille - France (Mars) and Duisburg in Germany (Dui).

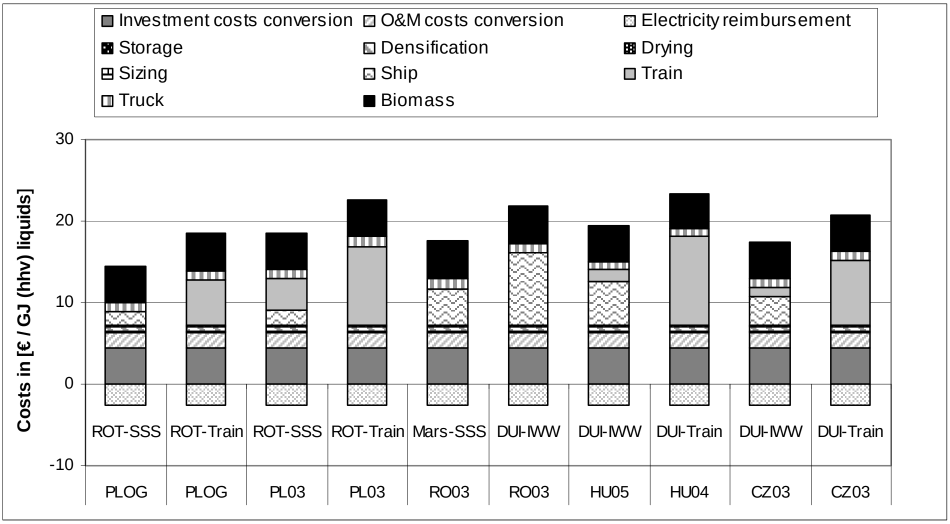
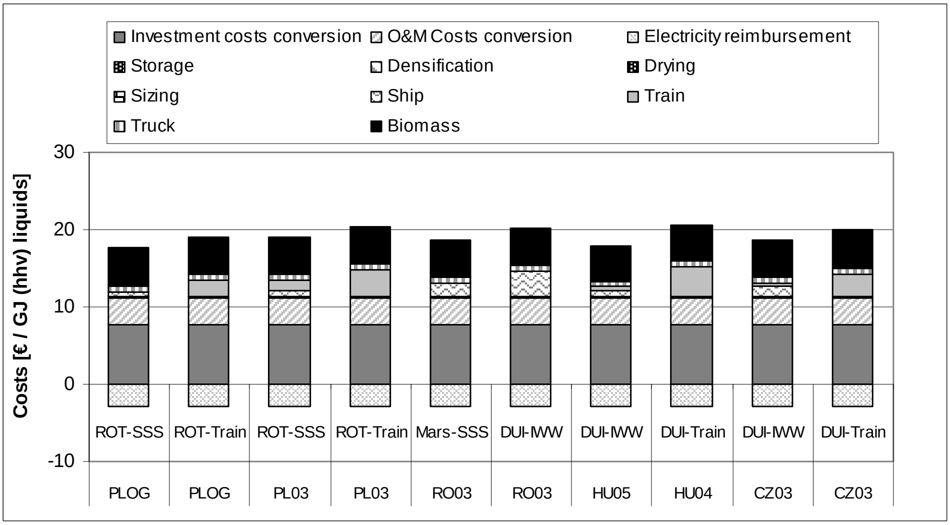


Figure 8: Costs for ethanol in € per GJ (HHV) liquids for selected logistic chains. Ethanol conversion (based on a 400 MW ethanol plant) takes place in the CEEC regions. Destination areas are in Rotterdam – the Netherlands (Rot), Marseille - France (Mars) and Duisburg in Germany (Dui).



Total production costs are lower when conversion takes place within the WEC region compared to the situation when conversion is performed within the CEEC region. The main reason for this is the higher ethanol conversion costs in the source area due to the assumption that smaller plant sizes are used in the source area than in the destination area.

Feedstock costs for ethanol supply are lower when conversion takes place within the CEEC region compared to the situation when conversion is performed at the destination area in the WEC (figures 7 and 8). The main reason for this is lower costs of international ship and train transport for ethanol than for pellets. Transport by SSS has the lowest costs for long distance transport. The cost reductions by SSS compared to railway or IWW transport are especially large for pellets. Chains for the region PLOG show a cost difference between SSS and rail transport to Rotterdam of 51.2 € per tdm for pellet transport and of 4.0 € per GJ fuel in case ethanol is converted in the destination area. The chains for RO03 show even a larger cost difference between SSS and IWW transport of 55.9 € per tdm for pellet transport and 4.4 € per GJ fuel in case ethanol is converted in the destination area. However, it must be considered that we deal in this case also with different destination areas and therefore with different transport distances for these regions.

It is cheapest to produce feedstock in the Szczecin region (PL03) in Poland, followed by the region in Czech Republic (based on ship transport) and subsequently the other regions. For all regions, the chains using train transport for the longer distances result in higher costs. Main reasons for the differences in feedstock production costs are the differences in biomass feedstock costs and, for the larger part, the differences in transport costs for long distance. The differences in biomass feedstock costs are due to cost variations for biomass production costs in the regions. The influence of the variation of the land quality and scenario parameters used for calculation of the biomass production potential and the related biomass production costs, see also (Dam e*t al.* 2007), are further discussed in the sensitivity analysis.

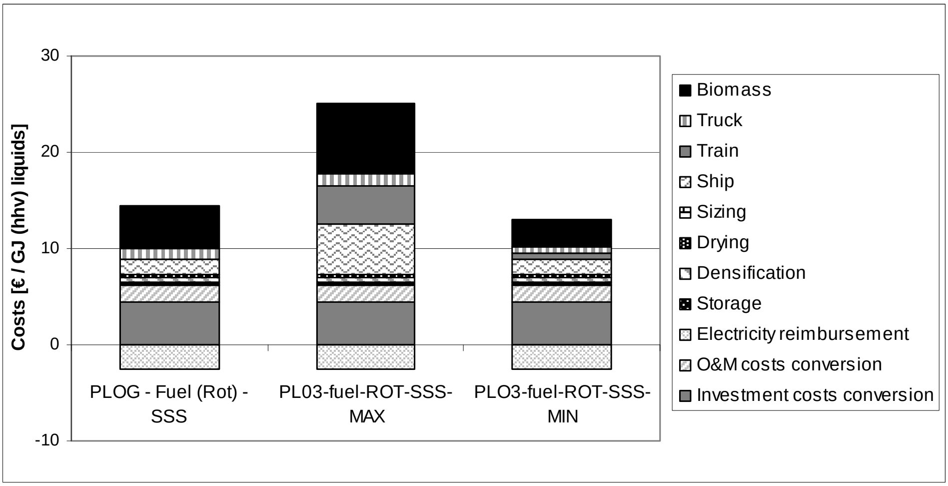
Differences in transportation costs can partly be explained by the fact that the biomass from, for example the PLOG region (closely located at the Baltic Sea) needs to bridge smaller distances to reach its destination area than the region in Hungary. As the Hungarian region is located in mainland Europe, large distance biomass transport from this region cannot use SSS (the cheapest transport mode for long distances) and chains are limited to IWW and rail transport.

3.4. Results of sensitivity analysis

The results for the biofuel trade chains shown here are based on cost data for the V3 scenario. Figure 9 shows the sensitivity of the results for the cost ranges for transport and biomass production for the region PLO3 between different scenarios. Within a given scenario (in this case study the V3 scenario in 2030, the selected land suitability for biomass production can have its influence on the performance of the total production costs. For the region PL03, biomass production costs vary from 34.9 € per tdm for suitable (S) land to 27.6 € per tdm for very suitable (VS) land and 127.0 € per tdm for marginally suitable (mS) land. The total cost range for ethanol conversion results in 15.0 € per GJ fuel for VS land to 27.8 € per GJ fuel for mS land. These results for the PLO3 region show that an optimal combination of land suitability and biomass production costs for the selected energy crop in a region are required for optimum economic performance of the feedstock costs for ethanol conversion. The differences in yield performance are due to the variation in land quality of the region and availability of biomass feedstock per region - due to differences in final energy consumption and availability of land - see also (Dam *et al.* 2007).

Minimum cost levels for biomass production can be achieved in the V1 scenario because of the high biomass yields under a high input agricultural production system that employs highly advanced technology. The lowest range for transportation costs comes from transport data based on the current situation in the CEEC (the V2 scenario) as current transportation costs in the CEEC are remarkably lower compared to current cost levels in WEC (Zeebroeck 2004; Dam *et al.* 2005a).

Figure 9: Results of sensitivity analysis ethanol costs, in € / GJ (hhv) liquids, for the region PLO3, chain transport with train and SSS for fuel conversion in Rotterdam. Left: data input from V3 scenario, Centre: data input with highest cost ranges for biomass production, train, truck and SSS transport. Right: data input with lowest cost ranges for biomass production, train, truck and SSS transport.



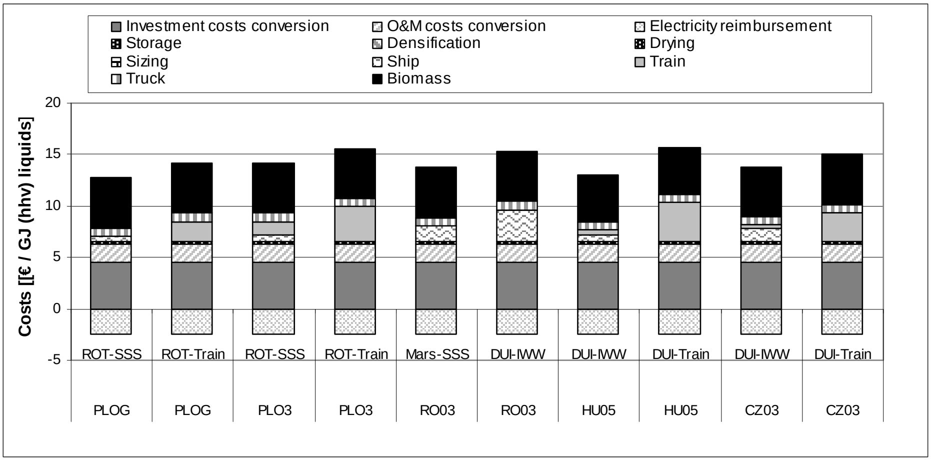
The V5 scenario results in the highest costs for biomass production and transport because the land-use and labour costs under the ecological agricultural production systems in this scenario are high. The V5 scenario also assumes that transport costs are high due to an increase of fuel prices, taxes to discourage truck transport and extra environmental regulations. The total cost range between the lowest and highest cost levels is 12.2 € per GJ HHV liquids (see also figure 9). The cost range for biomass production is around 4.5 € per GJ fuel. Cost ranges for transport modes are about 4.0 € per GJ fuel for train transport, 0.7 € per GJ fuel for truck transport and about 3.7 € per GJ fuel for ship transport.

Thus, results show that the largest feedstock cost variations between scenarios can be explained by the biomass production costs and transport costs for larger distances (ship and train) for the various chains. It is important to note that the chain with the lowest cost levels (in the centre of figure 9) consists of a combination of data from the V2 scenario (based on the current situation CEEC) and V1 scenario (assuming application of advanced technology). In this chain the low biomass production costs from the V1 scenario and the low transportation costs of the V2 scenario are combined.

The influence of the lay-out of the road system on costs for truck transport is calculated for the CZ03 region, a region with larger truck distances compared to other regions. Truck transport costs are in this case study 1.0 € per GJ fuel. This result is based on the assumption that the radius of the biomass production area is the average transportation distance. Using the formula (F * (2/3) * R) from Marrison *et al.* (1995) costs for truck transport are 0.98 € per GJ fuel for a radial road system (F=1) and 1.01 € per GJ fuel for a road system based on a typical agricultural area in the USA (F=1.4). The results show that the calculated costs for truck transport in this case study has a small overestimation compared to the results based on the formula from Marrison *et al.* (1995). However, as truck transport is only used for smaller distances, the influence of the lay-out of the road system is negligible. In case truck transport is used for longer distances, the lay-out of the road system has to be taken into account.

Conversion costs are based on two different input scales: 400 and 1650 MW input. It is assumed that conversion in the source area takes place in smaller plants while larger plant units are used in the destination area. No variation in scale and cost levels is made between the different scenarios. Due to scale-driven learning, the ethanol plants in the destination areas profit from a cost reduction in € per GJ fuel. In case a plant size of 1650 MW input would be used in the source areas, conversion costs would decrease with 4.6 € per GJ fuel for all chains (see also figure 10). This would on average result in 11.8 € per GJ fuel for the total production costs of ethanol production in the source area. In this case, ethanol production would be more cost-effective if the conversion process would take place in the source areas itself than in the destination area.

Figure 10: Costs for ethanol in € per GJ (hhv) liquids for selected logistic chains. Ethanol conversion (based on a 1650 MW ethanol plant) takes place in CEEC regions. Destination areas are in Rotterdam – the Netherlands (Rot), Marseille - France (Mars) and Duisburg in Germany (Dui).



Further cost reductions (or increases) in the ethanol conversion costs can be achieved by electricity reimbursement. The ethanol conversion costs as calculated in this study assume an electricity reimbursement of 0.05 € per kWh based on data from De Wit *et al.* (2009b). In case the electricity reimbursement would increase to 0.06 € per kWh, total conversion costs of a 400 MW plant would decrease with 9% from 8.4 to 7.7 € per GJ fuel. On the other hand, in case the electricity reimbursement would decrease to 0.04 € per kWh, conversion costs of a 400 MW plant would increase with 5% from 8.4 to 8.8 € per GJ fuel. The level of electricity reimbursement for ethanol conversion is policy-related and can differ strongly per country and over time.

4. Discussion and conclusions

A potential analysis showed that, under a scenario with intensive, advanced agricultural production methods and optimal land allocation within the CEEC, nearly 12 EJ could be produced from biomass (including biomass from energy crops, agricultural residues, forest residues and surplus wood) in the CEEC (Dam *et al.* 2007). For the more favourable scenarios (assuming efficient, high input agricultural production methods) the production potentials are larger than the current energy use in most CEEC. Combined with the low cost levels, this gives the CEEC major export opportunities for the European and perhaps the global market.

Based on the potential analysis in Dam *et al.* (2007) five key regions for biofuel export from Poland, Romania, Hungary, and the Czech Republic, were determined and a detailed analysis of biofuel trade chains for these regions was performed. From these regions pellets from willow can be provided at costs of 105 – 220 € per tonne. Ethanol can be produced at 12 to 21 € per GJ fuel if the biomass conversion is performed at the destinations in Western Europe or it can be produced at 15 to 18 € per GJ fuel if the biomass to ethanol conversion takes place (at smaller scale) at the region where the biomass is produced. Both, the pellets and ethanol costs include the costs for production, conversion and transport to the destination area in WEC.

The results for total ethanol production costs in the source and destination area coincide with projected ethanol production costs ranging from 22 € per GJ fuel in the short term to 11 € per GJ fuel for the long term mentioned in Hamelinck *et al.* (2005a). For comparing the calculated ethanol production costs with production costs for fossil fuels, the latter is roughly estimated on a price of an oil barrel (range 100–150 US$ per barrel with a € to US$ conversion of 1.35) plus 10% extra costs for refinement and transport (De Wit *et al.* 2009b). The caloric value of an oil barrel is 6.4 GJ per barrel (De Wit *et al.* 2009b), which results in a range of 13 to 19 € per GJ. This result shows that ethanol production costs can be competitive, both on the shorter and longer tem, with fossil fuels if an oil price is assumed of 100-150 US$ per barrel.

Ethanol may not be cost competitive when the oil price is 11 €/GJ (85 US$/barrel) or lower, as is the situation in the beginning of 2009 (IEA 2009). IEA gives a projection for the crude oil price of 100 US$/barrel for the period 2008-2015, increasing to over 120 US$/barrel in

2030. In this projection, the fluctuations of the oil prices in 2007-2008 are taken into account. The IEA outlook (2008) indicates that “while market imbalances could temporarily cause prices to fall back, it is becoming increasingly apparent that the era of cheap oil is over” and that “pronounced short-term swings are likely to remain the norm and temporary price spikes or sharp falls cannot be ruled out”. IEA predicts an upward pressure on oil prices through to the end of the project period beyond 2015, mainly because of required investments in (additional) capacity to increase supplies (OECD/IEA 2008a). Therefore, oil price increases are likely on the short to middle term already.

The variability in results from the scenarios shows that the selection of the biomass production location and the efficiency of the transport routes are decisive for a good economic performance of the chains.

Compared to pellet production costs of 74 to 119 €/t in Sweden and Austria (Thek 2004), the production and export of pellets are competitive for a limited number of biomass production regions due to higher transportation costs. This study assumes the use of pellets for ethanol conversion. For future use, it might as well be interesting to consider alternative competing uses of pellets like the use of pellets for fuel oil, for local use or for export to the WEC.

The costs for biofuels from CEEC depend on the transport mode, the place of fuel conversion, the position of the export regions and the destination area. There are several possibilities for cost reductions in the biofuel trade chains:

- Production and transport of feedstock from and within CEEC regions: Average biomass production costs in this calculation include the amount of biomass production from suitable land areas (see also 3.1). Further cost reduction can be achieved when the regions decide to include very suitable areas for willow production for export or when lower biomass production costs than assumed in the V3 scenario to 2030 are achieved. This will result in lower costs for biomass feedstock. Areas with low suitability can for example be used for land rehabilitation or multifunctional land-use purposes, which can result in other economic benefits that can lower the net biomass production costs (Lewandowski *et al.* 2006b). Multifunctional land-use and related possible economic benefits require more detailed research, though.

- High share of sea transport: Short sea shipping shows most cost advantages for longer distance international transport compared to Inland water way shipping and railway.

- Choose favourably connected export regions and destination areas: The regions in Romania and Poland show in general a better economic performance for long distance trade of biomass than the regions in Hungary and Czech Republic. This can partly be explained by the geographical location of the regions and the selection of the destinations. First, the regions in Hungary and Czech Republic are both located in mainland Europe which limits these regions to the more expensive options for international transport, which are IWW shipping and rail. The selection of the destination Duisburg for these regions has as consequence that a long distance has to be bridged over mainland. Another destination area (e.g. in Austria) located closer to the Hungarian and Czech borders, might give different economic performance results for these regions.

- Optimization of scale and technology for ethanol conversion plants combined with electricity reimbursement can further reduce costs for ethanol conversion in both source and destination areas. The lowest logistic costs can be achieved when biofuel conversion takes place within the CEEC region, based on the same plant size as assumed for the destination areas. Main cause is the reduced transport volume and therefore a reduction of transport costs for biofuels with higher energy density. Additionally, some pre-processing steps, as pelletizing, can possibly be left out of the biomass production chain in case the selected CEEC regions are able to produce large volumes of biomass, with a year long supply, closely located to large-scale regional facilities. However, the supply security and financial risks of such large, regional facilities should carefully be assessed. The possibilities for electricity reimbursement are dependent on the country's policy and can therefore differ per region.
- It can be concluded that those regions in CEEC with sea shipping transport options are best suited for delivering biofuels, or its feedstock, to international long distance markets. Biofuels from CEEC regions, which lack connection to favourable transport options, will be delivered mainly to local markets.

- The logistic capacity for key transport corridors (Donau, Short sea shipping) seems sufficient for intra-European biofuel trade on foreseeable term. On the Austrian Danube seven times the actual capacity is still available and a study of the Dutch inland waterway organization (Bureau Voorlichting Binnenvaart 2004) states that on the Dutch waterways, traffic could double without causing congestion effects. The weakest link on the Danube-Rhine route is the Danube-Rhine channel, which can only give access to ships up to 1800 tonnes.

- Some international rail corridors may be more critical. Detailed studies on bottlenecks of European railway routes are scarce, but it is clear that some railway paths are congested (UIC *et al.* 2004). Long term planning of rail and harbour capacity should include these potential biomass and biofuel flows.

- The energetic loss in the biofuel trade chain through transport is not a valid argument against intra-European trade of biofuels. Analysis of biofuel trade chains for pellets and ethanol transported over a distance as far as from Latin America to Europe have shown that the energy consumption for transportation sums up to about 10% of the energy value of the transported biofuel. Respectively, low greenhouse gas emissions for the process of transport are recorded too (Hamelinck *et al.* 2005).

From the results of this study it can be concluded that in coming decades, biomass and biofuel production in key CEEC regions can supply (pre-treated) biomass and biofuels to the European market at cost levels which are sound and very attractive to current and expected diesel and gasoline prices. This pleads for the development of an intra-European biofuel market and the development of the related infrastructural capacity.

Acknowledgements

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Chapter 5: Overview of recent developments in sustainable biomass certification[15]

Abstract

The objective of this paper is to give a comprehensive review of initiatives on biomass certification from different viewpoints of stakeholders, including national governments (such as the Netherlands, the UK, Belgium and Germany), the EC, NGOs, companies, and international bodies up until October 2007. Furthermore, opportunities and restrictions in the development of biomass certification are described, including international trade law limitations, lack of adequate methodologies, stakeholder involvement requirements and certification costs. Next, five different approaches for the implementation of a biomass certification system are compared and discussed. Main differences are the voluntary or the mandatory character and the geographical extent of the proposed strategies in terms of biomass end-use. It is concluded that criteria to ensure the sustainable production of biomass are urgently needed. To some extent criteria categories can be covered using existing systems, but others (such as GHG and energy balances or changing land-use) require the development of new methodologies. A gradual development of certification systems with learning (through pilot studies and research) and expansion over time, linked to the development of advanced methodologies can provide valuable experience, and further improve the feasibility and reliability of biomass certification systems. However, better international coordination between initiatives is required to improve coherence and efficiency in the development of sustainable biomass certification systems, to avoid the proliferation of standards and to provide a clearer direction in the approach to be taken. Finally, next to certification, alternative policy tools should be considered as well to ensure sustainable biomass production.

1. Introduction

Increases in the price of fossil fuels, growing environmental concerns regarding their use and impacts (including climate change) and considerations regarding the security and diversification of energy supply have driven the increased use of biomass worldwide. Expectations for the coming years, based on energy scenarios and various policy objectives, indicate a growing increase in the global production of biomass on a global scale and for many nations.

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The global production of liquid biofuels is now estimated to be over 35 Mm^3 (EC 2006). Ethanol currently accounts for more than 90% of the total biofuel production. The global fuel ethanol production more than doubled between 2000 and 2005, while production of biodiesel, starting from a much smaller base, expanded nearly fourfold (WWI 2006). Some examples: Brazil has exported in 2004 2.5 billion litres of ethanol (same in 2005) with as main destinations India (23.1%) and the USA (20.2%) (Walter *et al.* 2006). The rapidly changing character of worldwide biofuel production capabilities is also illustrated by recent trends in the United States. In 1995, U.S. biodiesel production was $2*10^3$ m^3; by 2005 this was more than $280*10^3$ m^3 (WWI 2006).

Beside the strong increase in liquid biofuels, trade and production in pellet and solid biomass production is also rising. Total Canadian exports of wood pellets were around 625 kt in 2006 (Swaan 2006). In the Netherlands, imports for electricity production have increased by a factor of seven from 2003 to 2005, and nowadays about 80% of all electricity produced from biomass is imported. For 2004, Essent, the largest user of biomass in the Netherlands, reported that approximately 30% of the biomass originated from North America, 25% from Western Europe and 20% from Asia, with the remainder from Africa, Eastern Europe, Russia and South America (Junginger *et al.* 2008).

The growing use and production of biomass as a renewable energy source has created an international biomass market and leads to increasing trade in biomass resources. International trade in biofuels and related feedstock may provide win-win opportunities to all countries: for several importing countries it is a necessary pre-condition for meeting self-imposed targets. For exporting countries, especially small and medium developing countries, export markets are necessary to initiate their industries (Zarrilli 2006).

However, the production of biomass energy crops and the removal of biomass residues from forest and agricultural systems for energy production can also result in negative ecological impacts, changing land-use patterns, socio-economic impacts and GHG emissions (e.g. for transport and versus. alternative use on-site). With considerable increase in feedstock and biofuels expected, sustainable production is becoming a key concern and is currently being considered as a possible requirement for market access, e.g. in the first draft of the EU biofuels directive (Zarrilli 2006).

Setting standards and establishing certification schemes are possible strategies that can help ensure that biofuels are produced in a sustainable manner (WWI 2006). Recently, policy makers, scientists and others have recognized these aspects. Certification is the process whereby an independent third party assesses the quality of management in relation to a set of predetermined requirements (standards). These are mostly formulated as criteria that have to be fulfilled for the certification of a product or a production process. To use criteria for the formulation of a certification standard they have to be operational and measurable. For this purpose, indicators and verifiers are used (Lewandowski *et al.* 2006). More information on this topic is available in a separate background report to this article with several annexes (Dam *et al.* 2008).

Over the last years, various efforts have been undertaken as steps towards certification of imported biomass. Key documents have been published by Lewandowski *et al.* (2006), Fritsche *et al.* (2006), Dehue *et al.* (2007), WWI (2006) and Zarrilli (2006). These studies focus on specific aspects in the discussion of biomass certification and include in their discussion relevant initiatives related to their studies. A comprehensive study providing an overview of recent developments in sustainable biomass certification is considered highly relevant for all actors involved, given the rapid developments in the field.

The objective of this paper is to give a comprehensive outline of initiatives on biomass certification from viewpoints of different stakeholders. The paper focuses on initiatives up until the end of 2006, though some developments were updated until October 2007. The scope of this paper includes mainly new initiatives in the development of a biomass certification system, though existing certification systems are also briefly described, as experiences from these systems provide valuable inputs in the discussion. A second objective of the paper is to identify opportunities and limitations in the development of biomass certification and to give, based on this, some recommendations and conclusions.

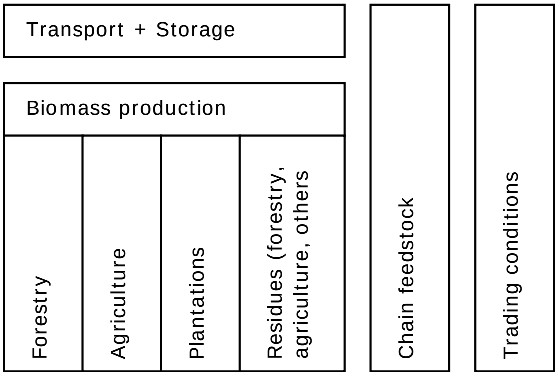
This paper starts in section 2 with an overview of existing certification systems, which can be used as a basis for a biomass certification system. The study includes in section 3 an inventory of initiatives in the field of biomass certification from the perspective of various stakeholder groups. Stakeholders included are NGOs, companies, national governments and international bodies and networks. Section 4 and 5 focus on possible strategies and limitations for the implementation of a biomass certification system, indicated by the various stakeholder groups. Section 6 and 7 conclude with an overall discussion of the developments and possibilities to move forward.

2. Overview of existing frameworks as basis for biomass certification

Precedents in the field of sustainability certification exist for a wide range of products. Criteria, basic principles and processes, see also Dam *et al.* (2008), of existing international certification schemes, indicator systems addressing sound resource management and responsible enterprise behaviour are being considered and partly used in the development of biomass certification systems. Relevant for the development of a biomass certification system are certification systems for forestry, agricultural products and electricity (figure 1).

The introduction of forest certification was led by the *Forest Stewardship Council* (FSC) and a range of other schemes became operational at the end of the last decade (Zarrilli 2006). Since 1994, over 84 million hectares in more than 82 countries have been certified according to the FSC standard (FSC 2008). FSC accredited certification bodies carry out FSC certification. Two types of FSC certificates are available from certification bodies: the Forest Management (FM) Certificate and the Chain of Custody (CoC) certificate.

Figure 1: Existing areas demanding criteria and indicator development for sustainable biomass trade.



Chain of Custody is the path taken by raw materials from the forest to the consumer, including all successive stages of processing, transformation, manufacturing and distribution. FSC is constantly reviewing its processes and criteria. At this moment the FSC Principles and Criteria in plantations (to further improve e.g. inclusion of social issues and issues on conversion of other land-uses) and on pesticides are under review.

Another large forest certification system is the *Programme for the Endorsement of Forest Certification* schemes (PEFC). PEFC is a global umbrella organisation for the assessment and mutual recognition of national forest certification schemes. PEFC covers both the forest management and chain of custody verification. PEFC has in its membership 32 independent national forest certification systems. Of these, 22 schemes (in total accounting for over 191 million hectares of certified forests) have been certified through a rigorous assessment process. The PEFC provides an assurance mechanism to purchasers of forest products that they are promoting the sustainable management of forests (PEFC 2006). An example of a national forest certification scheme is the FFCS (Finnish Forest Certification System). Commercially exploited Scandinavian forests are certified to a large extent, e.g. over 95% in Finland (FFCS 2006). The PEFC system can as such be applied for the certification of forest biomass (e.g. wood chips and pellet). Furthermore, in most Scandinavian countries, special sustainable forestry national legislation is already providing guidelines for forestry operations. Also, harvesting of energy wood is often integrated into round wood harvesting and thus forest certification is easy to use for both.

Another tool is the "CEN/TS 15234 - Solid biofuels, Fuel quality assurance" (Alakangasa *et al.* 2006) in which the whole fuel supply chain has to be traced back to the origin. In this technical specification the fuel supplier shall state the origin by documentation and fuel properties by quality declaration. The supplier or producer is advised to describe the fuel production process and state the critical control points where quality can change. This is a standard for fuel quality in terms of physical properties, but it could also be used for looking at other aspects in the entire production chain.

For the *agricultural sector*, different certification systems (e.g. EurepGAP, SAN) are developed. EurepGAP is a private sector body that sets voluntary standards for the certification of agricultural products around the globe. It is an equal partnership of agricultural producers and retailers, which want to establish certification standards and procedures for Good Agricultural Practices (GAP). It is a pre-farm-gate-standard. This means that the certificate covers the process of the certified product from before the seed is planted until it leaves the farm. The rules concentrate on quality management, minimization of negative environmental impacts of crop production and track-and-trace control. SAN stands for Sustainable Agriculture Network, which is a coalition of independent conservation groups that promote the social and environmental sustainability of production in several key commodity areas (WWI 2006). The systems have been developed to ensure that products are produced in an environmental sustainable way and are safer or healthier for the consumer. Certification systems for fair traded agricultural products (e.g. FAIRTRADE) have also been implemented to ensure 'fair' payments of agricultural products, enhance producers' quality of life and to improve their market access (Zarrilli 2006).

For the *energy sector*, a number of green electricity labels (EUGENE, Milieukeur, ok-power, Green Power, Austrian Ecolabel etc.) exist and some of them include a definition for biomass. In general, two approaches in defining green electricity from biomass can be found: (1) definition of the allowed feeding material in the first place and additional criteria defining the ecological quality of the biomass and exclusion of certain technologies or types of biomass and (2) specification of the technology (plant types) and assessment of the individual plant, which applies for certification. Criteria regarding the feeding material are additionally applied. Dam *et al.* (2008) gives additional information about the criteria applied by different green electricity labels, based on Oehme (2006).

Related to the certification systems as mentioned above, are the existence of different indicator and criteria systems to guarantee sustainability. For example, the International Labour Organization (ILO) has developed a set of criteria for sustainable labour conditions. Lewandowski *et al.* (2006) and Fritsche *et al.* (2006) provide further reading about existing certification systems.

3. Key actors in the development of biomass certification

Different stakeholder groups have recognized the need for biomass sustainability criteria and various groups started with the development of a biomass certification system or with principles and criteria to describe sustainable biomass trade. Stakeholder groups have different interest in biomass certification (Lewandowski *et al.* 2006). In this article, developments in biomass certification from the viewpoint of four stakeholder groups are described: national governments and transnational organizations (in this specific case the EC), companies, non-governmental organizations (NGOs) and international organizations and initiatives, see also table 1. The initiatives are discussed per stakeholder group and no distinction is made in the phases of development (starting with principles, to criteria and indicators to the development of the system for implementation) from the initiatives.

Table 1: Stakeholder groups and interests in certification, partly based on Lewandowski *et al.* (2006).

Stakeholders	Interests in biomass certification
National governments and transnational organizations	Policy instrument to promote sustainable management and sustainable consumption pattern; Provides information for policy making. The EU, one of the more powerful players for establishing international standards has a special role in this.
NGOs	Provides information on the impacts of products, provides information whether the product meets quality or technical standards, instrument to promote sustainable management.
Companies (producers, trade, industry)	Instrument for environmental marketing, risk management and market access, tool for controlling origin and quality of raw materials, products or services, provides information for optimization of production processes, allows for product differentiation.
Intergovernmental Organizations	The UN, FAO and UNEP in particular, play an important (potential) role as a neutral forum for negotiations between all kinds of stakeholders (particularly countries).
International bodies and initiatives	Instrument to promote sustainable management and sustainable consumption pattern, information for policy consultancy and collaboration.

3.1. Inventory of viewpoints of national governments

Many national governments in the world are promoting the use of biomass and the production of biofuels and renewable energy in their countries, see also Dam *et al.* (2008). A few of them have taken initiatives to work on the development of a biomass certification system or on principles and criteria to describe sustainable biomass trade. As far as known, these countries are Belgium, the Netherlands, the United Kingdom and countries as Brazil, Germany, Canada, and the USA to a limited extent. On supra national level, the European Commission is considering the development of sustainability criteria and a European biomass certification system. Besides, most countries have indirectly included some sustainability criteria in their policies, as e.g. sustainable harvesting of crops. Although these criteria are relevant for sustainable biomass production, they fall out of the scope of this paper and are not discussed here.

*Belgium***,** currently importing wood pellets for power production (about 700 kt in 2005), has ambitious targets for green electricity production. The sustainability of energy is a regional competence in Belgium and certificate systems are implemented in three regions (Brussels, Flanders, and Wallonia) for renewable energy sources and for combined heat and power. The different regions have chosen to apply different certificate systems (Verhaegen *et al.* 2005). The system in Flanders is based upon the energy balance and the use of fossil energy along the supply chain that is then subtracted ‘pro rata’ from the granted certificate per MWhe of green electricity. The system in Wallonia is compatible with the one in the Brussels region and is based upon avoided fossil CO_2 emissions according to a LCA with respect to the reference of the combined cycle power plant firing natural gas with an efficiency of (for now) 55% (Marchal *et al.* 2006).

The Walloon authority imposes that each supplier undergoes an audit within six months for certification of imported biomass, which examines the sustainability of the wood sourcing as well as the energy balance (through an energy audit including GHG emissions) of the whole supply chain. The sustainability of the wood sourcing can be delivered according to 1) forest certificates as FSC, 2) a traceable chain management system at the suppliers end or, in absence of such certification, 3) all public documents originating from independent bodies reviewing forest management or control in the considered country. SGS international, accepted as independent body by all Belgian authorities for granting green certificates, analyzes for each producer the global supply chain. If the product would appear in contradiction with the sustainability principle, the CwaPE (energy regulator in Wallonia) has the right to cancel the granted green certificates. So far, Flanders authorities have not requested audits or a certification procedure for imported biomass by law (Marchal *et al.* 2006).

Over the last years, *The Netherlands* has been importing wood pellets, agricultural residues and bio-oil for electricity production (Junginger *et al.* 2008). Due to the increasing imports, a project group “Sustainable Production of Biomass” was established in 2006 by the Interdepartmental Programme Management Energy Transition to develop a system for biomass sustainability criteria for the Netherlands for the production and conversion of biomass for energy, fuels and chemistry. The group, headed by prof. Jacqueline Cramer - nowadays Dutch Minister of the Environment and Spatial Planning -, was aiming to develop a framework for the sustainable production of biomass. This resulted in a report describing criteria for sustainable biomass production in July 2006 (Cramer *et al.* 2006), and was then further elaborated into a testing framework for sustainable biomass (Cramer *et al.* 2007). The framework identifies 6 main sustainability themes: greenhouse gas emissions, competition with food and other applications, biodiversity, environment, prosperity and social well-being. On these six themes, nine basic principles for biomass sustainability were formulated, including criteria, indicators with minimal requirements and reporting obligations (see table 2). For example, regarding principle 1, the emission reduction must now amount to at least 50-70% for electricity production and at least 30% for the application in transportation fuels. The percentages are to be calculated following a methodology set up by the commission. These percentages must increase further by innovation in the future. The percentages are minimum requirements. The methodology to calculate these emission reductions is published as a separate document (Kwant *et al.* 2007).

The report makes a distinction in the information that production companies must submit (at the ‘company level’) and the information that can only be obtained at the regional and/or national level (at the ‘macro level’). Dutch providers of bioenergy or biofuels, such as for instance applicants for subsidy or parties that have an obligation to provide a certain share of biofuels, must prove that they comply with the testing framework at the company level. The Dutch government is primarily responsible for the collecting of information at the macro level, and can cooperate with governments in the producing countries, the private sector and non-governmental organizations. At the macro level the project group attaches great importance to the monitoring of land and food prices, property relations, the availability of food, relocation of food production and cattle breeding, deforestation and change in the type of vegetation. Also, the report recognises the various standards (either existing or under development) such as FSC, SAN/RA, RSPO, RTRS, IFOAM and others. A benchmark with the developed framework revealed that many of the existing standards (partially) cover the Dutch criteria for biodiversity, environment and social well-being (except integrity), but that greenhouse gas emissions, competition with food and other applications are not covered at all.

The report is an advice, in the first instance to the Dutch government, but also to all other parties involved. In the time to come the government will translate this testing framework into its policy for the application of biomass in the Dutch energy supply. The government can for instance incorporate sustainability criteria into instruments supporting the use of biomass.

In September 2007 a Dutch report was released judging which obstacles can be expected when implementing the proposed framework in policy measures with regard to EU laws and WTO treaties (IPE/VROM/EZ 2007). The main conclusions were:

- A reporting obligation for companies to deliver information on the sustainability of their biomass is considered feasible under WTO/EU law. Also, putting minimum demands for GHG emission reduction (principles 1 and 2) is possible with minimal risk regarding WTO/EU law, but implementation is only possible within several years;
- Minimum demands for biodiversity and environment will require a new national legal framework, but are given a medium-high risk profile under EU/WTO law, i.e. policy measures enforcing these demands will have to be formulated very carefully, and will largely depend on the possibilities of specific biomass streams;
- Minimum demands on economic prosperity and well-being (principles 8 and 9) are considered impossible under WTO/EU law, except for extreme human rights violations (e.g. slavery).

The current status is that while the framework has no legal status so far, elements will be included in the new policy support mechanism for electricity from renewable energy sources. Minister Cramer announced in October 2007 that, based on the currently unsustainable production, palm oil will be excluded from the Renewable Energy Incentive (SDE) subsidy scheme (Milieudefensie 2007).

The *United Kingdom* announced in November 2005 the introduction of a new policy to ensure the inclusion of biofuels and, potentially in the future, other renewable fuels in UK transport fuels. The 'Renewable Transport Fuel Obligation' (RTFO) is the UK's primary mechanism to deliver the objectives of the Biofuels Directive and will place a legal requirement on transport fuel suppliers to ensure that a specified percentage of their overall fuel sales are from a renewable source. The obligation will commence in April 2008 with targets for 2.5% (by volume) of renewable fuels to be supplied in the first year, rising to 5% in 2010/11. A carbon and sustainability reporting scheme is part of the RTFO (Archer 2006).

Table 2: Summary of the Dutch framework principles and criteria; the corresponding indicators, minimum requirements and reporting obligations defined per criterion are not reported here, for details see (Cramer *et al.* 2007).

Principle	Criteria
1. The greenhouse gas balance of the production chain and application of the biomass must be positive	1.1. In the application of biomass a net emission reduction of greenhouse gases must take place along the whole chain. The reduction is calculated in relation to a reference situation with fossil fuels.
2. Biomass production must not be at the expense of important carbon sinks in the vegetation and in the soil.	2.1. Conservation of above-ground (vegetation) carbon sinks when biomass units are installed. 2.2. The conservation of underground (soil) carbon sinks when biomass units are installed.
3. Biomass production for energy must not endanger the food supply and local biomass applications (energy supply, medicines, and building materials).	3.1. Insight into the change of land-use in the region of the biomass production unit. 3.2. Insight into the change of prices of food and land in the area of the biomass production unit.
4. Biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity.	4.1. No violation of national laws and regulations that is applicable to biomass production and the production area. 4.2. In new or recent developments, no deterioration of biodiversity by biomass production in protected areas. 4.3. In new or recent developments, no deterioration of biodiversity in other areas with high biodiversity value, vulnerability or high agrarian, nature and/or cultural values. 4.4. In new or recent developments, maintenance or recovery of biodiversity within biomass production units. 4.5. Strengthening of biodiversity where this is possible, during development and by the management of existing production units.
5. In the production and processing of biomass, the soil, and soil quality must be retained or even improved.	5.1. No violation of national laws and regulations that is applicable to soil management. 5.2. In the production and processing of biomass best practices must be applied to retain or improve the soil and soil quality. 5.3. The use of residual products must not be at variance with other local functions for the conservation of the soil.
6. In the production and processing of biomass ground and surface water must not be depleted and the water quality must be maintained or improved.	6.1. No violation of national laws and regulations that is applicable to water management. 6.2. In the production and processing of biomass best practices must be applied to restrict the use of water and to retain or improve ground and surface water quality. 6.3. In the production and processing of biomass no use must be made of water from non-renewable sources.
7: In the production and processing of biomass the air quality must be maintained or improved.	7.1. No violation of national laws and regulations that is applicable to emissions and air quality. 7.2. In the production and processing of biomass best practices must be applied to reduce emissions and air pollution 7.3. No burning as part of the installation or management of biomass production units (BPUs).
8: The production of biomass must contribute towards local prosperity.	8.1. Positive contribution of private company activities towards the local economy and activities.
9: The production of biomass must contribute towards the social well-being of the employees and the local population.	9.1. No negative effects on the working conditions of employees. 9.2. No negative effects on human rights. 9.3. The use of land must not lead to the violation of official property and use, and customary law without the free and prior consent of the sufficiently informed local population. 9.4. Positive contribution to the well-being of local population. 9.5. Insight into possible violations of the integrity of the company.

The UK and Dutch Governments are cooperating on the development of sustainability requirements beginning with bilateral discussions in 2006 and leading to joint working and a common approach on many issues. The aim of this cooperation is to harmonize scheme design, reduce administration for business and demonstrate how such systems could be developed on an EU-wide basis. The European Commission and the German and Belgian governments have also been involved in this process.

The sustainability assurance schemes developed in the UK and in the Netherlands have complementary features, although the starting principles were different. In the UK, the focus has been on devising a practical scheme that can be operated by businesses supplying biofuels for transportation through the RTFO. Criteria categories are the same as in the Netherlands. Wider sustainability reporting is an integral part of the RTFO from the start and both environmental and social criteria and indicators have been proposed, based on an analysis of existing standards to achieve maximum consistency (Dehue *et al.* 2007). Especially the environmental criteria have to a large extent been coordinated with the Dutch criteria for sustainable biomass. In addition to having defined sustainability criteria and indicators, the draft methodology for the practical operation of the UK sustainability reporting has been designed. This so called "Meta-Standard" approach seeks to make maximum use of existing standards where these exist, seeks to stimulate existing initiatives such as RTRS and BSI (see section 3.4.) and finally seeks for harmonization of criteria on the long term (Dehue 2007).

Furthermore, expected levels of reporting have been defined for the period 2008-2011 and the various permissible Chain of Custody methodologies for RTFO sustainability reporting have been described. Finally, methods for verification of company reporting have been proposed. The above is described in the Framework Report for the RTFO sustainability reporting. During the entire process there was consultation with the Advisory group. Also a wider public consultation was held recently (both written and through sessions). The pilots have also been finished by October 2007. Based on the lessons learnt from the pilots and the public consultation, the technical guidance and the final version of the framework report (as a background document to the technical guidance) are currently finalized and are expected to be issued by the end of 2007. Reporting will commence in April 2008 (Archer 2006; Dehue 2007). For more information, see Department for Transportation (2007).

Brazil has since 1975 a government program to make ethanol from sugarcane and since 2002 a program for biodiesel. Starting in 2008, a 2% addition of biodiesel to petrol diesel will become mandatory (Zarrilli 2006). In Brazil, no certification systems for biomass and biofuels are currently in use. However, initial activities to include sustainability criteria into biomass production are taking place. The Social Fuel seal is for example part of the biodiesel program and establishes conditions for industrial producers of biodiesel to obtain tax benefits and credit. In order to receive the seal, the industrial producer must purchase feedstock from family farmers and enter into a legally binding agreement with them to establish specific income levels and guarantee technical assistance and training (Governo Federal 2006).

For sugarcane production, environmental licensing includes e.g. control on land-use and soil impacts. One of the harmful environmental effects from sugarcane production is the burning of fields to facilitate manual harvesting. This produces GHG, ash and other airborne particulates. In the State of Sao Paulo (produces 60% of all sugarcane) a schedule was established to gradually reduce sugarcane burning over the next twenty years. In 2000, additional steps were taken to eliminate burning and shift practices to mechanized harvesting. Controversial outcomes of these policies are immediate unemployment and creation of incentives for producers to relocate their farms to avoid regulation (Martines-Filhao *et al.* 2006). For other agricultural products, the EurepGAP system is applied to some extent and part of the forestry plantations are FSC certified.

Canada is a major producer and exporter of wood pellets and produces ethanol from grain. The Environmental Choice^{M} Program (ECP) is a national program in Canada sponsored by Environment Canada, to recognize manufacturers and suppliers that produce products and services which are environmentally preferable or less harmful to the environment. Companies meeting the criteria are certified with the EcoLogo^{M} and can use the certification to market to environmentally conscious consumers. The label, belonging to the Canadian Government, is an environmental certification mark for a wide range of products. The ECP has criteria in place for the renewable green power sector (water, solar, biomass, etc) in the North American region, incl. USA (NRC 2005). The EcoLogo^{M} has a general set of criteria for renewable energy sources, accompanied by specific criteria for biomass and biogas, see also (Dam *et al.* 2008; Environmental Choice Program 2006):

- Use of only wood wastes, agricultural wastes and/or dedicated energy crops;
- Requirements for harvest rates and environmental management systems or practices;
- Maximum levels for emissions of air pollutants.

In *Germany*, the Biofuel Quota Law came into force in 2007, which sets mandatory biofuel blending targets as well as mandatory sustainability requirements for biofuels under the Quota Law. The law further empowers the German Government to introduce a specific ordinance to detail the sustainability requirements for biofuels under the Quota Law. An informal working group established the key issues and requirements for biofuels sustainability to be included. The key requirements of the Biofuels Sustainability Ordinance (BSO) include:

- Sustainable production requirements for agriculture;
- Sustainable land-use and protection of habitats;
- Requirements for greenhouse gas emissions – biofuels eligible under the Quota Law must demonstrate a certain GHG reduction potential, taking into account the full life-cycle of biofuel production, including emissions from land-use change;

The final draft of the BSO was published in late October, and a final decision of the German Government will take place on December 5th, 2007. Parallel to preparing the BSO, the German Government also drafted sustainability requirements for bioenergy for the 2008 amendment of the Renewable Energy Act and is considering similar regulation for the draft Renewable Heat Law (Fritsche 2007).

In addition, research projects and governmental organizations as the German Technical Cooperation (GTZ) support the development of sustainable biomass. GTZ has carried out case studies on the potential and implications on agriculture and sustainability by liquid transport biofuels in four developing countries: Brazil (Kaltner *et al.* 2005), China (Gehua *et al.* 2006), India (Kashyap *et al.* 2005) and Tanzania (Janssen *et al.* 2005). The studies include an analysis of the sustainability of biofuel development related to environmental, social and economic criteria in the country's context.

A preliminary initiative has started in *California, USA*, where a roadmap is developed for the development of biomass production and use in California, commissioned by the California Energy Commission. This roadmap includes a chapter about standards and best practices for sustainable feedstock supply including aspects as land-use, environmental impacts and resource monitoring (Tiangco *et al.* 2006). Furthermore, in May 2007, SUNY ESF[16] sent out a survey on sustainability criteria for bioenergy systems to international bioenergy experts. By means of a range of criteria found in the literature, the goal was to identify areas of agreements and uncertainty areas with as long term goal to i) identify critical criteria and ii) keep their number at a feasible level. The survey was send to 137 participants. In total, 46 experts filled out the survey and send it back. Nineteen experts responded that they had no time, did not feel competent, participation might compromise with their duties, or forwarded it to colleagues. Final results will be released to participants by December 2007. A publication in a peer-reviewed journal is envisaged (Buchholz 2007).

On supra-national level, in January 2007, the *European Commission (EC)*, made proposals for a new Energy Policy for Europe, proposing:

- A binding 20% target for renewable energy in 2020;
- A binding 10% target for the share of biofuels in 2020;

The Commission is now drafting proposals to incorporate these targets to legislation for the so-called Climate and Energy package. As input, the commission held a public consultation, in which four main questions were to be commented on (EURActiv 2007a):

1. How should a biofuel sustainability system be designed?
2. How should overall effects on land-use be monitored?
3. How should the use of second-generation biofuels be encouraged?
4. What further action is needed to make it possible to achieve a 10% biofuel share?

This proposal yielded a response with more than three hundred responses from NGO's, institutions, member states, the industry and private sector, third countries and private citizens. The proposal for new legislation is now due in January 2008 (EURActiv 2007a). However, some information has so already been announced. The framework will cover at least three themes:

- Minimum level of GHG savings compared to fossil fuels, from production to actual use. The exact reduction percentage is still under debate;

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[16] SUNY ESF is an abbreviation for the State University of New York College of Environmental Science and Forestry.

- No use of land types with high soil carbon for biofuel production. A more specific definition is in preparation;
- No use of high biodiversity areas for biofuel production. Again a more specific definition is in preparation.

Possibly more themes will be included. Furthermore, according to Paul Hodson from DG Environment, quoted by PlanetArk (2007), the legislation will seek to promote 2nd generation biofuels. Also while the EU theoretically has the capacity to meet biofuel target through domestic production, a balanced approach between domestic production and imports is preferred. As the new legislation will still have to be ratified by all member countries, actual implementation in the member states is probably to be expected earliest from 2011 onwards.

Furthermore, the 1998 Fuels Quality Directive (Dir98/70), adopted by the Commission in January 2007, is now under discussion in the Parliament (Plenary vote due in January 2008) and in the Council. This directive contains a proposal requiring fuel suppliers to measure the lifecycle greenhouse gas emissions (i.e. production, transport and use) for the fuels they supply in the EU as of 2009, and reduce these emissions by 1% per year from 2011 to 2020. The directive therefore has also an effect on biofuels lifecycle emissions, being a strong incentive for the best-performing biofuels in that respect. However, during the debate in September 2007 in the European Parliament, voices were raised against these proposals arguing that it would conflict with similar rules currently being drawn up by the Commission for a separate Directive on the promotion of biofuels (EurActiv 2007b). As of October 2007, it was undecided whether and how GHG emission reduction or sustainability criteria will be included in the revised Fuels Quality Directive.

Summarizing, national governments worldwide are developing new biomass policies. Most of these policies relate to targets or incentives to stimulate the use of renewable energy sources. A few national governments (the Netherlands, the UK, and Belgium, with Germany coming up in 2007) and the EC on supra-national level have taken the initiative to start developing a policy framework to guarantee sustainable biomass. The systems in Belgium and UK have as main criteria for sustainable biomass feedstock the reduction of GHG emissions, as Germany will include as well. The Netherlands and the UK have developed a wider set of principles including environmental, social and economic criteria. A framework for implementation is still in process. Belgium has coupled the criteria with the granting of green certificates. The UK aims to develop carbon certification schemes for environmental assurance. The EC intends to develop a system of certificates so that only biofuels whose cultivation complies with minimum sustainability standards will count towards the targets.

3.2. Inventory of the viewpoints of companies

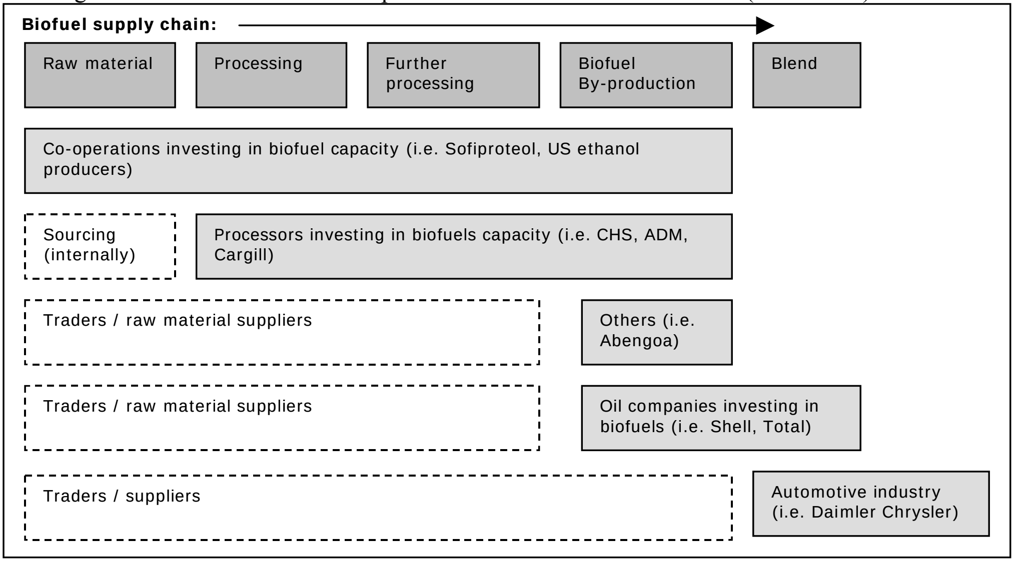
Nowadays, different support systems (e.g. feed-in tariffs, certificates) have been initiated and implemented to accomplish national targets on the use of renewable energy sources and biofuels. Recent developments in the field of biomass certification show that this stimulated companies - involved in the supply, finance or use of electricity from biomass or biofuels -

to start with initiatives in this field. Biomass certification serves as a tool for environmental marketing, risk management and market access.

3.2.1. Parties in the biofuel / biomass supply chain

National initiatives and legislation (see 3.1) have triggered initiatives on biomass certification at companies active in the biofuel and biomass supply chain. For biomass, the supply and processing chain leads to chain interaction of various parties, depending on the economic segments in which they are active (see figure 2). Various companies are involved in the discussion on biomass certification and their initiatives tend to focus on the part of the chain for which they are responsible. A number of companies who recently included the sustainable production of biofuels are listed below. Given the current rapid development of new initiatives, this list of examples should not be considered exhaustive.

Figure 2: Companies active in different economic segments of the liquid biofuel supply chain, resulting in differences in focus and responsibilities for biomass certification (Vaals 2006).



Both the companies *CARGILL B.V.* and *CEFETRA* (*traders, raw material suppliers)* are members of the Dutch project group ‘Sustainable Production of Biomass’. CEFETRA plays a coordinating and organizational role in several supply chains. It is important for the company to secure its (independent) sourcing and get as close as possible to the primary production / producer to directly influence factors as e.g. quality, track & tracing, the use of GMOs and sustainability. An integrated pricing system with a shortened supply system will increase the steering power of CEFETRA on these issues (Stam 2006). CARGILL is also a member of RSPO and RTRS (see section 3.4) as well as the company *Unilever*.

Unilever (processing and supply) has expressed its concerns about current biofuel policies (Mortished 2006), further explained in a ‘Biofuels Unilever Position Statement’ (Unilever

2006). Concerns relate, among others, to a decrease in the availability of raw materials and sustainability aspects due to increased pressure on land and environmental, cost and energy yield aspects of low-performance biofuels (Unilever 2006).

SHELL (*Oil Company*) is one of the larger blenders of transport biofuels. In 2004, foundation Shell Research and Probos Foundation have invited a group of experts to take place in the 'Biomass Upstream Steering Group' (BUS), enabling Shell to identify opportunities and threats of biomass use, to learn about sustainability and acceptability and to make the right choices (Voss 2004).

Volkswagen (*automobile company)* has developed a fuel concept based on second-generation biofuels, which can be produced from biomass, are to a large extent CO_2 neutral and do not compete with food production. Volkswagen is calling on politicians to develop a sustainable tax model providing a secure network for investing in the development and market launch of new fuels. Apart from taking CO_2 efficiency as criteria, other sustainability criteria should also be included in fuel taxation. Volkswagen has developed a tax model catering for both CO_2 efficiency (primary criterion) and a set of additional sustainability criteria (Volkswagen 2006).

DaimlerChrysler (*automobile company*) signed in 2005 the Magdeburg Declaration with the United Nations Environment Programme (UNEP) stating to promote sustainable mobility by supporting activities and to further tap the potential of biofuels. This was further agreed upon in a Memorandum of Understanding in February 2006. The two organizations call on biofuels'producers to take sustainability aspects into account throughout their lifecycle. An assurance scheme should be put into place, and to this aim UNEP and DaimlerChrysler looked at different existing schemes in different places. DaimlerChrysler intends to support the development of a 'sustainability seal' (similar to what FSC provides for wood products) for the cultivation of biomass for biofuels. Other activities of the partnership include conducting engine tests, developing field trials in India, organizing the biennial Magdeburg Environmental Forum (platform for experts) and the development of second-generation biofuels (DaimlerChrysler 2006), see also section 3.4.

BioX, a company for liquid biomass from palm oil imported from Malaysia, is RSPO member and has its own Code of Conduct and position paper of palm oil for energy generation. BioX, together with Control Union, is currently evaluating RSPO-criteria for auditing and certification purposes. It has developed a questionnaire and pre-auditing document to audit palm oil production locations on RSPO-criteria. The company will audit palm oil producers to verify if they comply with the RSPO sustainability principles and criteria. BioX started a study to determine the CO_2-emissions related to the growing, production and transportation of palm oil; an issue that has not been covered by the RSPO-criteria. Since 2006, BioX is joining the GGL program, see also 3.2.2 (BioX 2006).

Financing companies also play a role in the discussion of sustainable biomass production. The bank *Rabobank International* is a member of the Dutch project group 'Sustainable production of Biomass' and RTRS (Rabobank Brazil) and RSPO member. Recommendations given by the bank related to sustainable bioenergy are e.g. indicating that bioenergy projects should be judged on a case-by-case basis taking into account ecological, social and economic criteria (Fresco *et al.* 2006).

3.2.2. Companies in the electricity supply chain

Demand on using Renewable Energy Sources (RES) is stimulated by obliging end-users to produce a share of their electricity (imposed by a quota obligation) by RES. In practice, this obligation is usually not imposed on the consumer but on electricity suppliers or distribution companies. This has introduced market mechanisms and trade in sustainable energy production and has stimulated electricity suppliers in Europe, using biomass as feedstock, to start initiatives to develop their own biomass certification systems (Verhaegen *et al.* 2005).

Electrabel label is a certification procedure for imported biomass and developed by Electrabel, a European energy company. For Electrabel, it is necessary to inform a potential supplier of all requirements made by Electrabel concerning the sustainability criteria for being accepted within the Belgian green certificate systems (see 3.1) and the technical specifications of the product for firing it in a thermal power plant (Marchal *et al.* 2006). Electrabel applies similar certification procedures in the different Belgian regions, gathering the auditing requirements for the import of biomass of Flanders and Wallonia. The requirements for biomass to be accepted according to Electrabel’s standards are concentrated in a document called “Supplier Declaration” (Electrabel 2006). This document is signed by a representative of the producer and verified and stamped by a certified inspection body before being delivered to the Belgian authorities. The Inspection Company SGS is in charge for checking the document and carrying out a full audit of the plant and the supply chain within the 6 months following the first time the biomass is fired (Marchal *et al.* 2006).

For calculating the numbers of granted certificates, Flemish authorities require the knowledge of a list of parameters related to the plant. The supplier must therefore fill in an informative questionnaire that consists of three functional parts. These are: 1) sourcing and management: origin of biomass, 2) production chain, including energy consumptions and 3) transport and storage, including rail and sea transport (Electrabel 2006). The questionnaire, dedicated to the suppliers of the biomass products, includes both mandatory questions as well as informative (non-mandatory) questions. The questionnaire for part 1 can be found in Dam *et al.* (2008).

The largest Dutch user of biomass, *Essent* (also RPSO member), has developed the biomass certification system *Green Gold Label* (GGL) in cooperation with Peterson Bulk Logistics and Control Union Certifications. This development started in 2002 and aims at a track and trace system for biomass from (by)-products from the power plant (and the green power it produces) back to the sustainable source. In this system mixing or contamination with non-intrinsic or environmentally harmful materials is prohibited. In every link of the chain, written proof must be available that the GGL quality system is supported, sustained and maintained. The system consists of six different standards covering the complete biomass chain from production till end-use including the bioenergy plant. An example for standard 1 on Chain of Custody and processing is shown in Dam *et al.* (2008), see also GGL (2005). The standards define amongst others Chain of Custody standards, criteria for forest management and criteria for agricultural products (Control Union World Group 2006).

GGL accepts existing certification systems (e.g. FSC standards) but has additional guidelines for pellet manufacturing and transportation. A major criterion within GGL is the requirement for tracking custody of the biomass. The GGL label is continuously in development. It currently looks at possibilities to include social criteria in its certification system (Maris 2006). Beside Electrabel and Essent, also *other energy companies in Europe* (Fortum in Scandinavia, Eneco in the Netherlands, others) consider or develop at this moment their own biomass certification system (Maris 2006).

Thus, companies are actively involved in various parts of the biomass chain. Their interest in biomass certification depends on their role in the biomass chain. Energy companies have to justify the sustainability of their end product to the consumer, stimulating companies as Essent and Electrabel to develop a biomass certification system. Companies as DaimlerChrysler or Shell, also active on the end side of the chain, are involved in research and pilot projects related to new technologies and sustainability of their products. Companies on the production and transport side of biomass play a role in how to guarantee sustainable biomass production. For companies as Unilever or Cargill, trading products for food and/or energy production, the discussion on food security and change of economics for their products is highly relevant.

3.3. Inventory of the viewpoints of NGOs

Several NGOs have expressed their viewpoints on sustainable bioenergy production and started initiatives on biomass certification. In general, NGOs are positive about the possible opportunities offered by sustainable bioenergy production, but also mention concerns on potential environmental and socio-economic harm due to increased bioenergy production. For example, Birdlife International "could not support further development of the Bioenergy crops industry without an appropriate certification scheme" (Birdlife International 2005). In the so-called 'Bonn Declaration' from 2004 several *civil organizations from Latin America and the Caribbean* express their viewpoints on renewable energy in general. They stress the need, among other things, of energy access to civilians in the region with minimal local, national and global environmental impacts. Financial incentives should be redirected to sustainable renewable energy sources as biomass, excluding projects with negative social and environmental impacts (ANES 2004). *WWF Brazil* also stresses the need for a certification system in Brazil to better ensure that biofuels are produced in an environmentally and socially friendly way (Volpi 2006). These NGO viewpoints are written down in various position papers and reports.

Position papers, including sustainability principles or key concerns for sustainable biomass are developed by, as far as known, the following NGOs:

- *NGOs in South Africa* (Sugrue 2006), see also Dam *et al.* (2008);

- *FBOMS (Energy working group of the Brazilian Forum of NGOs and Social Movements for Environment and Development) in Brazil,* see Dam *et al.* (2008) and Moret *et al.* (2006);
- *WWF Germany* (coincide with criteria WWF International), see Dam *et al.* (2008) and Verweij *et al.* (2006);
- *NGOs in the Netherlands, including Milieudefensie, BothEnds, WWF, Greenpeace, Natuur en Milieu, Oxfam Novib,* see Verweij *et al.* (2006), Richert *et al.* (2006) and Dam *et al.* (2008);
- *IATP in the USA* developed sustainability principles for bioindustrial crop production, see Kleinschmidt (2006) and Dam *et al.* (2008);
- *Greenpeace* and *Birdlife International* (Birdlife International 2005; Greenpeace 2006).

Table 3 provides an overview of these sustainability criteria showing that, although there is a consensus on the need to develop criteria, there is also variation among them. For example, FBOMS has included 'gender equality' as a separate criterion, while this criterion is not or hardly mentioned in other lists. Also, there is a difference in priority (e.g. between environmental and socio-economic criteria), strictness (e.g. use of GMOs, GHG balance) and level of detail given to these criteria.

These differences arise from the different backgrounds and aims of the NGOs described. However, it would go beyond the scope of this paper to describe these aims as well. Furthermore, it was attempted to summarize all criteria in table 3 as comprehensive as possible. However, NGO activities to promote sustainable biomass production develop fast and more principles may be developed or under way. A compiled list of concerns and issues indicated by organizations is also developed by Bramble (2006), aiming to bring those pieces together into a coherent international governance structure for sustainable biomass production and use.

Various NGOs have started pilot projects and case studies to learn more about the use of sustainability criteria and the impacts of sustainable biomass production in developing countries. *A group of Dutch NGOs* (BothEnds 2006; Lange *et al.* 2006) has initiated three case studies with product/country combinations in developing countries (*Brazil, South Africa, Indonesia*) to gather information on risks and opportunities from export of biomass flows, analysed by a Sustainability Assessment Framework, see Dam *et al.* (2008). The report also gathered opinions from stakeholders in these countries to include their viewpoints in the debate in the Netherlands. The report reflects a comparison between results derived from this project and criteria proposed by the Dutch project group on sustainability criteria (section 3.1) and provides recommendations for a further dialogue.

Ahold coffee company has initiated the Corporate Social Responsibility label Utz Kapeh. The Dutch NGO *Solidaridad* is using the Utz concept for other commodities, including cocoa, tea, palm oil and also biofuels. To this, Utz has changed its name into Utz Certified and uses its label Good Inside.

Table 3: Summary of sustainability principles from various NGOs as mentioned in reports and position papers.

	South Africa	Dutch NGOs	IATP	Greenpeace	Birdlife	WWF Germany	FBOMS
GHG, energy balance	Full LCA, Energy balance crop > 1:3	Significant GHG emission reduction, positive energy balance	Energy η and conservation		Include LCA carbon savings	Defined levels of GHG outputs and η (LCA)	Diversification of energy mix
Competition food, energy	No extension productive land, energy to the poor by own production	No violation of right to food security, concern for – indirect- land competition				Priority for food supply and food security, include regional impacts	Food security, no monocultures, crop diversity
Economic prosperity	Economic stimulus to rural communities, access to (rural) energy for poor	Promote (local) socio-economic development, no economic burden on vulnerable groups	Economic sustainability			Ensuring a share of proceeds	Rural credits, job income and generation, diversification, decentralization of activities
Working conditions		Labour conditions, human health impacts	Safe and healthy conditions			Health impacts, worker rights, share of proceeds	Organization of production, labour relations
Human rights		No violation, right of children				No violation	Gender equality
Property rights and rights of use	Indigenous land ownership, land redistribution	Equitable land ownership, land-tenure conflicts to be avoided				Rights to land-use clearly defined	
Social conditions		Revenues invested in social well-being	Respect social, cultural heritage				Social inclusion Participation in decision making
Integrity							Social accountability
Environment	See for details: Dam *et al.* (2008)	Revenues invested in environment		See for details: Dam *et al.* (2008)	Environmental impacts general	See for details: Dam *et al.* (2008)	See for details: Dam *et al.* (2008)
Origin of biomass	Crop types, no annual crops						Crop diversity, no monocultures

Table 3 (continued): Summary of sustainability principles from various NGOs as mentioned in reports and position papers (continued).

	South Africa	**Dutch NGOs**	**IATP**	**Greenpeace**	**Birdlife**	**WWF Germany**	**FBOMS**
Biodiversity	Maintained	Maintained, production energy crops increases ecological quality, risk conversion land-use	Promote biological diversity, nature	Concern: burning wood from ancient forests	Include criteria on biodiversity	No additional negative biodiversity impacts, no negative land-use changes	Defined limits for occupation of biomes; comply with economic, ecological zoning;
Waste	EIA on potential waste						
Use of agro-chemicals			Sound nutrient management	No / limit use of fertilizer, pesticide		Avoiding negative impacts	Minimization or elimination of pesticide use;
Farming practices	Conservation farming techniques, intercropping	Associated farming practices to protect environment				Production practices	Use of best available practices; diversity of crops;
Soil quality	Maintained	Sustainable use of soil resources	Strengthening the soil	Concern: loss of topsoil		No additional soil erosion and degradation	Reduction of soil loss
Water quality and quantity	No extension irrigated land, measures	Sustainable use of water resources	Protecting water	Concern: risk for increase salinity		Protection of water bodies	
Emissions to air	EIA to determine potential pollution		Protecting air	Concern: toxic emissions			
No GMOs	Prohibited	Currently not allowed	Prohibit GMO	No Use of GMOs		Exclusion GMO	No priority
Training	Included						Training, technology transfer
Institutional, governance	Included	Good governance, government context included, land-use planning	Stakeholder participation, transparency			Land-use planning, EIA of biomass production	Regulatory compliance, region classified by EIA

Solidaridad is focusing in its program ‘renewable energy’ on biomass for export from developing countries and is implementing, together with the Dutch energy company Essent, a pilot biomass certification project for Utz Certified coffee husks from Brazil. The coffee husks originate from coffee plantations, certified by Utz Certified. An external monitoring of the pilot takes place according to the sustainability principles from Cramer (Solidaridad 2006; Cramer J., Wissema E. et al. 2007).

German NGO representatives from the environment and development sector (Maier *et al.* 2005), WWF (Fritsche *et al.* 2006; WWF 2006) and others also provide recommendations specifically related to approaches for the implementation of a certification system for sustainable biomass. These recommendations are further discussed in section 5.

Thus, various NGOs are actively involved in the development of a biomass certification system. Initiatives are taken to develop proposals on principles and criteria for sustainable biomass certification, including environmental, social and economic criteria. NGOs are mainly active on the production side of the biomass chain and have a strong concern about the environment and the well-being of the poor in rural areas. Some NGOs have provided suggestions on the implementation for a biomass certification system. NGOs play an active role in forums and have started pilot studies.

3.4. Inventory from viewpoints of international bodies, organizations and initiatives

On international level, activities to develop a biomass certification system are initiated by international bodies and organizations, international networks and Roundtables in which various stakeholders (NGOs, companies, government) participate. Different international bodies have recognized the need for biomass sustainability criteria. Within the UN, *UN-Energy***,** created in 2004 as a follow-up to the World Summit on Sustainable Development (WSSD), is the principal interagency mechanism in the field of energy. Its aim is to promote coherence in the UN system’s response to the WSSD and to collectively engage non-UN stakeholders. An overview of activities from UN-Energy and its members (e.g. World Bank, various UN organizations) can be found in UN-Energy (2006).

Biofuels is an issue addressed within the UN as it is considered as a possible instrument to stimulate development. At the same time, sound policies and some pre-conditions are required to realize this (Zarrilli 2006). The *UN Biofuels Initiative* (UNBI) is established within the UN as a mechanism to coordinate initiatives within different UN bodies related to biofuels. The Biofuels Initiative aims to support developing countries which are considering the option to engage in biofuels production. The Initiative is supported by the UN Foundation and is being undertaken in partnership with UNCTAD, FAO, UNDP, UNEP and UNIDO. It promotes a sustainable production, trade and use of biofuels in developing countries, under conditions that can attract foreign and domestic investment. UNCTAD aims to assess, in cooperation with the UNBI, biofuel potentials within developing countries and work with national decision-makers and private-sector groups to develop country-specific strategies (National Biofuels Action Programs) for the production and use of biofuels (Zarrilli 2006; United Nations Foundation 2006).

The *International Bioenergy Platform IBEP* (established by the FAO) is focused on knowledge management and transfer. IBEP provides expertise and advice for governments and private operators to formulate bioenergy policies and strategies. It also assists in developing tools to quantify bioenergy resources and implications for sustainable development in general and food security in particular, on a country-by-country basis. IBEP has developed a proposed plan of action. One of the activities mentioned is to assist in the development of an international scheme to develop workable assurances and certification based principles, methodologies, criteria and verifiable indicators (FAO 2006). One of the activities by IBEP, started in December 2006, is the development of an analytical framework to assess the implications of different types of bioenergy systems for a set of different food security contexts. This results in the formulation of national strategies, based on recommendations on how to undertake bioenergy development.

The *FAO Forestry Department* is working on biomass certification, in cooperation with *IEA Bionergy Task 31* (IEA bioenergy Task 31 2008), by evaluating principles, criteria and indicators for biomass from forest used for energy as well as for wood fuel and charcoal production. The study includes a review of existing forest certification schemes. Based on this study, criteria are developed to cover forest biomass for energy. These are tested in the field using case studies. For the production systems (including transport from the forest site), key factors influencing the production chain are assessed. Also, the impact of the various steps of that chain in ecological, social and economic terms is evaluated. The project is also analyzing the legal and institutional framework under which criteria for wood fuel production systems fall. Using the results of the assessment a set of criteria covering ecological and socio-economic aspects of the production cycle will be developed and eventually be tested in the field (Rose 2006).

Furthermore, amongst other projects, FAO recently started the BioEnergy and Food Security *(BEFS)* project. This three-year project will provide guidance to policy-makers and other stakeholders to assess the potential effects of bioenergy production on food security in developing countries. It will develop national strategies, strengthen national (and local) capacities and formulate suitable downstream projects with national counterparts. The proposed activities will help to ensure that linkages between food security and bioenergy are mainstreamed into development and poverty reduction strategies, that linkages to the right to food are established and that food needs of vulnerable people, particularly in rural areas, remain paramount.

Project activities will focus on the elaboration of a quantitative and qualitative framework to analyse land-use, bioenergy production potential and the relationship(s) to food security and poverty alleviation concerns in participating countries in Latin America, Asia and sub-Saharan Africa. First, an analytical framework will be developed. In a second phase, the project will formulate bioenergy strategies, that have mainstreamed food security considerations, and identify a preliminary set of sustainable bioenergy projects that will be suitable for investment, support rural development and readily adaptable to other countries and communities. The results of this project will provide the technical guidance, analytical and knowledge management tools necessary to ensure that food security remains central to the development of sustainable bioenergy policies. Planned training workshops will ensure that project outreach extends beyond the participating countries (FAO 2007a).

UNEP was asked to lead the development of a collective programme of work on bioenergy sustainability under the G8 Global Bioenergy Partnership (GBEP). UNEP has proposed a way forward which is currently under review by the GBEP members. Part of the suggestion is an initial set of recommendations for decision makers in governments and industry as well as a set of sustainability criteria covering the sustainability of the entire life-cycle i.e. production, conversion and use of bioenergy. Both are open for discussion, amendment and review by the GBEP members (Ernest 2006; Otto 2007).

Furthermore, UNEP joined forces with DaimlerChrysler, WWF Germany, BP, and the Ministry of Agriculture of Baden-Württemberg to develop sustainability criteria for the production of biomass for liquid biofuels with the aim of designing an assurance system (certification or other). UNEP, DaimlerChrysler and the Ministry of Agriculture of Baden-Württemberg issued a working paper including (Otto 2007):

- Review of existing certification systems linked to biomass certification;
- Compilation of certification labels (forestry, bioenergy and palm oil, agricultural and trade labels) - understanding the technical processes, structure, etc;
- Compilation of ongoing initiatives by the international communities and country policies on biofuels;
- Assessment of the requirement of different crops.

UNEP joined the Roundtable on Sustainable Biofuels (RSB) Initiative and is actively involved in its four working groups. Under this cooperation, UNEP and Ecole Polytechnique Fédérale de Lausanne (EFPL), as secretariat of the RSB, are organizing regional outreach events to ensure wide stakeholder involvement. Results of this work will be reported back to the GBEP process (Otto 2007).

Bioenergy has a large number of registered projects (32.5% of total) in the pipeline for the Clean Development Mechanism (CDM), administered by the *United Nations Framework Convention on Climate Change* (UNFCCC). UNFCCC has as one of its objectives the development of monitoring and baseline methodologies for CDM projects. Until now only a few methodologies for biofuels are approved, because of uncertainties in determining 'leakage' (Fritsche *et al.* 2006), lack of capacity in CDM project development in many developing countries, and a limited availability of CDM baseline methodology specifically developed for biofuels projects (UNCTAD 2006).

The *IEA Bioenergy Task 40* (IEA Bioenergy Task 40 2008) on International Sustainable Bioenergy Trade aims to investigate what is needed to create a commodity market for bioenergy. Parties as industry, NGOs, governmental bodies and FAO participate in this task. Key priorities are (amongst others) sustainability criteria, standardization and terminology for biomass trade. Main recommendations from a workshop, organized in 2005 in Brazil in cooperation with IEA Bioenergy Tasks 30 and 31, related to biomass certification were:

- The aim should be an internationally accepted framework based on existing experiences;
- Great diversity of competing systems should be avoided. A certification system could be created by initiating a gradual process for certification procedures, starting at regional level;
- A certification system should include a wide variety of stakeholders to ensure credibility.
- It should be based on current best practices and supported with high quality scientific knowledge;
- A gradual development is needed as such a certification system should not create new barriers, i.e. negative experiences as gained with CDM (e.g. in terms of complexity, required time and formulation costs) should be avoided;
- Crucial in a system is the build-up of credibility by verification and accreditation of the data.

Studies from Task 40 members on biomass certification relate to e.g. certification system development for sustainable bioenergy trade (Lewandowski *et al.* 2006) and to case studies on impacts of sustainability criteria on costs and potentials of bioenergy production in Brazil and in the Ukraine (Smeets *et al.* 2005).

The *Global Bioenergy Partnership, (GBEP),* launched in May 2006, consists of private sector associations, countries and international agencies (Canada, China, France, Germany, Italy (Chair), Japan, Mexico (Co-Chair), Russia, UK, USA, FAO, IEA, UNCTAD, UNDESA, UNDP, UNEP, UNIDO, UN Foundation, WCRE and EUBIA). GBEP's overall objective is to coordinate and implement targeted research, development, demonstration and commercial activities related to bioenergy supply and use, with a particular focus on developing countries. GBEP also provides a forum for implementing effective policy frameworks, identifying ways and means to support investments, and removing barriers to collaborative project development and implementation (GBEP 2008).

EUGENE, an independent network of environmental and consumer organizations and research institutes, promotes green electricity labelling as a market-tool to facilitate and stimulate additional production of renewable and energy efficient services. The EUGENE label applies to geothermal, wind, solar, electric, hydropower and biomass energy. The label is given to defined ‘eligible sources’. Eligible sources for biomass are e.g. dedicated energy crops, residual straw from agriculture etc. More specific criteria for eligible biomass resources, like production methods, are not provided (Lewandowski *et al.* 2006). A study from EUGENE, meant as support for possible certification of biomass, includes a proposal of biomass criteria for application by EUGENE standard. These criteria are subdivided in two groups (Oehme 2006), see table 4.

Issues surrounding the production of large commodities as palm oil, soybeans or sugarcane (which can all be used as biofuel feedstock) in Asia and South America have triggered initiatives as the establishment of Roundtables where all stakeholders in the chain are represented. *The Roundtable on Sustainable Palm Oil (RSPO)* is created by organizations carrying out their activities in and around the entire supply chain for palm oil.

Table 4: Summary of proposal biomass criteria for application by EUGENE (Oehme 2006).

Criteria, which can easily become operational and monitored / verified:
Eligibility of sources (including e.g. woody, herbaceous and fruit biomass)
Requirements on the origin of wood fuel (sustainable forest management, certification for plantations)
Use of Genetically Modified Organisms (GMO) is not permitted
Energy crops and SRC crops shall not be produced on converted land
Emissions of CH_4, N_2O and NH_3 by usage of manure have to be reduced
In the annual average, the plants need to meet an overall efficiency of at least 60%
Co-firing of solid biomass is permitted under conditions (e.g. required efficiency of 70%)
Criteria for which further elaboration is needed to become operational:
Wood fuel from non-certified forest has to meet a set of criteria
Maintenance of soil fertility
Biomass from dedicated cultivation on arable land needs to comply with guidelines for integrated crop protection, livestock waste should comply with principles of integrated farming
The non-renewable proportion of the energy that is used for extraction, transportation and processing, and also balancing, is not permitted to be greater than 10% of the electricity supplied with the label

Table 5: Summary RSPO principles to promote sustainable oil palm production (RSPO 2005).

Principles RSPO
Commitment to transparency
Compliance with applicable laws and regulations
Commitment to long-term economic and financial viability
Use of appropriate best practices by growers and millers
Environmental responsibility and conservation of natural resources and biodiversity
Responsible consideration of employees and of individuals and communities affected by growers and mills
Responsible development of new plantings
Commitment to continuous improvement in key areas of activity

RSPO has developed a set of 8 principles and 39 criteria for sustainable palm oil production, which were adopted end 2005 (RSPO 2005), see also table 5 and Dam *et al.* (2008). The principles relate to social, economic, ecological and general criteria. RSPO criteria are now in a 2-year trial phase. Third party verification arrangements are being put in place for evaluation of compliance with RSPO principles and criteria. In the supply chain, audits are put into place to verify compliance with requirements for sustainable palm oil traceability. The first certifications of oil mills, estates and growers are expected early 2008. Arrangements for trade in certified oil will be published at the RSPO conference in November 2007 (RSPO 2005; Vis 2007).

One of the objectives of the *Roundtable on Sustainable Soy* (RTRS) is to develop and promote criteria for the production of soy on an economically viable, socially equitable and environmentally sustainable basis. The 2nd Conference of the RTRS in 2006 included several presentations with examples of responsible production models and an overview of certification options (RTRS 2006). In September 2007, a technical working group has started to develop the RTRS principles, criteria and its verification system (RTRS 2007). The purpose of the Basel Criteria for Responsible Soy Production was to provide a working definition of acceptable soy production to be used by individual retailers or producers. Criteria were developed by the company Proforest (also involved in RSPO).

Table 6: Summarized overview of involvement of stakeholders in process of biomass certification.

Initiatives	Principles	I & C[a]	Status	Organization	Platform function
National Governments					
Netherlands	Yes (environment, socio-economic)	Yes	Pilot studies	Working group set up by government	Stakeholder consultation
Belgium	Yes (GHG, sourcing)	Yes	Criteria coupled to green certificate	Independent body in coop. with authorities	
UK	Yes (environment, socio-economic)	Yes	Certification expected in 2008	Legislation development (RTFO)	Stakeholder consultation
Canada	ECOLOGO (general), also for biomass	Yes	Since 2005	Government owned label	
Brazil	Social Seal for biodiesel	Yes	In implementation	Government regulation	
Germany	Yes (GHG and others)	No	In development	National regulation	
Others[b]	No	No	Not applicable	Not applicable	Partner in debate
E.C.	Yes, in development	No	Draft proposals	Policy development within EU	Partner in debate
Companies					
Essent	Yes (Environmental criteria, social criteria in development)	Yes	Green Gold Label	Independent body: Control Union	IEA Task 40 member
Electrabel	Yes (Sourcing, energy / GHG balance)	Yes	Electrabel label	Independent body: SGS	IEA Task 40 member
BioX	Based on RSPO criteria	n.a.	Auditing palm oil locations	In cooperation with Control Union	RSPO member
Daimler-Chrysler	Background studies	No	Studies, discussion, forum	Initiative in coop. with UNEP	Forum for environment
Volkswagen	Tax model incl. criteria	Yes	Model development		Partner in debate
Shell	Studies on sustainability biomass	No	Studies, small projects	Under framework of BUS initiative	BUS Forum of experts
Rabobank				Financing partner	Partner in debate
Others[c]	No	No	Position papers	Not applicable	Partner in debate
NGOs					
WWF	Yes	Yes	Road map	Approaches, see study WWF Germany	RSPO member
Solidaridad	Yes (Utz Certified label)	Yes	Project with case studies	Project in coop. with GGL (Essent)	Involvement stakeholders

For footnotes: see next page.

Table 6 (continued): Summarized overview of involvement of stakeholders in process of biomass certification.

Initiatives	Principles	I & C[a]	Status	Organization	Platform function
NGOs					
NGOs Netherlands	Yes	Yes	Proposals for policy tools, pilot studies	Study assigned by Dutch NGOs	Participation in debate (RSPO)
NGOs South Africa	Standpoints on concerns biofuel production	No	Position paper	Working group representing NGOs	
NGOs Germany	Yes	No	Policy Paper	Study through stakeholder process	
NGOs Brazil	Sustainability criteria	Yes	Report	Developed by various NGOs	
IATP	Sustainability criteria	No	Criteria combined with good practice	Through stakeholder process	
Others	Limited	No	Position papers[d]	Not applicable	Partner in debate
International organizations, initiatives					
UN-Energy	No	No	Not applicable	Platform (non-) UN organizations	Coordination, exchange info
UNBI	Background studies in trade & potential	No	In planning	UNCTAD chairs initiative	Coordination, support
FAO	Yes, for forest biomass	Yes	Pilot studies	Partner is IEA Task 31	Partner in debate
UNEP	In development	No	Preparatory studies	In cooperation with others (e.g. GBEP, Daimler-Chrysler)	Partner in debate
IBEP	Background studies	No		FAO chairs initiative	Knowledge exchange
G8 GBEP	White Paper; mandated UNEP to develop I&C	Yes	In planning	Initiative within G8 countries and UNEP	Coordination
EUGENE	Yes (sourcing), additional principles in process	Planned	Existing label, additional C&I	Network for green labels	Networking function
RSPO	Yes, for sustainable palm oil production	Yes	Pilot studies, working group	Roundtable on voluntary basis	Stakeholder process, platform
RTRS	Yes, for responsible soy production	Planned	Working group and consultation	Roundtable on voluntary basis	Stakeholder process, platform
RSB	Yes, for sustainable biofuels production	Planned	Working group and consultation		
BSI	Planned for sustainable sugarcane production	Planned	No	Roundtable on voluntary basis	Stakeholder process, platform

[a] I &C: Indicators and Criteria. [b] Various governments have started policy developments on biomass and biofuels, mainly focusing on stimulating the use of it by defining targets or policy incentives (see 3.1). [c] Companies as Unilever, Cargill and CEFETRA are actively involved in the discussion on biomass certification issues. [d] Various NGOs (Greenpeace, Birdlife) have published a position paper to express their views on biomass and biofuels in the EU and worldwide. A list of concerns is expressed in these papers (section 3.3).

Table 7: Started initiatives for a biomass certification system (+ criteria are included, - criteria are not included[a]).

Check list:	**Green Gold Label**	**Electrabel Label**	**Government (BE)**	**UK-RTFO**	**Project group (NL)**	**EUGENE (EU)**	**RSPO**
Type of biomass	Biomass (all), complete chain	Biomass (all), complete chain	Biomass certificate, energy generation	Biomass source for biofuels	Biomass (all)	Focus on end part of chain	Palm oil, production side
Status	Certification in implementation, also in development	Certification in implementation, also in development	Green certificates linked to GHG / energy criteria	Establishment certification system in development	Principles developed, testing phase C&I (pilot studies)	Actual label, adds extra principles for biomass in specific	Principles developed, testing phase C&I (pilot studies)
Principles included:							
GHG and Energy balance	-	+	+	+	+	+	+
Biodiversity	+	-	-	+	+	-	+
Competition of food supply, local sources	-	-	-	-	+	-	-
Leakage	-	-	-	-	- [b]	-	-
Economic well-being	- [c]	-	-	+	+	-	+
Welfare / social criteria	- [d]	-	-	-	+	-	+
Environmental criteria	+	+	-	+	+	+	+

Table 7 (continued): Started initiatives for a biomass certification system (+ criteria are included, - criteria are not included[a]).

Check list:	**Green Gold Label**	**Electrabel Label**	**Government (BE)**	**UK-RTFO**	**Project group (NL)**	**EUGENE (EU)**	**RSPO**
Procedure and organization:							
Track-and-trace Sourcing	Track-and-trace Sourcing	Cooperation with e.g. Electrabel, SGS	Track-and-trace Sourcing or book-and- claim, currently under consideration	Track-and-trace Sourcing or book-and- claim, currently under consideration	Track-and-trace sourcing of biomass types eligible under EUGENE	Track-and-trace Sourcing	
Organization	Established by company Essent, now open for 3rd parties	Label is developed by company Electrabel	Government provides green certificate based on criteria compliance	Initiated by government, organizational structure in process	Initiated by government, organizational structure in process	European Network of green energy labelling bodies	Roundtable with stakeholders in palm oil production
Verifier	Control Union	SGS	Independent 3rd party verification	Requirements not yet determined	Requirements not yet determined	Independent 3rd party verification	Verifier working group (in progress)
Relation to national policies	Stimulated by policy	Required by law	In regional policy (in development)	Plans to embed in national policy	Plans to embed in national policy	On voluntary basis	On voluntary basis
(Plans to) make use of existing systems	FSC, 'Organic' certification	Yes (e.g. FSC)	See Electrabel	Yes (e.g. FSC)	Will apply e.g. FSC, and GGL	Yes (e.g. FSC)	Makes use of existing systems

a) This is a general overview. When a criterion is included (+), the level of detail in methodology, indicators etc. may still vary per certification system, b) Currently investigated how to take this into account, c) The inclusion of socio-economic principles is taken into consideration, d) See footnote a of table 6, e) Track-and trace implies the physical traceability of the traded biomass. Under book-and-claim, production and redemption of a certificate is separated (and the certificates can be traded separately from the physical biomass). Similar systems exist for example for renewable electricity, where Certificates of Origin are traded. For some of the initiatives described here, this choice has not yet been made, but the requirement of calculating GHG and energy balances makes a track-and-trace requirement likely.

The developed 'Basel Criteria for responsible Soy production' forms a relevant background document in the light of these developments, see also ProForest (2004). A similar initiative has started for sugarcane by the establishment of the *Better Sugarcane Initiative* (BSI). One of the aims of the BSI is to determine principles and to define globally applicable performance-based standards for 'better sugarcane' with respect to its environmental and social impacts (BSI 2008).

Finally, in November 2006, the *Ecole Polytechnique Federale de Lausanne* (EPFL) initiated a multi-stakeholder workshop to investigate the potential for developing internationally accepted and implementable standards for sustainable biofuels (RSB 2007). This resulted in the establishment of the *Roundtable on Sustainable Biofuels (RSB)* in 2007. The RSB aims to achieve global, multistakeholder consensus around the principles and criteria of sustainable biofuels production and builds on existing national and commodity based initiatives. As latest document, they published a second version of global principles for sustainable biofuels production on October 23, 2007 for comments (Haye 2007).

Summarizing, initiatives initiated by international bodies focus on a wide range of activities as the promotion of coherence of activities, support of developing countries and exchange and transfer of information. Some of these international bodies have formulated specific projects, often in collaboration with more partners, to gain better insight in the development of a biomass certification system. International networks and Roundtables are based on a voluntary approach. They have started their own activities for the development of a certification system for their specific target product.

Table 6 provides a summarized overview of initiatives from stakeholder groups in the field of biomass certification. Table 7 shows that various biomass certification systems exist or are under development to guarantee the eligibility of the biomass source and its transport or to guarantee the sustainability of its production (woody biomass, palm oil or soy). These systems show some coherence but differ in the inclusion of the type of biomass, time frame, system (mandatory/voluntary) and demands of their criteria.

4. Limitations for the implementation of a biomass certification system and possible strategies to overcome them

Section 4.1 discusses the role of the World Trade Organization (WTO) in relation to international biomass certification. Section 4.2 discusses limitations and counter arguments for implementing a biomass certification system and possible strategies to overcome them.

4.1. Biomass certification and international trade law

Certification schemes and labelling programmes fall within a grey area of the WTO. The *Technical Barriers to Trade* (TBT) Agreement requires that regulations (mandatory) and standards (voluntary) should not create unnecessary trade obstacles and prohibits discrimination between domestic products and foreign products (the National Treatment Principle) and between products from different WTO members, called the ‘Most Favoured-Nation principle’ (MFN) (Bauen *et al.* 2005). The MFN and National Treatment obligations apply only if two products are “like”, which is determined on a case-by-case basis by four criteria (WTO 2006a): a) properties, nature and quality of the product; b) tariff classification; c) consumers’ tastes and habits and d) product end use.

Environmental trade measures that distinct between products based on their production *Process and Production Methods* (PPMs) that do not influence the physical characteristics of a product may violate the TBT obligations (Wessels *et al.* 2001; WTO 2006b), see also Dam *et al.* (2008) for some PPMs. This is important to consider, as criteria related to sustainable biomass certification are likely to be based on non-product related criteria.

At present, the applicability of the TBT Agreement that is based on non-product related PPMs is unclear. Jurisprudence is not conclusive and authoritative authors are divided on the subject (Zarrilli 2007). The Appellate Body in Asbestos, see Dam *et al.* (2008), has interpreted jurisprudence on the setting of PPM-based regulatory requirements, emphasizing that regulatory distinctions may be drawn between products found to be ‘like’, provided that the distinctions in question do not systemically disadvantage imports over domestic products (Zarrilli 2007). How this jurisprudence applies to biofuels and related feedstock is still an open debate as the jurisprudence is looked at on a case-by-case basis (Wijkstrom 2006). One specific characteristic of the Asbestos case, which may not be applicable to a biofuels or related feedstock case, is that it showed a physical difference between products: The presence of asbestos can or cannot cause cancer (health aspect).

Though countries do not hold a univocal position on it, several WTO members hold the position that standards and labels that refer to PPMs are not among the measures covered by the TBT agreement. On the other hand, labelling programs increasingly rely on Life Cycle Analysis and indeed refer to PPMs. Several recent certification proposals for biofuels are currently the result of individual initiatives and may escape from WTO rules. However, they can (or are meant to) have impacts on the accessibility of products in the markets of destination and on consumer’s choice (Zarrilli 2007).

Also, the complainant would have to establish that the ‘like’ imported product has been afforded less favourable treatment than the domestic product (Howse *et al.* 2006). The jurisprudence is e.g. applicable to measures relating to post-import environmental impacts. Measures to minimize overall impacts of a fuel throughout its lifecycle on global carbon emissions do not seem to interfere with local or domestic policies either as it relates to a global environmental problem (Howse *et al.* 2006).

In this respect, the prime requirement in almost all current initiatives is to meet GHG and/or energy targets (see table 7) and it is the expectation that biofuels from developing countries in general will be able to meet these criteria. For example, case studies on the sustainability of ethanol production from sugarcane in São Paulo, Brazil, show that GHG emission reduction potentials of 80% can be achieved (Smeets *et al.* 2008). Under current practices in São Paulo state, GHG reduction levels of, for example, 30 to 50% (the reduction level used by the Dutch government for criteria on GHG reduction) can easily be met, and a disadvantage of import products from Brazilian ethanol in European countries is therefore not likely. The feasibility of other criteria, e.g. labour circumstances, can differ largely on local scale and can only be assessed on a case-by-case basis.

The latter example also relates to the GATT (General Agreement on Tariffs and Trade) stating few exceptions, which may justify *environment-related measures* on products and the use of necessary measures to assure these standards are met, even though they violate the general principles of GATT. These exceptions are justified when a) it is necessary to protect human, animal or plant life or health or b) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption (Bauen *et al.* 2005). Air is considered as an exhaustible resource and the argument of adequate supply of (sustainable) biofuels within this context has plausibility as well (Howse *et al.* 2006). Another exception, stated in GATT, is the 'National Security Exception' allowing taking necessary measures for the protection of a country's national interest. It is acknowledged that energy security is a vital dimension of national security in general (Howse *et al.* 2006).

No provisions exist within WTO agreements to link trade with social issues and labour standards and any attempt to make such linkages has so far been met with opposition. However, the International Organization for Standardization (ISO) has recently launched the 'Working Group on Social Responsibility' with the task of publishing a ISO 26000 standard on guidelines for social responsibility in 2008 (Bauen *et al.* 2005).

The Code of Good Practice, see also Dam *et al.* (2008), provides disciplines to standardising bodies, including those related to transparency, for preparing, adopting and applying standards (Wessels *et al.* 2001). Members should use international standards where appropriate, but the TBT Agreement does not require members to change their levels of protection as a result (Fritsche *et al.* 2006). The value added of the Code is that it extends the TBT discipline to standards developed by non-governmental bodies, which have accepted it (Zarrilli 2007). Based on previous concerns and debates in the 1990s regarding the use of the Code, especially with reference to voluntary eco-labelling schemes, it was agreed that there should be a) an open market for all certification schemes, b) no political action to diminish the trade of uncertified products and c) no inclusion of the origin of the timber on the label to avoid discriminatory action against specific regions (FASE-ES 2003).

Sustainability standards can be linked to *subsidies and tariffs.* These may affect international trade and are therefore included in WTO rules. The *classification of a product* is important to define which tariff levels and which set of disciplines and domestic subsidies are applicable. Product classifications for biofuels are not consistently aligned with the actual consumer market in question, which leads to a number of problems with respect to consistency, certainty and non-discrimination of existing WTO obligations. An approach would be to define 'new' products for biomass-derived energy carriers. However, this is a complex process which can take many years (Howse *et al.* 2006). Subsidies are arranged in the Agreement of Agriculture (AoA) and the Subsidies and Countervailing Measures Agreement (SCM), the latter prohibiting export subsidies and subsidies contingent upon the use of domestic products over imported products. Based on the SCM Agreement, subsidies should not have certain adverse trade affects or cause adverse effects (injury) to a group and should be non-specific, not directed at limited group of particular products (Howse *et al.* 2006). Within the AoA, countries have agreed to pursue the harmonization of subsidies. A number of approaches allow countries to subsidize products. ‘Green boxes’ are permitted (in WTO terminology, “boxes” identify subsidies). In order to qualify for the “green box”, subsidies must not distort trade, or at most cause minimal distortion; they have to be government-funded and must not involve price support. They tend to be programmes that are not directed at particular products, and include direct income supports for farmers that are decoupled from current production levels or prices (WTO 2006b). At this moment “green box” subsidies are allowed within WTO, but may be difficult to maintain if liberalization of the agricultural sector proceeds (Fritsche *et al.* 2006).

Finally, it should be noted that WTO is an international forum where agreements are negotiated and signed by governments. In case policy measures do affect international trade, WTO provides a platform for other governments to complain and request for adjustments, and it is recognized that governments should not hold environmental policies in the way they consider legitimate (Wijkstrom 2006). Currently, as part of the Doha Round of negotiations, members are discussing the relationship between WTO rules and multilateral environmental agreements that may contain trade-related measures. At this stage of negotiation, it is not clear what the outcome will be (Pellan 2006). WTO agreements, also related to biomass certification, are a result of negotiations and in advance the outcome is thus unsure. In general it can be said that international consensus of criteria and broad consultation among states, taking into account the variety of conditions in diverse countries promotes the acceptance between WTO members (Howse *et al.* 2006).

Table 8: The compatibility of biomass sustainability criteria with the WTO context.

Criteria in line with WTO when:	Remarks
Related to post-import impacts.	Visible in end use of product.
Referring to a global scale with no to limited interference with local policies.	E.g. GHG levels.
Based on consumer preference, unspecified to a specific product and translated to voluntary standards.	These can include environmental or socio-economic criteria.
Needed to protect human, animal or plant life or health or relating to conservation of exhaustible natural resources.	Criteria applicable are e.g. air emissions or GHG balance.
Internationally agreed upon with broad consensus.	More complicated for criteria with impacts on local / regional level.
No international provisions exist within WTO for linking trade with social issues and labour standards.	Socio-economic criteria through voluntary standards (e.g. as FSC) possible at this stage.

Thus, based on above, the WTO context for biomass certification, we summarize:

- There are possibilities to design environmental measures and sustainability criteria for biomass (in line with WTO principles) that distinguish ‘like products’, see table 8;
- Subsidies should not have certain kind of adverse trade affects or cause adverse effects (injury) to a group and should be non-specific, not directed at limited group of particular products;
- There is an open market for certification systems, with a risk for proliferation of systems;
- International consensus promotes acceptance of criteria and the Code of Good Practice can serve as a tool to promote transparency and stakeholder participation;
- WTO agreements are a result of negotiations between members, and in advance the outcome of these agreements is unsure.

4.2. Limitations on the implementation of biomass certification and possible approaches to overcome them

Limitations mentioned on the development of a biomass certification system provide lessons learnt for future implementation. Not everyone sees certification as a means to guarantee sustainable biomass production and counter arguments are also heard in this section.

4.2.1. Lack of adequate criteria and indicators

There is a need for guidance on risk minimisation. To ensure the effectiveness of such guidelines, certification with monitoring and verification could be used, see also Otto (2007). Although there is consensus about topics that are at stake, there is no consensus yet which criteria should be included to guarantee sustainable biomass trade and how less quantifiable targets should be measured (WWI 2006). An implication mentioned for the development of a biomass certification system is how to make some of the concerns and sustainability principles operational into effective indicators and verifiers. There is experience in applying some and little to no experience of applying others. Better insight is e.g. required on the design of criteria and indicators according to the requirements of a region and on how to include avoidance of leakage effects and the influence of land-use dynamics (ProForest 2006), with a first step for a “priority rule” as being suggested by Fritsche *et al.* (2006). For other issues mentioned by various organizations on how sustainability criteria can be translated into operational indicators and verifiers, see also WWI (2006), Dam *et al.* (2008) and BothEnds (2006). Pilot studies are needed to build up experience of how sustainability criteria can be met under diverse conditions (Lange de *et al.* 2006). The development of new methodologies, to measure impacts, and valuation approaches on how to assess overall damage and benefits is recommended (Smeets *et al.* 2008).

4.2.2. Requirement of effective control and monitoring system

Procedures and solid (documentation) systems are needed to implement a reliable certification system, see also ProForest (2006). Besides, establishing an effective, reliable international biomass certification system is complicated due to large differences between regions in production and scale (monocultures, small scale, different crops), national context (legislation, stakeholders, their view on sustainability) and environmental vulnerability (drought, fire, soil) as also indicated in the pilot studies from BothEnds (2006). Also, NGOs have indicated in several cases that the frequency of field visits is often too low. If stricter monitoring is required, this will also have an impact on the costs and feasibility of a system. How, in this light, a certification system would have to be given shape must be worked out further (Cramer *et al.* 2007).

It is advised to design and adopt specific, quantifiable criteria for sustainability indicators. Despite their specificity, they should be flexible enough to be adapted to the particular requirements of a region. Criteria have to be enforceable in practice, easily comprehended and controlled without generating high additional costs (WWI 2006). More insight is needed in the monitoring compliance and limitations of sustainability criteria developed for biomass. Cramer *et al.* (2007) recommend that a biomass certification system must be based on a track-and-trace system, in which the traceability of biomass is guaranteed. The guarantee of complete traceability in the short term is still difficult, making a transition period necessary.

4.2.3. Open market limits effectiveness certification system

FASE-ES (2003) mentions that the open market for (in this case) FSC certification has transferred the responsibility for 'combating environmental and social crime from governments to consumers faced with hundreds of eco-labels, the vast majority of which are a result of opportunistic product marketing'. This competition has as consequence that some certifiers lax application of FSC-standards e.g. by including vague formulations that criteria have to be fulfilled 'within a certain timeframe' after the certificate had been issued. This resulted in abuse of the possibilities of the system. WWI (2006) indicates that open competition in certification schemes and –therefore- confusion for consumers has hampered efforts to develop meaningful certification systems in ecotourism and organic foods. FASE-ES (2003) also mentions that certifiers often have a commercial relationship through direct contracts with the certification client, which results in an interest of the certifiers in a positive assessment which weakens the objectivity of the problem.

WWI (2006) recommends that a proliferation of standards, differing from one country or region to another, has to be avoided. Further coherence in biomass certification systems, possibly through promotion of international agreements and standardization of criteria, is needed.

4.2.4. Small stakeholders' limitations to implement requirements

Small stakeholders, often operating with limited resources and technical skills, may lack the capacity (knowledge, financial resources) to implement necessary changes required for a transition to a new certification system (ProForest 2006). This may be, without a transition period, too complicated for smaller companies. There is a risk that only larger producers can fulfil new demands in short time which involves a risk for marked disturbance as only few producers can offer certified feedstock resulting in artificial high prices (Maris 2006). While a certification scheme should be thorough, and reliable, it should not create a hurdle for nascent industries (WWI 2006).

It is recommended to pair a certification scheme with assistance and incentives (WWI 2006) and to look for possibilities for group certification to guarantee that small producers are not excluded (Cramer *et al.* 2007). Using existing certification systems in the development of a biomass certification system, at least for the short term, may promote the involvement of smaller stakeholders. Existing systems may not cover all required criteria, but it limits the risk for market disturbance. Including extra criteria in a certification system can then be achieved over time by mutual consultation (Maris 2006). Because of the difficulties for small stakeholders, a scheme would have to be accompanied by capacity building (Otto 2007).

4.2.5. Stakeholder involvement required for a legitimate and reliable system

While expert judgment can flag the issues, alert the stakeholders to major concerns and provide methodologies for measuring, valuating and monitoring the different aspects, experts should not unilaterally decide which sustainability criteria to include and how to prioritize them. To a large extent, the judgement of local stakeholder is crucial as well to take into account the circumstances and needs in specific situations.

Furthermore, ProForest (2006) and Ortiz (2006) mention that an adequate understanding and involvement of primary processors and workers in the field, often the ones controlling and monitoring the criteria, is required for the successful implementation of a biomass certification system. Their involvement in the strategic development of the criteria, as e.g. currently developed in Europe, is however limited and often starts (too) late in the process (Ortiz 2006). Main arguments for participation failures in certification systems from FASE-ES (2003) are that the selection of consulted groups is often arbitrary, tending to include most influential actors while local groups are often neglected. Also, people without access to modern communication channels (e.g. rural people) are often not informed. Other limitations mentioned are the gap of 'technical expertise' between certifiers or specialists and the local population and, in case questions or problems are raised, the lack of budget in the certification assessment to include more detailed studies.

It is important that all concerned and affected in a participatory process (multi-stakeholder approach) set the certification criteria (Maier *et al.* 2005) and that broad consensus about basic underlying principles in the certification process is achieved. Where strict, specific criteria and indicators are difficult to establish due to differing opinions of stakeholders, the use of "process indicators" showing continuous improvement may help to facilitate progress in moving forward. Relying on existing certification systems should be approached with caution, as they may (be perceived to) represent only some of the stakeholders' interests (WWI 2006).

4.2.6. Limitations related to national legislation and governance

A biomass certification system needs to comply with international (see 4.1) and national legislation. The latter is a minimum requirement in most existing certification systems. Smeets *et al.* (2008) mention in a study on the sustainability of Brazilian bioethanol, that a weak government and law enforcement system is an implication related to national legislation. This is also acknowledged in case studies from Lange de *et al.* (2006) mentioning that a lack of governmental land-use planning can increase risks for local food security and leakage effects. Lack of land certification is another concern, limiting the position of local communities. Although legislation might be in place, a weak governmental law enforcement system in developing countries to ensure compliance of these laws may remain a problem (see also 4.2.2). Additional control mechanisms may be required in countries with weak governmental and law enforcement systems. Support is needed to national governments to improve their law and enforcement systems.

4.2.7. Cost levels of biomass certification

Compliance with criteria has to be controllable in practice, without incurring high additional costs (Faaij *et al.* 2005). Within the frame of extra costs for the sustainable production of biomass and certification, two different cost aspects are identified, see also Dam *et al.* (2008):

- Extra costs to meet sustainability criteria for the production and transport of biomass like measures against soil erosion or an additional wastewater treatment facility;
- Costs for monitoring, compliance with the sustainability criteria and the physical traceability of the product. Components of these costs are e.g. the costs of field study by a certifier or sampling the palm oil during loading and unloading.

A brief attempt to quantify possible cost ranges for these cost items, based on existing sustainability schemes and certification systems, is included in Dam *et al.* (2008). Based on this, it can be concluded that costs for complying with (strict) sustainability criteria can be substantial: a range of 8-65% additional costs was found in literature, though incidentally also a slight cost reduction was reported. Costs for the certification process itself and chain-of-custody are (in case of large-scale operations) much lower: a range of 0.1 - 1.2% was found. However, for small-scale farmers, again this number may be much higher. Costs are strongly related to the scale of operation, the strictness of sustainability criteria, the number of sustainability criteria and the expertise required to check them adequately. In addition, many biomass types (especially not pre-treated, bulky biomass) have already a relative low economic value. For small-scale production, extra costs for sustainability certification could potentially become prohibitive.

Zarrilli (2006) mentions that developing countries have traditionally encountered difficulties getting certificates (see 4.2.4) issued by their domestic certification bodies and recognized by the importing countries. They often need to rely on (expensive) services provided by international certification companies. Issues of costs and who pays are therefore critical to the success of a certification program, particularly when seeking participation of smaller-scale producers with fewer resources (WWI 2006). It is recommended to make as much as possible a link with existing certification systems to limit administrative burdens and costs (Cramer *et al.* 2007), see also 4.2.4.

4.2.8. Issues related to inequalities in development and international trade

There is concern that biomass certification can become an obstacle for international trade and develop trade restrictions due to proposed sustainability criteria. Measures to ensure conformity may act as powerful non-tariff barriers (especially for developing countries) if they impose costly, time-consuming tests (Zarrilli 2006). Also, some sustainability indicators under development go beyond indicators developed in many other sectors and it should be avoided that this backfires on biotrade if too many restrictions are put in place (Cramer *et al.* 2007). WTO (2006b) also mentions a number of arguments why not to distinguish between products on the basis of how they are made, i.e. on the basis of sustainability criteria:

- If one country sets rules (such as requiring eco-labels), which deals with the way products are made in another country, then it is intervening in the producing country's rules;
- When products are identified only by what they are, not on how they are made. Countries can set their own standards as appropriate for their level of development and can then make their own trade-offs between their own needs (and values) for development and environmental protection;
- If countries do not impose their standards on each other, standards can be tailored to conditions, priorities and problems in different parts of the world.

Sustainability criteria should be developed through a transparent and fair process, taking into account local conditions, where all countries involved are effectively presented. A multi-stakeholder approach is needed to get input from the different players in the area (Otto 2007). Support is needed to improve developing country’s capacity to play an active role in the development of biomass certification (Zarrilli 2006). It must be considered that there is a large diversity in the technical efficiency level in biomass production in the world, ranging from large-scale, high-tech production to smaller-scale, low-tech biofuel production focused primarily on poverty alleviation.

The appropriate technologies and policy orientations required to promote these two objectives are different. Policymakers need to clearly define their outcomes and design policies accordingly. The larger and more developed biofuel industries become, the greater the policy effort required to fulfil social and environmental aims (WWI 2006).

5. Proposed strategies for implementation of a biomass certification system

Certification is one of the policy tools available to pursue the sustainability of biomass. Various policy tools which can be used to promote the sustainability of biomass are mentioned by Richert *et al.* (2006):

- *Certification*: Only biomass that is certified according to criteria derived from sustainability principles is allowed to be imported as a result of government support for sustainable bioenergy production.
- *Product Land Combinations*: Only biomass from regions that comply with sustainability principles are allowed to be imported as a result of government support for sustainable bioenergy production. Government decides which products from which regions are eligible for government sponsored bioenergy production.
- *Regionalization:* In this strategy, Europe utilizes its own biomass resources before importing biomass from developing countries.

The three tools were analyzed by scoring the effectiveness, the technical, juridical and political feasibility and the time needed to implement the tool. Advantages and disadvantages for certification as a policy tool in specific are included in table 9 (Richert *et al.* 2006). In this section, we discuss proposed strategies and pathways for the implementation of a biomass certification system as can be found in several studies and in literature. Five main strategies can be distinguished (see figure 3), which will be discussed one by one.

Approach 1: Government regulation for biomass (minimum) standards

This approach is based on a government regulation for biomass minimum standards, possibly combined with incentives (Cramer *et al.* 2007). It coincides with e.g. the viewpoint described in the study by WWF (2006) that ‘promotes the adoption of a mandatory GHG certification scheme for all biofuels, whether produced in the EU or imported, combined with reporting obligation for environmental and social sustainability issues with a view to improve performance over time’. Maier *et al.* (2005) also favour this approach, mentioning that the EU must insist upon the development of an eco-fair certification scheme for sustainable bioenergy sources, which guarantees privileged market access to the EU. Initiatives to embed biomass certification into national policy can be found in countries as UK, Belgium and the Netherlands (see section 3.1).

Table 9: SWOT analysis for certification to pursue sustainable biomass (Richert *et al.* 2006).

Strengths	Weaknesses
• Flexible in land choice; • Clear translation 'do no harm' possible; Connects to approach NGOs to stimulate forerunners (promotes continuity).	• Controllability system is low (control by private parties) • Political discussion on approach & considerations lacking; • Translation "do more good" is limited; • Expensive (administration is expensive for companies and therefore difficult to apply for small holders); • The system is inflexible once a standard is developed (in practice it turns out to be difficult to adapt a standard);
Opportunities	Threats
• Certification is not dependent of a national political context so that local initiatives can be rewarded.	• Because of decentralized implementation, there is a risk that the quality of certificates is variable; • Due to low technical feasibility of high quality certification, there is pressure to weaken quality of standard; • Is applied without consideration, automatism.

Approach 2: Voluntary certification system, bottom-up approach

In this approach, also called the *bottom-up approach* (Fritsche *et al.* 2006), a group of governments, companies, and other interested parties voluntarily adopts standards and certification schemes, as e.g. several Roundtables are developing. Collaborative certification schemes could be a starting point, setting minimum standards for cultivation and harvesting practices for producers.

As trade increases in volume and complexity, a more advanced and innovative certification scheme may build off of earlier efforts. While not all biomass types may fulfil the entire set of sustainability criteria initially, the emphasis should be on the continuous improvement of sustainability benchmarks (WWI 2006).

Relevant in this approach is to see which player can take the lead in the process. Also, time and interest is needed to introduce and implement standards. Existing instruments or organizations can be used to push the process - e.g. bi- and multinational financing institutions are relevant players in this process - to start implementing sustainability standards for their project (co-financing) operations (Fritsche *et al.* 2006). Currently, two voluntary certification systems (GGL and Electrabel) that cover the complete biomass chain are in implementation. More certification systems are under development (see section 3.2 and table 9).

Approach 3: Private label with higher standards than those mandated by law

As part of a voluntary certification scheme, it would be possible to develop an eco-label for those biomass related products that meet higher standards than those mandated by law (WWI 2006). The objective of certification is a governmental regulation for biomass minimum standards combined with a set of private standards. Higher standards or special cases are based upon voluntary agreements of biomass producers. The latter would include companies in the Chain of Custody whose statutes or internal regulations contain several biomass standards and based upon goodwill (Fritsche *et al.* 2006).

In this approach, there are several institutions that can take care for the certification of biomass: governmental institutions (certification with regard to governmental guidelines) or private certification institutions (governmental guidelines combined with stricter private guidelines) (Fritsche *et al.* 2006). An example for this approach can be found in the UK (see section 3.1) which is considering to link GHG certification to RTFO and to cover other environmental and social criteria by a separate voluntary scheme (Bauen *et al.* 2005).

Approach 4: Voluntary bioenergy label combined with international agreement

Promoting international general agreements on 'well functioning global markets for bioenergy is suggested by Hektor (2006). These agreements could be established through written general guidelines or 'Codex of Behaviour' for direct actors involved. A similar kind of approach is suggested by Verdonk (2006) giving proposals for governance systems for bioenergy, based on a comparative case study research on the governance of comparable commodities as e.g. coffee and wood. The proposal results in a system consisting of two pillars: a Bioenergy Labelling Organization (BLO) and an International Agreement on Bioenergy (IAB), see also table 10.

Table 10: Characteristics of the proposal (Verdonk 2006).

Instrument	Description	Purpose
Pillar BLO:		
Progressive certification	Multiple levels of compliance on sustainability criteria	Certification of production; Enables participation of many producers
Progressive price premium	Linked to the level of compliance and product quality	Incentive for producers to participate and to increase the level of compliance
Impact assessments	On local economy, food & energy supplies, complementary GHG using LCA studies	Prevents leakage effects and food & energy shortages; ensures GHG complementary
Marketing assistance	Advice programs on certification and organizing trade relations; certification subsidies for small producers from developing countries	Enhances involvement of and benefits for small producers from developing countries
Buyers groups	Actors from industry and civil society	Stimulate demand of BLO certified bioenergy
Monitoring	Chain-of-custody certification	Certification of trade
Pillar IAB:		
Covenants	Agreement between industries and governments	Increases use of BLO certified bioenergy
National import & production rules	Based on BLO certification	Limits import and production of non-BLO certified bioenergy
Regulation of market prices	Internalize environmental costs in prices energy	Lowers the price difference with unsustainable sources of energy

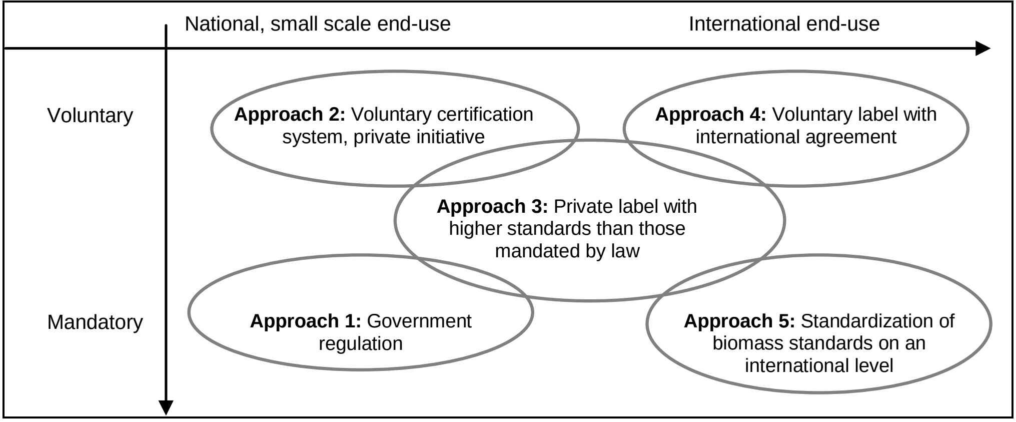
The BLO, for example a FSC-based certification system, might be able to penetrate the market within short time and offers stakeholder participation and standards that secure most sustainability concerns. The BLO seems acceptable to industry and the WTO (Verdonk 2006). The attractiveness for small producers from developing countries is enhanced in this system using Fair Trade based instruments, but remains in balance with downstream interests at the same time. The framework of universal sustainability principles enables geographical differentiation of standards and accommodation of numerous bioenergy feedstocks. In order for the BLO to be manageable in the starting phase, it is proposed to limit the number of bioenergy feedstock and/or the number of sustainability concerns in its starting phase. Within time, the scope can be widened further (Verdonk 2006).

As the BLO suffers from dependency on conscious consumers, governmental intervention was originally proposed by Verdonk (2006) through a UN Agreement on Bioenergy (UNAB) in order to realize significant market penetration (the 2nd pillar). However, as the establishment of an UNAB was considered a bridge too far (based on interviews), the development of an IAB by front running (Western) countries was chosen as alternative option. Western countries are assumed to have less divergent views on sustainability and foreign politics and already have markets for sustainable production.

Approach 5: Standardization of biomass minimum standards on international level

An option to regulate sustainable biomass standards internationally in a legally binding form would be through adopting a Multilateral Environmental Agreement (MEA) or by integrating the standards into existing international agreements or standards (Fritsche *et al.* 2006). An agreement on the objectives about standards for bioenergy is recommendable on international level. The framework conditions for bioenergy should be regulated from which criteria for different sectors can be further established. Further step of refinement of these standards can take place on a regional level with regard to objectives and conformation to the regional legal framework. This regulation can go beyond the minimum criteria of the international agreement and concrete instruments can be applied (Fritsche *et al.* 2006). No international agreements (voluntary or legally binding) exist yet for sustainable biomass standards. However, on a regional supra-national level, the EC is currently proposing the development of standards and a policy framework to secure sustainable biomass for the European region (see 3.1).

Figure 3: Possible approaches for implementation of biomass certification.



6. Discussion

In this section, the strategies as described in section 5 for the implementation of a biomass certification system are discussed (section 6.1), followed by a discussion on possible roles of stakeholder groups in the development of such a biomass certification system in section 6.2.

6.1. Recommendations in development of a certification system

The approaches as mentioned in chapter 5 are discussed based on the indicators used in the study from Verdonk (2006) and concerns indicated in section 4.3.

6.1.1. Stakeholder involvement

The success of a biomass certification system depends on the involvement and support of the wide range of parties involved in the biomass production, trade and processing chain. Full involvement of all stakeholders, including small stakeholders, is advisable. A bottom-up approach (approach 2) includes the interest and involvement of all relevant players. Roundtables as RSPO serve well as forums to discuss topics relevant for biomass certification between stakeholders and to reach common agreement. This approach requires a strong commitment of the stakeholders involved, as it lacks an obligation for the market to fulfil the sustainability criteria. This diminishes a guarantee for international sustainable biomass trade. To secure sustainability concerns (see 6.1.2) some governmental intervention (approach 1, 3 and 5) might therefore be required. Top-down approaches (approach 1, 5) might, on the other hand, involve the risk to exclude smaller stakeholders in the consultation process.

6.1.2. Securing sustainability concerns

Most stakeholders agree that a set of environmental, social and economic criteria should be included in a biomass certification system. Currently, various organizations are preparing principles or criteria (see section 3) but only few have started to bring them into practice. Lack of consensus and limited experience in translating some concerns for sustainable biomass production into indicators and verifiers hampers operationalization (see 4.2.1) and leads to the tendency to simplify sustainability criteria for the short term, taking into consideration extra criteria for the future. Weakening criteria may create a risk for securing biomass sustainability. On the other hand, a gradual development of a certification system with gradual learning (to gain insight and experience in criteria, see 6.1.4) and expansion over time might to be desirable (approach 2, 3, 4) for the short term to guarantee some level of sustainability for biomass production and trade. Sustainability concerns are more secured in a certification system where standards of a certification system are (partly) translated into policy instruments (approach 1, 3, 5). A consideration in the development of a biomass certification system is therefore whether a certification should be legally binding or with restricted or without binding force. See also 6.1.4.

6.1.3. Level of flexibility (regional refinement)

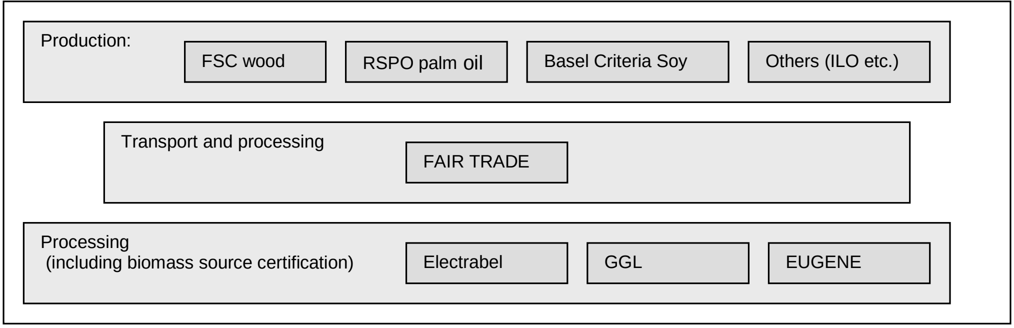
Environment, policies (see 6.1.5) and possible implications vary from place to place (see 4.2.2) and a possibility for regional refinement of standards is therefore relevant. A developed voluntary or government regulated certification system (approach 1, 2, 3) may turn out to be, once standards are developed, inflexible (see table 11). A framework with minimum standards may enhance the flexibility of a system, as national or local relevant standards can be set (approach 5).

6.1.4. Feasibility in costs

Criteria need to be controllable in practice, without incurring high additional costs. At this moment, existing biomass certification systems (table 7) have included environmental criteria to a limited extent and socio-economic criteria are not included yet or only to a certain limit. Compliance with the complete list of criteria (as proposed by various NGOs or governments) means therefore in reality a further expansion of criteria and principles for these systems. The feasibility of biomass certification systems (based on a more extended list of criteria) with respect to controllability and costs is therefore at this point still largely unknown.

Acceptance of existing certification systems (figure 4) although not covering 100% of the proposed criteria to secure sustainable biomass may facilitate in the development of an international biomass certification system, at least on the short term. This practice, already used by voluntary certification systems (approach 2, 3) as GGL and Electrabel, requires a certain level of flexibility in a transition period of a certification system. Currently, knowledge is built up through the development of certification systems, policies and pilot projects. This may provide (new) initiators in this field with insights in the development of a certification system.

Figure 4: Making use of existing certification systems.



6.1.5. Scope of possible regulation (legitimacy)

A biomass certification system has to comply with international trade regulations. This in itself requires coherence and coordination for the development of standards and policies from national to international level (approach 4, 5, see figure 3). Regulation for a limited number of criteria (energy use, GHG balance) seems to be possible according to WTO requirements, but is more complicated for other criteria to secure sustainable biomass (see 4.1). Although it is possible to try to reach international consensus on these criteria, this is considered to be complicated for criteria with an impact on local scale. In this case, a possible solution is to translate criteria to voluntary standards. With this respect, a private label with higher standards than those mandated by law (approach 3), can be a solution. In general it is desirable for a sustainable biomass standard to be internationally regulated, because this requires acceptance of such standards under international law.

Using international environmental agreements, however, also has its limitations. Standards agreed upon are unlikely to be ambitious and international agreements and in full implementation by contracting parties can take a long time. Also, Multilateral Environmental Agreements are often inadequately implemented due to a combination of factors and problems (limited jurisprudence, soft commitments). An international agreement (approach 4, 5) will therefore have to be pursued over a longer period. With the need to secure the sustainability of biomass in a fast growing market, the initial development of a biomass certification system on national or regional level (approach 1, 2, 3 and 4), possibly expanded into an agreement on international standards (approach 5) on a longer term, seems to be more feasible.

In addition to the establishment of a biomass certification system, there is the possibility for governments to use financial incentives to stimulate the use of certified biomass (approach 1, 3 and 4). In this case, it is important that the incentives (e.g. subsidies) provided comply with WTO rules (see 4.1). For the longer term, harmonization of subsidies is pursued, which might be a reason for governments to select alternative policy measures on the longer term to stimulate compliance of sustainable biomass criteria.

6.1.6. Compliance with national legislation

It is expected that progress to develop national policies and standards to secure sustainable biomass will vary strongly from country to country. Certification systems often need to comply with national legislation, which is not always in place or enforcement is weak (see 4.2.6). Thus priorities, problems, government structures and processes vary in different parts of the world, as well as national legislation.

On one hand, these differences require to look at existing governance structures and to refine standards with respect to a regional scope (approach 1, 2, 3, 4). On the other hand, it might be desired to develop a set of minimum international standards to encourage countries to reach a certain level of sustainability for biomass production (approach 5). In all cases, additional support may be needed to improve a country's governance system in general: a task reaching beyond the scope of biomass certification.

6.1.7. Level of comprehensiveness and international coherence

There is a risk for proliferation of criteria, standards and systems that differ from one country or region to another (see 4.2.3). This trend is already visible today. Table 3 shows for example differences in the extent and strictness of sustainability criteria between various NGOs. Table 7 shows differences in the inclusion of socio-economic and environmental criteria between existing biomass certification systems or the ones in development.

Proliferation of certification systems in the market involves various risks (see also 4.2.3). To prevent this, international coherence between certification systems is desired. From a policy perspective, the preferred situation is one in which countries agree on common standards. This can be reached by an international framework of standards facilitated by a voluntary agreement by front running countries (approach 4) or by a binding international agreement (approach 5). For both approaches, the Code of Good Practice may serve as a useful instrument to encourage coherence and further international standardization of a biomass certification system.

6.1.8. Limited time horizon for implementation

A comprehensive, reliable and controllable biomass certification system is most efficient to secure the sustainability of biomass. This can be best achieved through a certain form of regulation (approach 1, 5) and international coherence (approach 5). However, achieving this requires a long process of negotiating towards an international treaty (approach 5), which can take a very long time. The question is whether other options are available in the interim. It is expected that the establishment of a voluntary biomass certification system, with its limitations to secure the sustainability of biomass, can be established in only a couple of years (approach 2, 4).

6.1.9. Avoiding the creation of additional trade barriers

A voluntary certification system (approach 2, 3) diminishes the risk for possible additional trade barriers as standards have fewer implications for trade than regulations. A (combination of) a limited number of mandatory regulations (approach 3), or (extended with) a set of standards established by government or a private institution (approach 2, 4) is a possibility for a biomass certification system. Concerns related to the impacts of a biomass certification system in developing countries (especially for small stakeholders) relate to stakeholder involvement (6.1.1), regional flexibility (6.1.3 and 6.1.6) and additional support. The latter is further discussed in section 6.2.

6.2. Role stakeholders in development of international biomass certification system

Current initiatives on biomass certification from various stakeholder groups range from building up experience through research and pilot studies, to further developing sustainability criteria and certification systems and providing assistance. When discussing assistance, the role of developing countries in the development of a biomass certification system requires specific attention. Stakeholders recognize the opportunities of bioenergy for developing countries, but express at the same time their concerns. In various cases, certification may not be achievable without outside assistance. Based on the previous sections table 11 provides an overview of possible roles of stakeholder groups in the development of biomass certification.

The implementation of an international biomass certification system involves a wide range of parties and requires therefore good coordination and coherence within and between stakeholders. Recommendations for further cooperation within and between various groups of stakeholders are:

- Companies, especially larger ones, active within the entire bioenergy chain may play a leading role in knowledge exchange and coordination of initiatives;
- Cooperation between companies and NGOs in specific elements of the chain, especially on the biomass production side, might be supplementing;
- Coordination in the wide range of initiatives is desired to prevent overlap of activities and to promote coordination and participation of all stakeholder groups, including the less powerful, in the discussion on biomass certification.

There are a range of international initiatives with, partly overlapping, activities and objectives. A strong focus per initiative, based on own strengths, is recommended. The most appropriate international body or initiative could take the lead in facilitating and promoting an international standardization or agreement for sustainable biomass standards.

Table 11: Overview of possible roles stakeholder groups in development of biomass certification.

Stakeholders	Possible roles
International bodies	• Assist in development international framework conditions or agreement for bioenergy • Initiator debate about role WTO in biomass certification • Coordinating role in stakeholder debate from various stakeholder groups • Support to promote sustainable biomass (financially, expertise, sharing knowledge) • Provide specific assistance to developing countries[a]
Regional bodies	• Policy or legal framework on biomass certification on regional level, integrating standards certification system into regional policy • Promoting coherence national policies on regional level • Refinement standards to local and regional conditions, further specification of set biomass standards • Support to build up expertise in implementing biomass certification system • Provide specific assistance to developing countries[a]
Government bodies	• Policy framework for biomass certification, set of biomass minimum standards possibly with more extended set of private standards • Policy measures (subsidies, regulations) to promote sustainable biomass • Support to build up expertise in implementing biomass certification system • Provide specific assistance to developing countries[a]
Companies	Key activities with the focus of initiatives depending on interests of the company: • Build experience in certification through (pilot) studies over the complete biomass chain, gradual learning and expansion of system over time • Promoting coordination and cooperation between companies on development certification system, e.g. energy companies in Europe may stimulate coherence in the development of biomass certification systems, at least on regional level, and form a strong incentive to other producers in the world. • Technical improvements of biomass related products • Financial assistance (especially for banking sector)
NGOs	• Keep watch over the reliability of the system in development • Representing and involving the less powerful in discussion on biomass certification • Building up experience through pilot studies and work in the field, mainly on the biomass production side • Trigger the discussion proposals by the development of principles and pathways for implementation of a biomass certification system.
Roundtables	• Facilitate discussions on biomass certification among stakeholder groups, at this time mainly on biomass production side • Promote initiatives on biomass certification (via biomass production side) in coordination with other initiators on biomass certification systems • Implementation of pilot studies

[a] Assistance from international and national governments can be provided in various forms. Based on own expertise, assistance can be provided in e.g. integrating sustainability standards for biomass into national policy or strengthening national legislation. It is desired to embed specific assistance on sustainable biomass to developing countries in broader development programs in which wider development issues (e.g. poverty alleviation, energy security) are addressed.

7. Summary and conclusions

The need to secure the sustainability of biomass production and trade in a fast growing market is widely acknowledged by various stakeholder groups. Setting standards and establishing certification schemes are recognized as possible strategies that help ensure sustainable biomass production and trade. Recently various stakeholder groups have undertaken a wide range of initiatives as steps towards the development of sustainability standards and biomass certification systems. Sustainability standards and criteria are developed by various organizations. Between them, there seems to be a general agreement that it is important to include economic, social and environmental criteria in the development of a biomass certification system. However, differences are also visible in the strictness, extent and level of detail of these criteria, due to various interests and priorities.

Concrete initiatives to translate these standards into operational criteria and indicators and to monitor and verify them through an established biomass certification system are more limited. At this moment, there are two certification systems for biomass in operation, both initiated by energy companies, and some pilot studies are in implementation or under development.

The development of biomass certification systems is impeded by a number of issues. Many uncertainties on the feasibility, implementation and costs of international biomass certification systems and its compliance with international laws and agreements on trade have to be solved. Also, the possible risk of proliferation of individual standards and systems causes loss of efficiency and credibility. Therefore, it is worthwhile to consider in this preliminary phase which ways can be followed to develop a reliable, efficient biomass certification system.

Section 5 discusses five possible approaches for a way forward, all with its own strengths and limitations. However, for all apply that some urgent actions can be identified, needed for further development:

1. *Better international coordination between initiatives is required to improve coherence and efficiency in the development of biomass certification systems.* Various international organizations can take the lead in this like the European Commission (for European region), UNEP, FAO, UNCTAD or others. This does not only prevent proliferation of biomass certification systems, but also provides a clearer direction in the approach to be taken (e.g. national or international oriented, mandatory or voluntary) for national and local initiatives.

2. Existing WTO agreements already provide ideas about the role of WTO within the development of a biomass certification system. However, no precedent within WTO exists for biomass certification. *A process to assess the WTO compatibility of a biomass certification scheme and to provide countries with the opportunities to exchange views on this topic is needed.*

3. Certification is not a goal on itself, but a means to an end. It can be one of the policy tools that can be used to secure the sustainability of biomass production and use. Setting up good practice codes and integrating sustainability safeguards in global business models may also be effective ways to ensure this. Thus, *an open vision for (a combination with) alternative policy tools should be maintained to look for the best suitable options to secure sustainable biomass production and trade.*

4. At this moment, experience is limited to make some criteria operational. The design of specific criteria and indicators related to the requirements of a region, how to include avoidance of leakage effects and the influence of land-use dynamics, require the development of new methodologies and integrated approaches. This may take a number of years. On the other hand, there is a need to secure the sustainability of biomass in a fast growing market on the short term. *A gradual development of certification systems with learning (through pilot studies and research) and expansion over time, linked to the development of advanced methodologies can provide valuable experiences, and further improve the feasibility and reliability of biomass certification systems*. This stepwise approach gives possibilities for coherence, monitoring and adjustment of activities needed.

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Chapter 6: A unified methodology and tool to evaluate greenhouse gas balances and cost-effectiveness of various biomass energy systems[17]

Abstract

The current strong increase in investments in biomass energy projects and the various requirements to demonstrate the greenhouse gas (GHG) balance of biomass energy projects, require an accurate and standardized methodology and tool that enables transparent calculations of socio-economic and environmental impacts. Also, these should be applied independent of the country, biomass technology and biomass resource used. This paper describes a methodological framework and a user-friendly software tool that can be used to analyse the GHG balance and cost-effectiveness of GHG emission reductions for a wide range of biomass energy projects. Key issues taken into account in the methodological framework are the functional unit, mitigation parameters, the system boundary, the reference energy system, direct and indirect land-use change, carbon stock changes, allocation procedures, timing issues, cost measurements, site specificity and uncertainty. Main characteristics of the software architecture of the tool are the flowchart design and the concept of working with different tiers of calculation and data input. Four examples of case studies are included in the tool. The case study 'Biodiesel from rapeseed in the UK' demonstrates for example that the allocation procedure should be carefully defined as is shown by the variation in results, which is 35 to 50 kg CO_2 eq. per GJ delivered in GHG emissions. The case study 'Heat from Miscanthus in the UK' shows that the issue of direct and indirect land-use cannot be neglected, illustrated by the range in avoided GHG emissions from 13 to 128 kg CO_2 eq. per GJ delivered depending on the reference land-use system assumed. The results show that outputs of the GHG balance and energy costs calculations can differ largely in time. Moreover, site specific and disaggregated analyses are preferred. This requires data collection and consistent databases. It is concluded that the software tool can be useful to compare and screen GHG emission reductions and expected costs of energy delivered and of avoided emissions so as to further improve the performance of biomass energy systems.

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1. Introduction

The reduction of human induced greenhouse gas (GHG) emissions has become an issue of great international importance which is reflected by the adoption of the Kyoto Protocol and a number of regional (e.g. EC 2008), national (e.g. US Department of State 2004), bilateral and multilateral agreements (e.g. G8 2008 or APP 2008). Many countries are implementing measures to mitigate net GHG emissions as agreed upon under the Kyoto Protocol (IEA-Task38 2006). Specific instruments have been introduced to mitigate GHG emissions such as emission trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI) (UNFCCC 2008a). These and other instruments are used to promote energy efficiency and cleaner production and use of energy carriers, especially the development of renewable energy sources such as bioenergy (IEA-Task38 2008).

It is recognized that no single energy source, technology or approach can solve the problem, suggesting the need for a diversified portfolio of measures to be adopted. A portfolio approach also offers the opportunity to reduce risks and costs (IPCC 2007). Within the options available, bioenergy can play an important role as it has a substantial growth potential (IPCC 2007). There are different technologies and approaches that present considerable potential for the large-scale exploitation of a wide range of biomass energy sources. High fossil energy prices will enhance the economic competitiveness of bioenergy systems. An increased use of bioenergy can also contribute to energy security and reduce the dependence on oil and gas delivering countries. It also creates opportunities for rural development and employment. Many countries have therefore developed policies to increase the use of biomass energy in the transportation sector and in the energy sector (IEA-Task38 2006).

The Renewable Energy Directive (RED) of the European Union, as agreed upon in Brussels in December 2008, aims to establish an overall binding target of a 20% contribution of renewable energy sources to the final energy use. The agreement foresees that by 2020 renewable energy - biofuels, electricity and hydrogen produced from renewable sources - accounts for at least 10% of the EU's total fuel consumption in all forms of transport (EC 2008; European Parliament 2008). Bioenergy will be an important instrument to reach these targets.

The need to secure a sustainable production and trade of biomass for energy is becoming a key concern for biomass importing countries such as the Netherlands and the UK and on a supra-national level the EU. In recent years, various efforts have been undertaken to develop criteria and indicators as steps towards certification for imported biomass or biofuels to guarantee its sustainability. In all of these initiatives, the GHG balance is an important criterion because the presumed GHG emission savings of bioenergy compared to fossil energy are a key driver to increase bioenergy use (Dam *et al.* 2004a).

Currently, the use of so-called first generation liquid biofuels is often criticized, due to doubts about its potential to significantly reduce GHG emissions. As an example, Crutzen *et al.* (2008) commented that the N_2O release from agro-biofuel production can negate global warming reduction by replacing fossil fuels. Other studies find similar features but indicate that the GHG balance largely depends on local conditions as well as technologies, crops and approaches applied (Smeets *et al.* 2008a). Furthermore, Fargione *et al.* (2008) and Searchinger *et al.* (2008) suggest that including GHG emissions from indirect land clearance could drastically reduce or even eliminate the GHG benefits of growing plants for bioenergy during many years or decades. Moreover, the possible diversion of existing croplands into biofuels could trigger rising food prices and clearance of forests and grassland.

Although the warnings are well taken from Crutzen *et al.* (2008), Fargione *et al.* (2008) and Searchinger *et al.* (2008), the selection of parameters involved (crop, system boundary, land-use input data) can drastically change the outcomes. The nuances and variability of GHG balances, due to the complexity of biomass energy systems and the sensitivity of the results for a wide range of parameters and factors, is illustrated by various other authors (Gustavsson e*t al.* 2002; Dornburg *et al.* 2005; Smeets *et al.* 2008a; Larijssen *et al.* 2008; Wicke *et al.* 2009). Several issues need to be taken into consideration in a standardized methodology to investigate GHG balances, such as leakage effects, the impact of by-products, trade-offs between GHG emissions and costs, carbon stock dynamics, up-stream energy inputs, the efficiency of energy systems, emission factors and permanence (IEA-Task38 2008).

Still, the development of an accurate methodology to investigate the GHG balance is needed as GHG balances have to be calculated for various purposes and objectives often related to the United Nations Framework Convention on Climate Change (UNFCCC), such as the Kyoto protocol, the Clean Development Mechanism and the Joint Implementation mechanism (Kwant *et al.* 2007). These international systems, combined with documentation from the International Panel on Climate Change (IPCC) and IEA Task 38, provide guidelines for the calculation of GHG balances.

The wide range of factors that need to be taken into account implies that the calculation of GHG balances of biomass energy systems is complex. In addition, the cost effectiveness of biomass energy systems to reduce GHG emissions in comparison to fossil reference system is increasingly needed to meet societal demands. Investigations of the GHG balance and the emission reduction costs are important for policy-makers and certifying bodies as well as for stakeholders who intend to promote and invest in biomass energy technologies. A standard tool, based on a unified methodology and enabling different user groups to compare the GHG and cost results of a wide range of biomass energy systems, is therefore needed in a wide range of regions.

In the BIOMITRE (BIOmass based Climate Change MITigation through Renewable Energy) project, we developed a standard, user-friendly software tool that can be used to analyse the GHG balance, the energy balance and the costs of different biomass energy systems in relation to fossil fuel reference systems. The tool is applicable for different user groups such as universities, policy-makers and companies involved in the development and application of biomass energy technologies. As preparation for the development of the tool, first a unified methodology was developed to evaluate GHG-balances, energy balances and the cost-effectiveness of biomass energy systems. The aim of this paper is to describe this unified methodology related to core methodological issues and the design of the software tool as well as the application of the tool in some case studies.

This paper uses the following definitions:

- Biomass: the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (European Parliament 2008);
- Bioenergy: this is energy that is derived from biological sources (e.g. plants or animals) and which has not undergone any geological process. Sources of bioenergy may be solid, liquid or gaseous (DG Agriculture 2008);
- Bioliquids: liquid fuel for energy purposes, including electricity and heating and cooling, produced from biomass (European Parliament 2008);
- Biofuels: liquid or gaseous fuel for transport produced from biomass (European Parliament 2008);

Section 2 gives an overview of current initiatives in the development of methodologies and tools to investigate the GHG balance of bioenergy projects. Section 3 discusses the review of the GHG accounting methodologies resulting in recommendations on key methodological issues and on how to translate these issues in a software tool. Section 4 discusses the design of the software tool. A demonstration of the key methodological issues on GHG and cost calculation results is shown by the four case studies in Section 5. A discussion and final conclusions are given in Section 6.

2. Current initiatives in GHG methodologies and calculation tools

GHG emission reduction is considered an important criterion to guarantee sustainable production and utilisation of biomass energy resources. In December 2008, the European Union adopted a proposal of the European Commission to include an obligation of GHG emission saving from the use of biofuels and other bioliquids of at least 35% compared to the reference fossil fuel use (EC 2008; European Parliament 2008). To set demands on the GHG balance it will be necessary to calculate the GHG performance unambiguously. Calculation methods and models are currently being developed by various national governments and on EU level (European Parliament 2008; Cramer *et al.* 2007; Fehrenbach 2008a; E4Tech 2006). According to the European Commission there is also a need for the development of a GHG calculation methodology as basis for the proposed Fuel Quality Directive, which introduces a mechanism to monitor and reduce GHG emissions (1% per year from 2011) from road transport fuels such as petrol and diesel (Jol 2008).

Sustainability criteria developed in the Netherlands (the ‘Cramer criteria’) require a minimum GHG emission reduction of at least 30% for transportation fuels and at least 50-70% for electricity (Cramer *et al.* 2007). On the longer term a minimum emission reduction target of 80-90% is expected. The GHG performance should be measured along the whole energy supply chain and will be dependent on the fuel that is replaced by the biomass. A methodology has been developed to calculate the GHG balance. Based on that, calculator tools are developed specifically for the use of biofuels and for bio-electricity and bio-heat production. These tools, available on-line since mid 2008, enable companies and other stakeholders to calculate GHG balances of bioenergy and biofuel chains (Kwant *et al.* 2007). In 2009, the tools (and possibly the methodology) will be adapted to the EC Directive currently under development (SenterNovem 2008).

In the UK, a GHG calculation methodology forms the foundation of the broader process of reporting on the net GHG saving of biofuels, which is expected from companies obligated under the RTFO (Renewable Transport Fuels Obligation). The UK system has set targets for the overall level of GHG saving achieved by the biofuel supplied in each obligation period (E4Tech 2006): in 2008-2009 40%, 2009-2010 45%, 2010-2011 50% etc.

Since 2007, the law of a mandatory biofuel quota (Biokraftstoff-quotengezetz) is effective in Germany. It requires from mineral oil companies that an increasing share of fuels on a biomass basis has to be admixed to gasoline and diesel or sold as genuine biofuel as such. The Biomass Sustainability Ordinance in Germany requires a minimum level of CO_2 savings for biofuels. Biofuels must have a greenhouse gas reduction potential (GGRP) of at least 30% and, from beginning of 2011, 40% as base value (Fehrenbach 2008b). The federal government is authorized to modify the actually acknowledged quota by regarding the real GHG savings by introducing a correction factor of the annually sold amount of a specific biofuel. Emission reduction targets for other forms of bioenergy use, such as heating and electricity production, are not defined yet. A GHG calculation methodology for biofuels is developed and for other bioenergy use ongoing. At the end, one methodology for both categories has to be developed. This process is ongoing in close cooperation with other EU countries (Fehrenbach 2008a).

Belgium has committed itself to reduce the greenhouse gas emissions with 7.5% by 2012. In addition, electricity sales are submitted to a renewable obligation of 6% renewable electricity by 2010 in the frame of targeted green certificate systems. The system in Wallonia and in the Brussels region is based upon avoided CO_2 emissions with respect to a reference system being a combined cycle power plant firing natural gas with a conversion efficiency of 55% (Ryckmans *et al.* 2006). Default values on specific CO_2 emission factors from all fossil fuels and the major biomass resources are employed to determine whether the obligation for electricity suppliers to produce a certain percentage of ‘green’ electricity is fulfilled, using parameters established by scientists in consultation with government and industry. The result determines the number of green certificates awarded (Kwant *et al.* 2007).

In Switzerland, from 1 July 2008, biofuels are exempted from the mineral oil tax, provided their production complies with environmental and social criteria. Biofuel Tax Exemption can be obtained if biofuels reduce GHG emissions with a minimum of 40% compared to the fossil reference system (SwissFederation 2008). A full life cycle inventory (LCI) is the basis for this tax reduction and biofuel providers have to deliver the LCI according to the

Ecoinvent methodology. The full LCI is based on the cradle to grave approach and includes an analysis of GHGs as well as other environmental emissions (Jungbluth 2008).

Beside the initiatives mentioned on national government and EU level, several other initiatives from international organizations, NGOs and the private sector are ongoing to develop methodologies to calculate the GHG balance of bioenergy use. In the Nordic countries, the Swan label (voluntary label) requires that fuel, based on at least one third (in % volume) renewable raw material, does not give rise to more than 50 g $C0_2$ eq. per MJ of fuel. The applicant must be able to document that from a life-cycle perspective, and guidelines are given to calculate the GHG balance (NordicEcolabelling 2008).

The energy company Electrabel (Belgium) implements, amongst other sustainability principles, the energy and CO_2 balance of the supply chain including electricity use, fossil primary energy use and transport (Ryckmans 2008). A spreadsheet model is used by stakeholders delivering feedstock, mainly wood pellets, for bioenergy. The user has to give the input of fossil and non-fossil primary energy in kWh/ton. The GHG balance is calculated from the outcome of the energy balance (Laborelec 2008).

The Roundtable on Sustainable Biofuels published in 2008 a draft standard on principles and criteria for sustainable biofuels. Principle 3 of in total 12 principles deals with the topic of GHG emissions (RSB 2008a). The aim of this principle is to establish a standard methodology for comparing the GHG benefits of different biofuels in a way that can be written into regulations and enforced in standards.

Table 1 shows how some key methodological issues are approached by various initiatives in the EU to calculate the reduction of GHG emissions. This illustrates that differences between these initiatives exist between e.g. the scope of the tool (biofuels and/or bioenergy for heating and power production), the allocation method, direct land-use change (LUC) and indirect land-use change (ILUC). The methodology to calculate the cost-effectiveness of GHG emission reductions for these initiatives is not included.

There are also several non-European tools and methodologies to calculate GHG balances (Robertson *et al.* 2006). The CO2Fix model, TimberCam, CAMFor and the HWP model have been designed to calculate specifically the GHG emissions coming from forest and land-use (IEA-Task38 2008). Examples of energy and GHG analysis tools and databases are SimaPro, Ecoinvent, KCLEco (IEA-Task38 2008) and the GREET model (Wang 1999). The RETScreen model, developed in Canada, includes both cost and GHG calculations specified to renewable energy technologies (IEA-Task38 2008).

Although existing international protocols (developed within e.g. the framework of UNFCCC) do exist, diversification in methodological approaches for evaluating the GHG balances and cost-effectiveness of GHG savings continue to exist as well (Kwant *et al.* 2007). The differences between the various initiatives presented here show the difficulty in achieving a unified and internationally accepted methodology as well as default values - which are (often aggregated) input data supplied to the user when own data are not available - to calculate the GHG balances and cost-effectiveness. Although the focus can be different, consistency in the methodology used between these initiatives would be of the interest to all. Eventually, also one standard GHG and cost-effectiveness calculation tool is preferable over many different tools which all may yield different results.

There are several initiatives to promote the harmonization of methodologies to calculate GHG emission reductions. These are the Task Force on GHG methodologies from GBEP (Garibaldi 2008), the Technical Committee (CEN TC 383) on ‘Sustainably produced biomass for energy applications’ from the European Committee for Standardization (Costenoble 2008) and the Greenhouse Gas Protocol Initiative (IEA-Task38 2008). However, the development of a standardized methodology to calculate the cost-effectiveness of GHG emission reduction is not included in these initiatives.

Table 1: Overview of key initiatives in the European Union to calculate GHG emission reduction for bioenergy and biofuels, and their approaches (as of end 2008) to main methodological issues.

Initiative	Biomass included	Functional unit	System boundary	Allocation matters	Time scale	Fossil fuel ref. system	ILUC	LUC	Calculated N_2O emissions	Default values
EC	Biofuels and bioliquids	g CO_2 eq./MJ	Included, clearly defined	Allocation by energy content LHV (proposed)[a]	20 years for soil carbon	Included	ILUC penalty under discussion	Formula soil carbon / default	(JEC 2007) in EU, IPCC outside EU	Conservative
UK-RTFO	Biofuels	g CO_2 eq./MJ	Included, clearly defined	Subtraction is 1st choice	20 years for soil carbon	Included	Conversion forest only	Calculated, monitoring	IPCC approach	Conservative
Germany	Biofuels, Bioenergy for heating and power to be included	g CO_2 eq./GJ	Included, clearly defined	Allocation by energy content (LHV)	20 years for soil carbon	Included	In discussion, risk adder approach?	Formula soil carbon, IPCC	Included, IPCC when data limited	Conservative
Netherlands	Two tools: a) Biofuels and b) Bioenergy for heating and power	Tool a: g CO_2 eq./km Tool b: g CO_2 eq./MJ	Included, clearly defined	Allocation by energy content	Typical lifetimes	Included	Methodology proposed (monitoring)	Methodology based on IPCC	Included, IPCC when data limited	Conservative / typical / best practice
Wallonia (Belgium)	Main biomass sources for bioenergy for power	kg CO_2 eq./ MWh of primary energy	Conversion step	Not included	Not included	Included	Not included	Not included	Not included	Provided by Wallonian government

Table 1 (continued): Overview of key initiatives in the European Union to calculate GHG emission reduction for bioenergy and biofuels, and their approaches (as of end 2008) to main methodological issues.

Initiative	Biomass included	Functional unit	System boundary	Allocation matters	Time scale	Fossil fuel ref. system	ILUC	LUC	Calculated N_2O emissions	Default values
Electrabel / Laborelec (Belgium)	Bioenergy for heating and power	In g CO_2 eq./ ton or / kWh	Production and transport	Not included	Not included	Not needed	Not included	Not included	Not included	Some data provided
Swan label (Nordic countries)	Biofuels	g CO_2 eq./MJ	Included	Subtraction is 1st choice	20 years for LUC	Not needed	Not mentioned	No negative balance is required	Included	Yes. Not for production
RSB (based on draft standard 2008)	Biofuels	kg CO_2 eq./GJ	Included, clearly defined	Guidelines are being developed	100-year time horizon GWP values, IPCC lifetimes	Global, based on IEA projections fossil fuel mixes	ILUC to be minimized. Under discussion.	Based on IPCC methodology and values	To be addressed	Criteria for acceptable default values under development

[a] The European Commission has proposed allocation based on energy content LHV for co-products other than electricity. Emissions from the excess electricity are not allocated but subtracted from the total amount of final emissions (EC 2008).

3. Review of methodologies to calculate GHG balances

Our literature review of the main existing methodologies to calculate GHG emission reductions was collected from international databases. Research networks were consulted to assure that well-known suitable references were not missed. The survey included refereed scientific papers, technical reports and books. About 500 references were originally collected. A shorter list of references was selected as representative for a detailed evaluation of methodological issues based on a selection of key characteristics considered in the indexing of literature such as the conceptual methodology of the paper, the coverage and application of biomass resources and the reference system, including indirect emissions (Vikman *et al.* 2004).

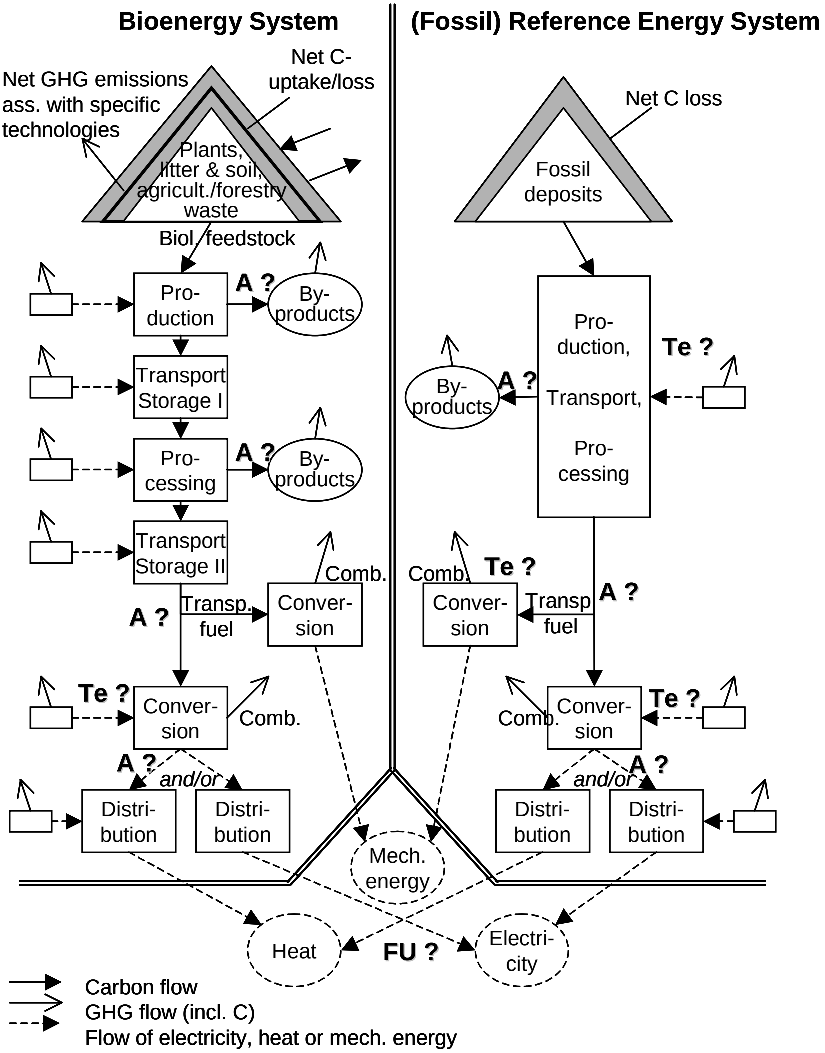
The selected papers typically describe project level applications of analyses of GHG-emissions from biomass energy systems using a life-cycle approach, including comparisons to fossil fuel reference systems. Cost-assessments in relation to GHG emission reductions are of high interest for us too, but few references present such a combined approach.

3.1. Methods for reviewing

The selected methodological approaches were evaluated for their strengths and weaknesses in relation to the evaluation of the GHG balances and the cost-effectiveness of emission savings of prominent biomass energy systems relevant to the EU. Although various criteria for methodological comparisons were found in the literature (Baumann *et al.* 1999; Metz 2001; Watson *et al.* 2000; Menichetti 2008), the list of criteria suggested by Schlamadinger *et al.* (1997) was found most comprehensive and well adapted for the objectives of this study (figure 1). The importance of accurately defining the reference system was further stressed by Gustavsson *et al.* (2000). Hence the current review is largely based on the methodological recommendations from these two papers.

Three categories of key questions were recognized and applied to each methodology evaluated (Vikman et al. 2004): (i) The accuracy of the methodology; considering comprehensiveness (functional unit, system boundaries in time and space, reference system etc.).

Figure 1: Graphical representation of bioenergy system and reference energy system used for the characterization of reviewed reports. Question marks indicate examples of special methodological interest for allocation methods (A?), choice of functional unit (FU?) and choice of technology (Te?), (Schlamadinger *et al.* 1997).



Consistency (consistent treatment of actual and reference system, etc.) is of importance for any methodological approach; (ii) The level of transparency (assumptions clearly shown, use of flow charts, sensitivity analysis) is important for the 'user-friendliness' of the approach including the possibility to understand limitations to the usefulness of the results; (iii) The efficiency of the approach (appropriate level of detail balanced with ease-of-use, comparable output parameters) partly determines whether the methodology will be used or not in practice since resources to assess GHG emissions are likely to remain limited.

A main finding of the review of methodologies is that accuracy is the foremost methodological aspect to consider. Comprehensiveness and consistency are key factors for an accurate methodological approach. The methodology used to describe the compared systems must be consistent and the same technical level should be used in all comparisons. All assumptions and calculations should be shown in a clear and structured way. For good transparency, flow charts should be used to describe the process-trees of all systems studied, including the reference system (Vikman *et al.* 2004).

3.2. Methodological issues

Apart from an evaluation of the general methodological approaches divided into Life Cycle Analysis (LCA), energy system analysis and other approaches, methodological components investigating GHG emission reductions of biomass energy systems and their cost-effectiveness were evaluated in more detail (Vikman *et al.* 2004). A summary is presented in the following eleven subsections.

3.2.1. Functional unit

In all system analyses the choice of an appropriate functional unit, as the basis for comparisons, is of major importance. The establishment of a functional unit enables a comparison of results between the biomass energy and the fossil reference energy system (SETAC Europe LCA Steering Committee 2008). Special considerations are necessary in studies of systems with more than one output, for instance energy systems with combined heat and electricity production (CHP-plants). Gustavsson *et al.* (2006) show results from studies of CHP-plants where the functional unit was defined in either a multifunctional or a subtraction approach. The multifunctional approach is preferable compared to the subtraction approach due to its transparency, since the subtracted parts of the system are not shown anymore when the subtraction approach is used.

3.2.2. Outputs

For comparative assessments of GHG mitigation and the energy performance of biomass energy systems, a range of parameters has been used (Horne *et al.* 2004). Having calculated the total energy inputs and outputs and the associated GHG emissions, it is possible to compute a number of indices and indicators which summarize the energy and GHG balances. The most widely used is a parameter relating the net release of CO_2 equivalent emissions to the amount of energy available for end-use (kg CO_2 eq./MJ fuel). Authors with an interest in an efficient use of biomass resources on land have used GHG-emissions per cultivated land area. Other authors, stressing the efficiency of the energy system, have used parameters expressing the net energy requirement or energy efficiency, based on the ratio between the total primary energy input (MJ) and the total useful energy output (MJ) or vice versa.

For a biomass energy system, another important parameter is the net amount of energy generated per hectare of land (GJ/ha). This may be defined as the total useful energy recovered minus the total primary energy input per unit of land area. This value can be calculated over the life cycle of the energy system. Energy ratios and GHG emissions factors have been used extensively in the discussion about the direct and indirect substitution of fossil fuels that can be achieved by biomass energy, but these statistics are not without limitations (Schlamadinger *et al.* 1997) as their calculation and interpretation depends to a great extent on the context of the bioenergy system being evaluated or compared. The results should therefore not be used in isolation but in combination with a full description of the energy and emissions budgets of the system (Horne *et al.* 2004).

A limited number of studies did include cost calculations. This may explain why the number of suggested parameters to evaluate costs related to GHG emission reduction is rather low. Production costs have been used (cost/GJ useful energy) and specific abatement costs (costs/ ton CO_2 eq. avoided), while authors focusing on the effect of investments have used the inverse, called the GHG saving of cost effectiveness. Generally, a mitigation cost is calculated as the ratio between net difference in costs and net reductions of GHG emissions between the biomass energy and the reference energy system (ΔCosts /ΔGHG). The mitigation costs could include the biomass production costs, land-use cost, transportation and conversion costs, monetary costs and primary energy costs as suggested by Gustavsson *et al.* (2007).

We conclude that the following parameters are relevant when comparing the GHG mitigation potential of different systems: cost efficiency (GHG emission reduction / unit of investment), primary energy efficiency (GHG emission reduction / unit of primary energy input), and biomass efficiency (GHG emission reduction / unit of biomass produced) (Vikman *et al.* 2004).

3.2.3. System boundaries

The system boundary of a bioenergy chain defines the inputs and outputs to be included in the analysis, recognising outputs (disposal) and inputs along the process chain (Horne *et al.* 2004). Different authors treat the system boundary differently, which creates uncertainties when comparing results of different studies. For example, in a study of liquid transportation fuels, a comparison of performances was made on the basis of the energy content of each fuel (Elsayed *et al.* 2003). Validity would have increased if end-use efficiency in the transportation sector had been included in the assessment, since this factor may depend on the fuel used (Jungk 2000; Jungmeier *et al.* 2002; Beer *et al.* 2002). Schlamadinger *et al.* (2005) recommend that the system boundary is wide enough to include all GHG emission reductions achieved by the energy and non-energy products of the bioenergy system in a comparable way.

We conclude that system boundaries, in time and space, should be set such that all differences in GHG emission and costs between the biomass and the reference energy system are included in a comparable way. In the case of bioenergy production using cultivation, the evaluated system should also include assumptions about the land-use in the reference system.

3.2.4. The Reference Energy system

In assessments of mitigation effects, a comparison with the reference energy system, or baseline, is an inherent and central component of the analysis. Accordingly, the choice of the reference system has a profound impact on the results. Therefore, this choice should be given serious attention (Larijssen *et al.* 2008; Schlamadinger *et al.* 1997; Gustavsson *et al.* 2000).

The reference energy system can vary per country, per region, per time period investigated and per individual case. One important feature of the reference system is the choice of energy carrier and conversion technology. Gustavsson *et al.* (2006) presented data from biomass based CHP-plants, applying alternative technologies for the reference energy system. The study demonstrates the importance of the chosen reference technology for the ranking of bioenergy systems with respect to GHG emissions reductions and reductions in costs. When options for new investments in energy systems are studied, the biomass and reference energy system should be comparable, applying the same base level of technology and considering in both cases technology improvements over time. The appropriate choice of technology for the reference system is discussed in some studies (Beer *et al.* 2002; Faaij *et al.* 1998; Groscurth *et al.* 2000). Other studies also include a sensitivity analysis to quantify the importance of the chosen technology level (Gustavsson *et al.* 2002; Jungmeier 1999).

We conclude that the reference energy system should in general be similar to the biomass energy system. It can be accurate enough to use generic data, if it can be shown that the data used are consistent with the data used for the biomass energy system. Moreover, a low transparency in generic data will limit the usefulness of the study (Elsayed *et al.* 2003; Faaij *et al.* 1998; Kaltschmitt *et al.* 1997; Mortimer *et al.* 2003). Based on the review, an appropriate choice of the reference energy system will in general be the least-cost fossil energy system with minimized environmental impact, fulfilling the same goals as the bioenergy system. Other alternatives may have to be considered as well (Schlamadinger *et al.* 1997).

3.2.5. The land-use reference system: Direct land-use and carbon stock changes

Direct land-use change (LUC) describes the plantation of a new crop in an area where this form of cultivation has not taken place before (RSB 2008b). To determine the carbon gains and losses related to the change in land-use due to biomass energy production, the change in carbon content between the biomass production system and reference land-use system needs to be estimated. A particular combination of site, vegetation type and management regime results in a characteristic long-term average carbon stock on that site. Due to biomass energy production, a change in vegetation type or management regime is likely to lead to a change in carbon stock, which influences the GHG balance of a bioenergy project

(Horne *et al.* 2004). Five major types of carbon pools can be distinguished according to the IPCC Good Practice Guidance for Land-use, Land-use Change and Forestry (LULUCF): aboveground and belowground biomass, soil organic carbon, litter and dead wood (IPCC 2003). The role of soil carbon in total carbon stock changes has been discussed by various authors such as Freibauer *et al.* (2004), Smith *et al.* (2007) and Smith (2008). The time taken for sink saturation to occur for soil carbon after a land-use change is variable and asymptotic (Smith 2008). For the calculation of soil carbon stock changes over time, we therefore recommend to use the so-called ‘broken-stick model’ presented in the IPCC guidelines, which has the following formula:

$$\Delta \text{ Carbon stock soil (t C/ha)} = \sum_{i} \text{Carbon stock change factor (t C/ha* yr)} * T_i \text{ (yr)} \qquad (1)$$

Using this formula, different soil carbon stock change factors can be applied in different years so that stock changes are not underestimated soon after a change or overestimated when the soil carbon stock approaches a new equilibrium (IPCC 2005).

Gustavsson *et al.* (2002) discussed the variation over time in decay rates of logging residues when the change in carbon stocks of the biological system is included in evaluations of biomass based energy systems. Larijssen *et al.* (2008) showed for a case study in Mozambique that the carbon balance can vary substantially depending on the chosen time scale. A study from Wicke *et al.* (2009) on palm oil production in Indonesia shows that a variation in the allocation period from 25 years (in the base case) to 13 years can result in negative GHG emission reductions. Conversely, an extension of the allocation period to 100 years leads to GHG emission reductions which in all but one case (peat land) meet the target set by the Cramer Commission (Cramer *et al.* 2007).

Thus, depending on the nature of the changes and the period of time over which their impact is spread, land-use changes result in a GHG emission gain or loss. Fargione *et al.* (2008) call the amount of CO_2 released during a defined time period the ‘carbon debt’, also called negative credit, of land conversion. Over time, biomass energy production from converted land can repay this carbon debt if net GHG emissions of the biomass energy system itself are less than the GHG emissions of the fossil energy that is replaced.

Wicke *et al.* (2009) also show that palm oil production on logged-over forest in Indonesia can only meet a GHG emission reduction target of 50% compared to coal-based energy production. In case palm oil production takes place on degraded land in combination with improved management of the production of crude palm oil, GHG emission reductions of 150% or more can be achieved, turning oil palm plantations into carbon sinks. Also two other studies dealing with trading biomass produced in Brazil and in Mozambique. Larijssen *et al.* (2008) show the influence of direct land-use changes, both positive and negative, on the total carbon balance. The case studies of Larijssen *et al.* (2008) and Wicke *et al.* (2009) demonstrate that land-use change, the land-use reference system and the integration time (‘allocation period’) investigated are decisive factors in overall GHG emissions of bioenergy projects.

Based on this review, we conclude that:

- When selecting an appropriate land-use reference system, it is recommended to select one which is most likely in practice and reflects current and expected reality (Horne *et al.* 2004).
- The fact that the results can be significantly altered by the length of the interpretation period means that an appropriate time period for the selected ecosystem to restore the carbon balance must be considered when evaluating the GHG emissions reduction potential of bioenergy.
- The length of this interpretation period has its limitations though as bioenergy projects and, more in general, solutions to mitigate climate change require GHG emission reductions within the coming 20 to 50 years.

3.2.6. Indirect land-use change and leakage

Indirect land-use change (ILUC) occurs when current land-use switches to biomass production, and elsewhere a land-use change occurs to maintain the previous level of e.g. food or wood production. This is also called ‘leakage’ or ‘displacement effect’ (RSB 2008b). Fargione *et al.* (2008) and Searchinger *et al.* (2008) have shown that including GHG emissions from ILUC could drastically worsen or even revert the GHG emission balance of growing plants for bioenergy. Leakage can be (largely) avoided by developing effective systems that guarantee that biomass resources are derived from waste products, excess croplands (due to yield improvements) or carbon-poor lands that will not trigger large emissions from land-use change.

Because emissions from land-use change are likely to occur both directly and indirectly and displacement effects of food or wood take place on a global level, ILUC is difficult to quantify and predict. Due to the potential significance of ILUC emissions on the GHG balance, different authors (Searchinger *et al.* 2008; Kwant *et al.* 2007; Cramer *et al.* 2007; Delucchi 2006; Farrell *et al.* 2008; Gallagher 2008; Hellmann *et al.* 2008; Gnansounou *et al.* 2008) as well as the EC (EC 2008) have stated the need for further research on the quantification of ILUC and the calculation of GHG emissions from ILUC. Also attention should be given on how to include these emissions in a Life Cycle Assessment.
We conclude that ILUC should be taken into account when investigating the impact of bioenergy projects on GHG emissions. Essential elements for determining the emission factor of ILUC include the system boundaries, the reference system used and the integration time that is considered.

3.2.7. Allocation procedures

According to UNFCCC (2008b) and ISO14044 (2006), each LCA study has to identify the processes that generate co-products[18], by-products[19] and/or residues or wastes[20]. Process

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[18] Co-products: products that are produced along with the main product and having similar financial revenues as the main product.

[19] By-products: products that are produced along with the main product and having smaller financial revenues than the main product

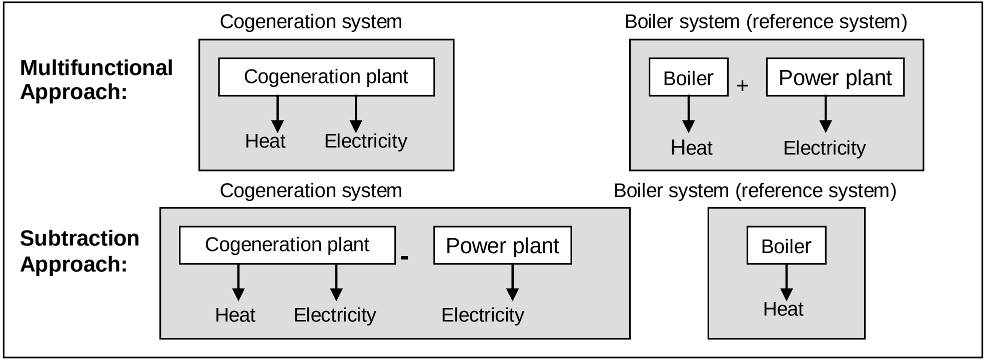
chains which involve the provision of more than one product or service may require that inputs like energy consumption and outputs like emissions are allocated to the different products or services. However, when possible allocation should be avoided as it always creates uncertainties and a need for judgements (Schlamadinger *et al.* 1997; ISO14044 2006).

Two main approaches exist to avoid allocation: the multifunctional and the subtraction (also called substitution) approach (see also figure 2).

- In the *multifunctional* approach, the functional unit is expanded to include all products produced. For example, to compare systems producing both heat and electricity with systems producing heat or electricity only, both energy carriers should be considered in the functional unit. This can be done if the functional unit is expanded (Gustavsson *et al.* 2006).
- In the *subtraction* approach, the main conventional process for producing a co-product, by-product or residue / waste product is used to generate comparative effective credits, which are then subtracted from the life cycle inventory of the process chain under investigation (Horne *et al.* 2004).

The multifunctional approach is preferred due to its transparency, since the subtracted part of the bioenergy system is not shown when the subtraction method is used (Gustavsson *et al.* 2006). Although allocation is avoided with the subtraction and multifunctional approach, they expand the system boundary and the approaches can only be used when sufficient information is available to determine the GHG intensity of the conventional process. Also, the conventional production process for the co-product or by-product needs to be clearly identified. The latter is not always possible as numerous co-products, by-products and waste products generated by biomass energy production (such as straw, bran, and glycerine) are produced in other process chains as by-products mainly (RSB 2008a).

Figure 2: An example of systems in the case of cogeneration of heat and electricity. Top: an example of systems with multifunctional products, also in the functional unit. Bottom: an example of systems where the cogenerated electricity is subtracted such that the functional unit is heat (Finnveden *et al.* 1998).



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[20] Residues or wastes: products that are generated along with the main product but have no, negligible or even negative revenues.

For reasons which may vary from data availability to the impossibility to identify the conventional production process (Horne *et al.* 2004), it is sometimes necessary to revert to simpler allocation procedures.

One option for allocation is by using *fixed physical relationships* between the main product and the co- or by-products. The underlying physical relationships (mass, volume or energy content in lower heating value) of products can be used in allocating credits to all products. The physical allocation method works well when there is a close correlation between the chosen physical property and the value of the co-products. Several problems using the mass allocation approach were pointed out in some studies. Punter *et al.* (2004) remarked that different dispositions of the co-products can produce different environmental impacts, which would not be reflected in the calculation. The mass of corn oil and DDGS from corn feedstock is different, but it does not reflect the difference of GHG emissions in reality. Malça *et al.* (2004) mention that mass allocation in, for example, a bioethanol LCA does not reflect physical causality between functional units and environmental burdens as the approach assumes that the more co-product one produce in the process of ethanol, the better the environmental performance with respect to the ethanol will be. Allocation based on the energy content value of different products has similar problems (Malça *et al.* 2004).

Where physical relationships alone cannot be established or used as the basis for allocation, a second option for allocation is *allocation by market price and subsequent revenue.* The market price, which has as disadvantage that it can fluctuate over time and in such case the results will change, should reflect the value of the co- or by-product in proportion to the main product as far as the producer is concerned. It is a valid measure of the proportional value society places on each main and co- or by-product, and therefore the same proportion can be used in allocating credits to all the products (Horne *et al.* 2004).
If both the crop and residues of co-products (e.g. wheat and straw) from a certain production hectare are used for biomass energy production (fuel, heat or power) the allocation method for all biomass products must be equal to prevent shopping. Furthermore, attention is necessary if a biomass chain produces both biofuels and other energy carriers to avoid double accounting of GHG reduction credits (Kwant *et al.* 2007).

We conclude that allocation should be avoided when possible by using the subtraction or the multifunctional approach. However, there is no single approach which is appropriate for all circumstances. Thus, it is desirable to allow for opting different approaches (including various allocation methods) and results. When allocation is needed, it would be desirable to get political agreement on the preferred approach e.g. using the energy value of each product as proposed by the European Commission (EC 2008).

3.2.8. Timing issues

IPCC has given attention to the importance of time dynamics in calculations of GHG-balances (Watson *et al.* 2000; McCarthy *et al.* 2001). However, little attention has been given to the time factor in studies of energy systems on a project level. Energy inputs and outputs occur at different moments during the lifetime of a project. For example, energy inputs (and the GHG emissions from that) for building an infrastructure generally occur mainly during the inception phase of the project. The same applies for costs, as investments in the starting phase are dominating this figure.

Specific attention requires the production side of the biomass energy system in case crop cycles extend beyond annual patterns, for example in forestry or perennial systems. In this case, inputs and outputs - including emissions that are related to operations like cropping, fertilizing and harvesting - are spread over several years. Also, the vegetation carbon stock changes over time, associated with the inception of a biomass energy project, as discussed in 3.2.5. Gustavsson *et al.* (2002) discussed the variation over time in decay rates of logging residues when the change in carbon stocks of the biological system was included in studies of biomass based energy systems.

When choosing a time frame for the conversion factors in calculations of CO_2 equivalents, most authors use the data established by IPCC for 100 years, some have used 500 years (Jungk 2000), while some don't show this assumption at all (Groscurth *et al.* 2000; Kaltschmitt *et al.* 1997).

We conclude that transparency of a study in the choice of time frames used in cost and GHG calculations is important for comparability (Horne *et al.* 2004) and a methodology that allows variable time frames is highly recommended.

3.2.9. Cost measurements

Cost assessments are needed to get insights in costs and benefits of various bioenergy systems to reduce GHG emissions. The main costs of interest are those associated specifically with achieving reductions in fossil energy consumption or mitigation of GHG emissions. The cost of GHG mitigation (in €/CO_2 eq.) is defined as the difference in expenditure between the biomass energy system and the fossil energy reference system per unit GHG emission measured in CO_2 equivalents. This can be expressed with the following formula (Karlsson 2003):

$$C = (C_i - C_{ref}) / (E_{ref} - E_i) = \Delta C / \Delta E \text{ for } E_{ref} > E_i \qquad (2)$$

C_i and C_{ref} are the cost of, and E_i and E_{ref} are the GHG emissions from producing one functional unit by the bioenergy and the reference system respectively. The costs C_i and C_{ref} are dependent on numerous factors, including feedstock, land, labour and equipment costs and the costs of fossil fuel and agricultural commodities used (DEFRA 2008).

In energy systems analyses, costs of conversion and distribution are calculated based on investment, operation and maintenance costs, while fuel costs for all energy carriers of the system are based on market prices (Gustavsson e*t al.* 2002). This approach has the advantage of a consistent treatment of data for costs and emissions, based on the same inventory data. The approach is also used consistently on the biomass and reference systems, further increasing accuracy of the results.

Results from Larijssen *et al.* (2008) show that the price of fossil fuel compared to the biofuel produced is an important parameter determining the costs of avoiding CO_2 emissions. The sensitivity of CO_2 mitigation costs for changes in fossil fuel costs has also been demonstrated by Börjesson *et al.* (2006). Full investment costs can be accounted for both the bioenergy and reference energy system. Alternatively, if the investment in a bioenergy system would have been considered to be additional, GHG mitigation costs would increase (Gustavsson *et al.* 2007).

Various studies, as Hamelinck *et al.* (2005) and Smeets *et al.* (2008b), have calculated the cost performance of bioenergy systems for upstream parts of the life cycle, like transportation and agricultural production, using a bottom-up approach. Upstream costs have also been estimated from national input/output statistics (Faaij *et al.* 1998; Groscurth *et al.* 2000). This may be seen as a top-down approach for easier data acquisition, but the accuracy of results obtained by this method is difficult to evaluate.

The GEMIS software has modules to calculate production and mitigation costs for various processes, which have been applied in a study of biomass energy systems by Jungmeier *et al.* (2002). The accuracy of this approach is hard to evaluate due to a low transparency. The SimaPro software has no function for cost assessments.
Although the impact of external costs have been included in the assessments of biomass energy systems by some authors (Faaij *et al.* 1998; Groscurth *et al.* 2000; Karlsson 2003; Jungmeier *et al.* 1998; ECOTEC 2002) this issue is outside the scope our study because of huge uncertainties in calculating the costs and the risk of double counting these costs.

We recommend that only direct costs are considered in the calculation of the cost difference between fossil and bioenergy systems, while fuel costs for all energy carriers of the system are based on market prices. Climate change costs must be excluded to avoid double counting (Horne *et al.* 2004). We also recommend that input data for cost calculations (such as the used interest rate) are clearly presented for reasons of transparency. Also, a sensitivity analysis of the results for e.g. various interest rates and fossil fuel prices is a good practice (Vikman *et al.* 2004). The annualising of costs must be carried out with great care, particular for biomass energy projects that involve a complex pattern of investment, operation and maintenance costs over many years. More importantly, all costs must be discounted to the base year of the project before being combined and annualised (Horne *et al.* 2004).

3.2.10. Site specificity

Site-specific circumstances should be taken into account to increase the accuracy of a system analysis. This requires the availability of local data. A modular LCA-tool like GEMIS holds already data for more than 30 countries (Fritsche 1999). Site-specific circumstances also affect the choice of an appropriate reference technology. Another dimension of site-specificity is the difference in results that can be obtained when the energy system investigated should not operate in base-load but in peak-load, having a high influence on the calculated costs. Gustavsson *et al.* (2002) have shown how the impact of the variability of the load on the results can be presented, also when the choice is not unambiguous.

In conclusion, the use of site-specific data, selected with care, is recommended to improve the accuracy of a system analysis.

3.2.11. Uncertainty

There are several types of uncertainty like uncertainty due to input data (parameter uncertainty), uncertainty due to normative choices (scenario uncertainty) or model uncertainty. Insight in the impact of these uncertainties on the outcomes provides useful information to assess the reliability of LCA-based forecasts and decisions (Huijbregts *et al.* 2003).

Several methodological issues discussed above involve the use of variable or uncertain data. Input data characterized by a large variability and uncertainty are for example the indirect and direct N_2O emissions of bioenergy production systems as debated by Crutzen *et al.* (2008) and Smeets *et al.* (2008a). A case study on palm oil plantations in Indonesia, for example, showed that the range of the N_2O emission factor from managed soils given by IPCC can cause the calculated overall GHG emissions to increase or decrease by more than 10% (Wicke *et al.* 2009). A study on soybean agriculture in the Cerrado region (Reijnders L. *et al.* 2008) shows overall uncertainties from yearly typical GHG emissions - caused by initial C loss, yearly C soil loss and yearly N_2O emissions - from 10–30%. Bernesson *et al.* (2004) show in a sensitivity analysis the changes in impact categories and energy requirements when some production factors are changed for small-scale production of RME.

Comparing different scenarios is one way to handle uncertainties. Another useful tool is the sensitivity analysis, by which the impact of a variation on the total results of the study can be made clear. Sensitivity analyses have been performed by many authors (Jungk 2000; Faaij *et al.* 1998; Kaltschmitt *et al.* 1997; Mortimer *et al.* 2003) and is a feature of the SimaPro software (Goedkoop *et al.* 2002).

A summary of our findings and suggestions is presented in table 2.

Table 2: Translation of methodological issues into components of the BIOMITRE tool.

Methodological issue	Components of the BIOMITRE tool
1) Functional unit	The BIOMITRE tool is designed to examine primary energy, GHG emissions and cost-effectiveness of different bioenergy systems. The user can select three different functional units: 1) 1 GJ final output (GJ), 2) Plant scale for project lifetime and 3) Based on available area for project lifetime.
2) Outputs	The BIOMITRE tool provides the following outputs: • Fossil fuel use: Total primary fossil fuel input / unit of energy delivered (GJ/ $GJ_{del.}$) • GHG emissions: Net GHG emissions / unit of energy delivered (kg CO_2 eq./$GJ_{del.}$) • Energy costs: Costs per unit of energy delivered (€/$GJ_{del.}$) • Avoided fossil fuel use: Net fossil fuel requirement reference system – Net fossil fuel requirement for project per unit of energy delivered (GJ/$GJ_{del.}$) • Avoided GHG emissions: GHG emissions reference system – GHG emissions for project per unit of energy delivered (kg CO_2 eq./$GJ_{del.}$) • GHG mitigation costs: Δ costs / Δ GHG emissions, see also 3.2.9 (€/kg CO_2 eq.) • Net GHG cost effectiveness system: Costs / unit of GHG emission (€/kg CO_2 eq.) • Avoided energy costs: Δ costs / unit of energy delivered (€/$GJ_{del.}$) • Net energy cost effectiveness system: Costs / unit of fossil fuel requirement (€/$GJ_{del.}$)
3) System boundaries	The user of the BIOMITRE tool can draw the system boundary of the process chain to be considered around each production, logistics, conversion, distribution and end-use step, see also section 3.2.3
4) Reference energy system	The reference energy system should in general be as similar as possible to the biomass energy system. It is recommended to use the least-cost fossil energy system with minimized environmental impact, fulfilling the same functions as the biomass energy system.
5) Direct land-use and changes in carbon stocks	The land-use reference system is the land-use system that would have been applied most likely in practice and reflects current and expected reality. To calculate soil carbon changes over time, the formula of the 'broken stick model' is applied, see 3.2.5. The user has to select an appropriate length for the period of change.
6) Indirect land-use change (ILUC)	ILUC is embedded in the tool as an additional factor to describe indirect land-use changes due to biomass energy projects. The quantification of expected indirect land-use and its effects should be done with care. A uniform approach still has to be developed.
7) Allocation procedures	The tool accommodates the multifunctional and subtraction approach and in addition allocation procedures (based on price, mass, energy) so that the user can select the most appropriate procedure for its specific project.
8) Timing issues	The tool relies on a simplified approach to handle energy inputs and outputs that may occur at different times. This involves annualising system inputs and outputs over the life cycle of a biomass energy project and its reference system.
9) Cost measurements	Direct costs are taken into account neglecting external costs. A sensitivity analysis (see 3.2.10) provides insight in the impact of the value of main cost parameters on the total results of the study.
10) Site specificity	The BIOMITRE tool provides the option to include site-specific data about the project and process chain. In case specific data are not available, the user has the option to include more general input data such as country or regional data (see 3.2.11)
11) Uncertainty	The user is able to assess the impact of changes within a range of a particular data value where uncertainty exists by means of using multiple runs of the tool. Since multiple runs can be saved within the same spreadsheet, the effects of varying a parameter or parameters can be calculated and assessed by the user. Where key data are uncertain, the impact of the uncertainty should be reported when results are presented.

4. GHG and cost calculation software tool

A calculation tool was developed to provide total or detailed primary energy inputs, GHG emissions and costs for the selected biomass energy project in relation to reference fossil energy systems through the following components:

- Calculation of the net GHG (CO_2, CH_4, and N_2O) emissions associated with the biomass energy system and reference fossil energy system;
- Calculation of the net monetary costs of avoided GHG emissions by implementing the biomass energy system instead of the reference fossil energy system.

The tool, see also (Dam *et al.* 2004a), has been developed in the software program Excel. The calculations can be carried out and saved up to three runs for three different functional units for a range of outputs (see table 2).

When developing the software tool, two practical challenges were encountered. First, the large variety of biomass energy technologies which can be implemented to reduce GHG emissions on a national and international scale, and second, the large variety in data available for different biomass energy technologies and systems as well as countries and user groups.

These challenges were addressed by two key characteristics of the tool:

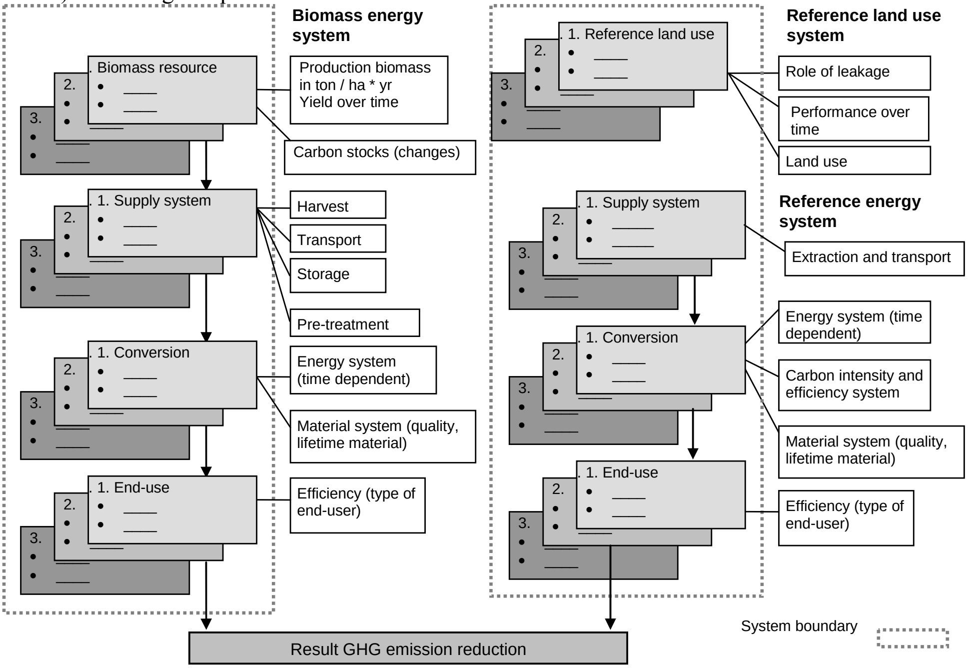
- Flow charts and modules that summarize the characteristics of any given biomass energy technology;
- Data that are successively disaggregated.

The strength of the tool is its standard methodology, transparency and the successively disaggregating of data which will be explained there in more detail.

4.1. Flow chart and module design

The flow chart design (see figure 3) was governed by the need to summarize data so that the biomass energy technology is specified in a clear, unambiguous and transparent manner. The flow chart represents all the inter-linked processes, being part of a biomass energy system. Each major process is identified. Essential data are specified for the inputs and outputs associated with each process.

Figure 3: Flow chart design software tool for bioenergy and reference system, see also (Dam *et al.* 2004a). In this figure specified for the calculation of GHG emission reductions.



In the tool, the user starts filling in its project data in a starting sheet, where the main outputs and indicators for the calculations need to be selected. From this sheet, the user is guided through the modules of the bioenergy chain and its reference system. Four different modules reflect the total bioenergy chain. The first module is the biomass resource module that includes perennial crops, annual crops, forest and waste. In terms of supply, the main initial input (seed, cuttings, land, etc.) are indicated. Co-products and by-products that occur at any stage in the bioenergy chain are taken into account since these can have a significant role in final evaluation through allocation procedures, in case the user cannot apply the multifunctional or subtraction approach (see also 3.2.7).

The second module includes logistical steps (e.g. truck, train or ship transport) and biomass pre-processing activities. A modular approach in accordance with the model developed by Hamelinck *et al.* (2005) is used for the logistics (train, ship, truck transport) and pre-processing activities to supply biomass to the conversion unit. The third module is the conversion component of the bioenergy chain. The end-use possibilities are forms of delivered energy (solid, liquid, gaseous fuels, heat, electricity, heat, etc.). The fourth module includes the distribution and end-use of the bioenergy product.

4.2. Data levels for modules and data aggregation

The variation in data availability has its impact on the levels of calculation (as explained below) within the software tool. Therefore, successive disaggregation is used to cope with this data diversity. The key concept is that different levels for GHG (and cost) calculations and, thus, data requirements are used. This will enable users to adopt either aggregated or disaggregated data for subsequent analysis. The input of three data levels is allowed (see figure 10 for the biomass resource module) providing the user the possibility to choose its own attainable degree of data precision. For all levels, a range of basic data is required, which covers both the basic parameters for the biomass production systems as well as key information about the reference system and allocation. The data can be changed to fit a wide range of users and projects that are specific and unique in location and site.

The first data level is a very generic level of data collection and calculation. Input data are totals of primary energy use and GHG emissions for each stage of the system. Prices are used for cost data. The second level requires more specific and detailed data that can generally be found in the literature or from other sources. The logistics and pre-processing stages can be broken down into up to nine steps.

The third level is project specific: the biomass production stages can be broken into more operation steps for each selected system. In this case, the user will have to collect its own data for energy and resource inputs, machinery, labour input, etc. This requires detailed cost data availability which is often difficult to achieve. As output is closely related to data input, it must be considered that data accuracy and consistency have their impact on the output, generated by the tool.

5. Examples of case study analyses

To test and demonstrate our tool, four case studies have been selected in such a way that they represent the wide diversity of biomass energy systems that should be accommodated by the tool. The case studies[21] are:

1. *Fuel production in the Netherlands from wood residues in Canada;* the system consists of pellets that are produced from wood residues, transported to the Netherlands and converted in a Fischer-Tropsch (FT-) plant (400 MW) to diesel and, as co-product, electricity;
2. *Combustion of forest processing residues under Finnish / Swedish conditions*; the system consists of logging and sawmill residues that are converted in a wood fuel-fired CHP plant, generating electricity and power distributed to the district network. Two different CHP plant technologies are compared, which are the steam turbine (BST) technology (based on year 2000) and the biomass integrated gasifier /combined cycle (BIG/CC) technology (based on year 2020).

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[21] The four case studies have been prepared by partners of the BIOMITRE project. A description of the case study and the input parameters were delivered by the partners as input for the tool. See also Dam *et al.* (2004a).

3. *Heat from Miscanthus in the UK*; the system consists of the cultivation of Miscanthus for subsequent use in a boiler (70 kW output), which is used for heating purposes. The case study is based on an actual system under commercial development in 2004 (base year);
4. *Biodiesel from rapeseed in the UK.*; the system consists of the cultivation of rapeseed, transported to a typical biodiesel plant in the UK. The rapeseed is dried and converted to biodiesel by solvent extraction. The biodiesel is transported to a distribution point and used as fuel by the end-user, based on a car from the base year 1996.

Table 3 provides information about the system boundary, the reference energy and land-use system (including literature references) and used allocation procedure for the selected case studies.

Table 3: Main characteristics of the four case studies presented with the BIOMITRE software tool, see also Dam *et al.* (2004a).

Case study:	System boundary	Multifunctional or subtraction approach, or allocation	Reference energy and land-use system	Literature reference
Case study 1: Fuel production in the Netherlands from wood residues in Canada.	Includes composition of fuels, heat and electricity for all main process steps and the provision of these fuels and electricity from fossil fuel resources.	Outputs from debarking at the mills are forest-processing residues and logs. Forest processing residues are the main product and logs are the by-product. Allocation based on market price takes place in the beginning of chain. Diesel (main product) and electricity (co-product) are generated in the conversion process. Here, the substitution approach and allocation based on energy content are applied.	Reference energy system: Diesel from fossil fuels; Electricity generated via average electricity generation mix in the Netherlands is used as a reference for substitution of electricity. Reference land-use system: Biomass decomposition in landfills.	Smeets *et al.* (2008a), Hamelinck *et al.* (2005), Hamelinck *et al.* (2006), Damen *et al.* (2006), Hekkert *et al.* (2005).
Case study 2: Combustion of forest processing residues under Finnish / Swedish conditions.	The final product in the system is heat and electricity distributed to the district network. The end-use of these energy carriers is not taken into account in the case study as this would not influence the results.	Allocation takes place in the beginning of the chain during felling of the trees (residues and logs) and during the processing at sawmills. Outputs are sawn timber, dust and bark. Allocation takes place based on mass. Multifunctional approach is used in conversion step.	Reference energy system: Natural gas. In case additional electricity has to be produced by the bioenergy system to attain reference entity, it is assumed to be produced from a wood-fired stand alone power plant. Reference land-use: Forest area under circumstances where timber wood harvesting exists but logging residues are not collected.	Gustavsson *et al.* (2003), Lehtonen *et al.* (2004), Palosuo *et al.* (2000), Soimakallio *et al.*(2002), Wihersaari *et al.* (2000).

Table 3 (continued): Main characteristics of the four case studies presented with the BIOMITRE software tool, see also Dam *et al.* (2004a).

Case study:	System boundary	Multifunctional or subtraction approach, or allocation	Reference energy and land-use system	Literature reference
Case study 3: Heat from Miscanthus in the UK.	Consumption of fuels and electricity for main process steps, provision of these fuels and electricity from fossil fuel resources, production of major agricultural supplies, manufacture of major agricultural machinery and equipment. Possible changes in soil carbon are not taken into account.	No allocation procedure is needed; there is only one significant product. Ash is considered as waste product, spread on the field. Any benefit derived from this ash as fertiliser or soil conditioner is not taken into account.	Reference energy system: Oil-fired boiler to provide heat. Reference land-use system: managed set-aside cultivation of the land; set-aside land with annual topping with a tractor and mower.	CRC (2000), McCormack *et al.* (2000), Mortimer *et al.* (2001), Woods *et al.* (2008).
Case study 4: Biodiesel from rapeseed in the UK.	Consumption of fuels and electricity for main process steps, provision of these fuels and electricity from fossil fuel resources, production of major agricultural supplies, manufacture of major agricultural machinery and equipment. Possible changes in soil carbon are not taken into account.	Price allocation of the main, co- and by-products is applied successively to each part of the system associated with the production of a main product and its co- or by-products.	Reference energy system: Ultra low sulphur diesel derived from conventional sources of crude oil. Reference land-use system: mowing grassland in UK.	Beer *et al.* (2002), CRC (2000), ESRU (2007), Edwards *et al.* (2003).

5.1. Case study 1: Fuel production in the Netherlands from wood residues in Canada

Case study 1 'Fuel production in the Netherlands from wood residues in Canada' is characterized by a large number of individual logistics and processing steps and is therefore considered appropriate to demonstrate the impact of data aggregation or specificness on GHG emissions and costs.

The case study uses wood processing residues as feedstock. Saw logs (by-product) and wood processing residues (main product) are generated at two different sawmills located in Canada. Allocation of energy inputs, emissions and costs between the logs and the wood processing residues is based on market price. Energy costs and GHG emissions for the residues in the biomass resource module are zero as it is assumed that the residues have no market value and the logs have a market value of 93 €/tdm (Damen *et al.* 2006).

The case study assumes that one output product is generated: FT-diesel. Electricity is generated as a co-product. Allocation of energy inputs, emissions and costs between the generated fuel and electricity is based on substitution. The average electricity mix in the Netherlands is selected as conventional process for producing electricity and the generated comparative effective GHG emission credits (171 kg CO_2 eq. /GJ_{del}) and costs are subtracted from the life cycle inventory of the process chain under investigation. A cost price value of 8.34 €/GJ_{del}[22] (Hamelinck *et al.* 2006) is assumed for the electricity generated in both the reference and biomass energy system. For comparison, the energy inputs, emissions and costs between the generated fuel and electricity are allocated based on energy content (based on the efficiency of the FT-plant for fuel and electricity, see table 5). The reference land-use system is biomass decomposition in landfills. It is assumed that the CH_4 in the landfills is captured for combustion.

Table 5: Key data input for Case study 1: Fuel production in the Netherlands from wood residues in Canada*.

Conversion module	
Efficiency FT-plant fuel: 33.5%	*Total emissions:*
Efficiency FT-plant electricity: 12.8%	0.15 kg CO_2 eq./GJ_{del}
Capacity plant: 400 MW	

Distribution and end-use module	
Efficiency distribution fuel: 97.8%	*Total emissions:*
Efficiency distribution electricity: 96%	0.18 kg CO_2 eq./GJ_{del}

* Case study is delivered by Utrecht University (one of the BIOMITRE partners). References used are shown in table 3.

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[22] This is based on € 0.03 per kWh, based on on-site capacity power generation or purchase-sale price industry for base load.

Table 4: Data input for level 1 and level 3 (for main product 1 only) for the transport and pre-processing module in case study one: 'Fuel production in the Netherlands from wood residues in Canada'*.

Transport and pre-processing module for main products 1-3 – level 1 *(*Costs on data level 1 are reflected by end-price product)*		
Main product 2:	49.5 MJ_{prim}/yr	5.1 kg CO_2eq. / yr
Main product 3:	0 MJ_{prim}/yr	0 kg CO_2eq. / yr
<u>Main product 1:</u>	1205.1 MJ_{prim}/yr	172.7 kg CO_2eq. / yr
Transport and pre-processing module for main product 1 – level 3		
Step 1: Truck transport		
Distance: 75 km	MC[a] biomass: 48%	*Emissions:*
Diesel use: $2*10^{-2}$ l / t.km	LHV biomass 18.1 MJ / tdm	$7*10^{-2}$ kg CO_2/ t.km
Energy content diesel: 35.7 MJ/ l	Truck capacity max: 40 tonne fw[b]	$7.8*10^{-5}$ kg CH_4/ t.km
Primary conversion factor: 0.9 MJ_{prim}/MJ	Costs: 3.8 €/ t.km	$2.0*10^{-6}$ kg N_2O/ t.km
Step 2: Merging of product streams		
Step 3: Pelletising		
LHV biomass: 18.1 MJ / tdm	Bagging costs: €13.3 / t_{del}	Heat: $2.3*10^{-5}$ kg CH_4 / MJ_{del}
MC[a] end: 7%	Drying costs: €8.3 / t_{del}	Power: $8.6*10^{-5}$ kg CH_4/MJ_{del}
Dry matter loss: 1%	Direct costs: €40.8 / t_{del}	Fuel 1: 0 CH_4 / MJ_{del}
Use biomass energy: $1.4*10^5$ GJ / tdm	*Emissions:*	Fuel 2: 0 kg CH_4 / MJ_{del}
Energy heat (internal): 12346.1 MJ_{prim} / t_{del}	Heat: $6*10^{-2}$ kg CO_2 / MJ_{del}	Heat: $1.8*10^{-5}$ kg N_2O / MJ_{del}
Energy power: 806.5 MJ_{prim} / t_{del}	Power: $6*10^{-2}$ kg CO_2 / MJ_{del}	Power: $3*10^{-6}$ kg N_2O /MJ_{del}
Energy fuel 1: 42.4 MJ_{prim} / t_{del}	Fuel 1: $8*10^{-2}$ kg CO_2 / MJ_{del}	Fuel 1: 0 kg N_2O / MJ_{del}
Energy fuel 2: 8.5 MJ_{prim} / t_{del}	Fuel 2: $7*10^{-2}$ kg CO_2 / MJ_{del}	Fuel 2: 0 kg N_2O / MJ_{del}
Step 4: Truck transport		
Distance: 75 km	MC[a] biomass: 7%	*Emissions:*
Diesel use: $1*10^{-2}$ l / t.km	LHV biomass 18.1 MJ / tdm	0.1 kg CO_2 / t.km
Energy content diesel: 35.7 MJ / l	Truck capacity max: 46 tonne fw[b]	$1.7*10^{-4}$ kg CH_4 / t.km
Primary conversion factor: 0.9 MJ_{prim}/MJ	Costs: 3.4 € / t.km	$2.7*10^{-6}$ kg N_2O / t.km
Step 5: Storage		
MC[a] biomass: 7%	DM loss: 0%	*Emissions:* 0 kg CO_2 / t_{del}
LHV biomass 18.1 MJ / tdm	Costs: 15.0 € / t_{del}	0 kg CH_4 / t_{del}
	Energy use: 0 MJ / t_{del}	0 kg N_2O / t_{del}
Step 6: Oceanic ship transport		
MC[a] biomass: 7%	Ship capacity max: 63000 t	(Un-)Load costs: €2.1 / t_{del}
LHV biomass 18.1 MJ / tdm	Distance (Roundtrip) 5010 km	Other charges: € 1.4 / t_{del}
Dry matter loss: 0%	Fuel use HFO[c]: $1.1*10^{-3}$ l / t.km	*Emissions:*
Primary conversion factor: 0.9 MJ_{prim}/MJ	Energy content HFO[c]: 40.2 MJ / l	$1*10^{-2}$ kg CO_2 / t.km
Share biomass load: 100%	Charter costs: €1.4 / t_{del}	$1.2*10^{-5}$ kg CH_4 / t.km
		$5.0*10^{-8}$ kg N_2O / t.km
Step 7: Storage		
MC[a] biomass: 7%	DM loss: 0%	*Emissions:* 0 kg CO_2 / t_{del}
LHV biomass 18.1 MJ / tdm	Costs: 15.0 € / t_{del}	0 kg CH_4 / t_{del}
	Energy use: 0 MJ / t_{del}	0 kg N_2O / t_{del}
Step 8: Inland ship transport		
MC[a] biomass: 5%	Dry matter loss: 0%	Share biomass load: 100%
LHV biomass 18.1 MJ / tdm	Distance (Roundtrip) 104 km	*Emissions:*
Primary conversion factor: 0.9 MJ_{prim}/MJ	Ship capacity max: 4000 t	$3.1*10^{-2}$ kg CO_2 / t.km
Diesel use: $4.8*10^{-3}$ l / t.km	Total costs: € 7.9 / t_{del}	$6*10^{-5}$ kg CH_4 / t.km
Energy content diesel: 35.7 MJ / l	Other charges: € 1.4 / t_{del}	$3.6*10^{-7}$ kg N_2O / t.km

[a] MC = Moisture Content, [b] fw = fresh weight, [c] HFO = Heavy Fuel Oil, * Case study delivered by Utrecht University in the Netherlands. References used are shown in table 3.

The data input for the transport and pre-processing steps of the wood processing residues is described in table 4. Key input data for the conversion and distribution / end-use module are shown in table 5. The reference energy system for FT-diesel is fossil fuel diesel.

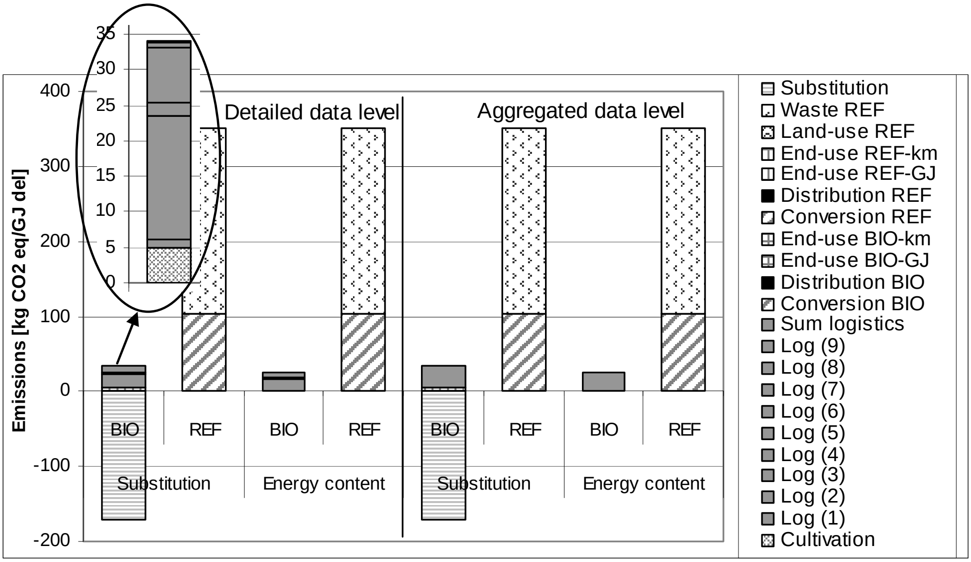
Figure 4 and 5 show the results for the GHG emissions per unit of energy delivered and the energy costs for the biomass energy system and the reference system for two different runs. Run 1 shows the results for data level 3 (most accurate and specific data level). Run 2 shows the results for data level 1, which is the aggregated data level.

Total GHG emissions of the biomass energy system (see also figure 4) in Run 1, characterised by a detailed data level, are -137 kg CO_2 eq./GJ_{del} when substitution is applied to allocate the emissions between the co- and main product and 25 kg CO_2 eq./GJ_{del} when allocation based on energy content is applied. Most GHG emissions in the biomass energy system take place in the logistics and pre-processing module and, more specifically, in the pelletisation process (60%). Total GHG emissions of the biomass energy system in Run 2 (aggregated data level) are more or less similar to Run 1. However, Run 1 does not show the contribution of different processing steps, as pelletising, to the total GHG emissions.

For both Runs, the calculated GHG emissions for the reference system are 352 kg CO_2 eq./GJ_{del}. The emissions are caused by the emissions from diesel (whole chain) and the CH_4 emissions from waste biomass decomposition that would occur if the biomass is not used for energy but land filled.

The energy costs of the biomass energy system are based on the calculated cost data in Run 1 and on the market price value of the generated fuel and electricity in Run 2 (see also figure 5). Detailed cost data are not available to calculate the energy costs of the reference

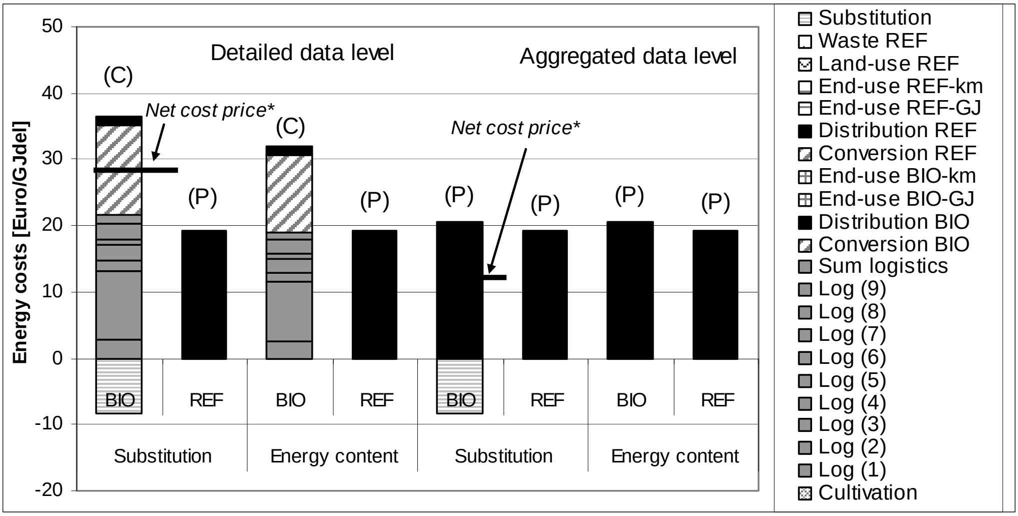
Figure 4: GHG emission distribution in kg CO_2 eq./GJ_{del} of the biomass energy system (BIO) and reference system (REF) for Run 1 (detailed data level) and Run 2 (aggregated data level) for Case study 1 on 'Fuel production in the Netherlands from wood residues in Canada', differentiated to various steps in the chain (log 1 to 9 showing different logistics steps). The results are shown for allocation based on substitution and based on energy content.



energy system per processing step. The energy costs of the reference energy system are therefore based on the market price value of the generated fuel in both Run 1 and Run 2. A market price value of 19.2 €/GJ (0.68 €/liter[23]) is assumed for the fuel generated in both the biomass energy and the reference system. Total energy costs of the biomass energy system in Run 1, characterised by a detailed data level, are 28 €/GJ$_{del}$ when substitution is applied to allocate the costs between the co- and main product and 32 €/GJ$_{del}$ when allocation based on energy content is applied. The larger share of the costs in the biomass energy system is caused by the pelletisation process (36%) and the conversion process (19%).

Based on an aggregated data level, total energy costs of the biomass energy system in Run 2 are 12 €/GJ$_{del}$ when substitution is applied to allocate the costs between the co- and main product. They are 21 €/GJ$_{del}$ when allocation based on energy content is applied. Difference in energy costs for the biomass energy system between Run 1 and Run 2 can largely be dedicated to the difference in price data at the end of the biomass energy chain (level 1) and the calculated costs per process step in the biomass energy chain (level 3). The energy costs for the reference system are 19 €/GJ$_{del}$ for Run 1 and Run 2 respectively. The economic contribution of CH_4 capture during waste decomposition is negligible, lowering total energy costs with $3*10^{-2}$ €/GJ$_{del}$ fuel in the reference system.

Figure 5: Energy costs in €/GJ$_{del}$ of the biomass energy (BIO) and reference system (REF) for Run 1 (detailed data level) and Run 2 (aggregated data level) for Case study 1 on 'Fuel production in the Netherlands from wood residues in Canada', differentiated to various steps in the chain (log 1 to 9 showing different logistics steps). The results are shown for allocation based on substitution and based on energy content.



(P): Energy costs are based on market price value end products, (C): Energy costs are based on calculated costs per processing steps.

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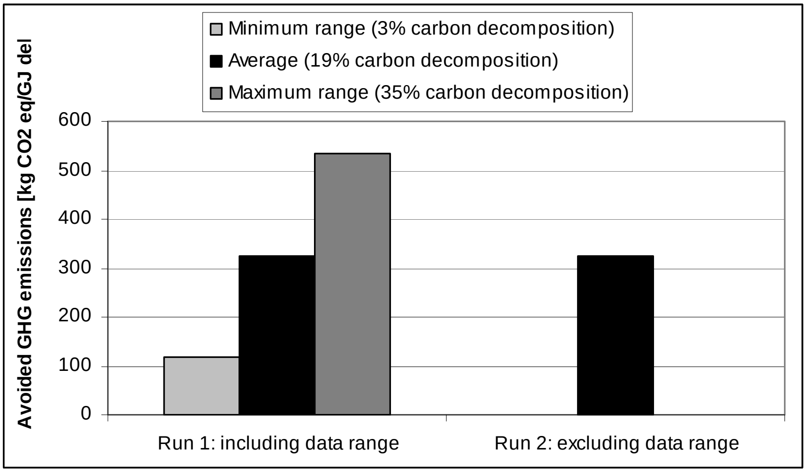
[23] This is based on 150 US$ per oil barrel, 10% extra refinery costs and a €/US$ ratio of 1.35.

The results in figure 4 and 5 show that more precise input data enable the user to specify the energy cost or GHG emissions of the biomass energy system and reference system. This results in a better insight in the contribution of individual steps in the chain to the total GHG emissions and energy costs. In case of lack of data, less detailed data (e.g. for cost calculations) can be used.

Figure 6 gives insight in the range of results for avoided GHG emissions when a variability of input data is included (Run 1) or not (Run 2). In this example, the percentage of carbon that is being decomposed at landfills is the variable input parameter. The base case, as also presented in figure 4 and 5, assumes an average amount of 19% of carbon that is being decomposed at landfills.

Figure 6: Avoided GHG emissions in kg CO_2 eq./GJ_{del} for biomass energy and reference system for Run 1 (including data range) and Run 2 (excluding data range) for Case study 1 on 'Fuel production in the Netherlands from wood residues in Canada'. See also text.



Damen *et al.* (2006) mentions, however, an uncertainty range of 3 to 35%. Including this uncertainty range in the data input for Run 1 results in this example, based on allocation on energy content, in a range of avoided emissions from 117 to 536 kg CO_2 eq./GJ_{del}. Run 2 only shows the avoided GHG emissions for the base case, which is 326 kg CO_2 eq./$GJ_{del.}$ The results in figure 6 illustrate the relevance of including data ranges in the data input as this enables the user to get insight in the uncertainty range of the results and the sensitivity of the results to the contribution of relevant parameters. This also confirms that calculated energy costs or GHG balance results should always be accompanied with an explanation of the data input used and expected impact of these data input (range) on the results.

5.2. Case study 2: Combustion of forest processing residues under Finnish / Swedish conditions

Two different CHP plant technologies are compared in case study 2 on ‘Combustion of forest processing residues under Finnish/Swedish conditions’. These technologies are the biomass steam turbine (BST) technology (based on year 2000) and the biomass integrated gasifier /combined cycle (BIG/CC) technology (based on year 2020).

Table 6: Key data input for Case study 2: Combustion of forest processing residues under Finnish/Swedish conditions*.

Biomass resource module	
Annual soil carbon loss: $9.5*10^{-3}$ t C/ha	*Emissions:*
Lifetime soil carbon loss: 100 years	2000: 13.5 kg CO_2 eq./GJ_{del}
Moisture content biomass: 53%	2020: 9 kg CO_2 eq./GJ_{del}
LHV biomass: 16.5 GJ/tdm	

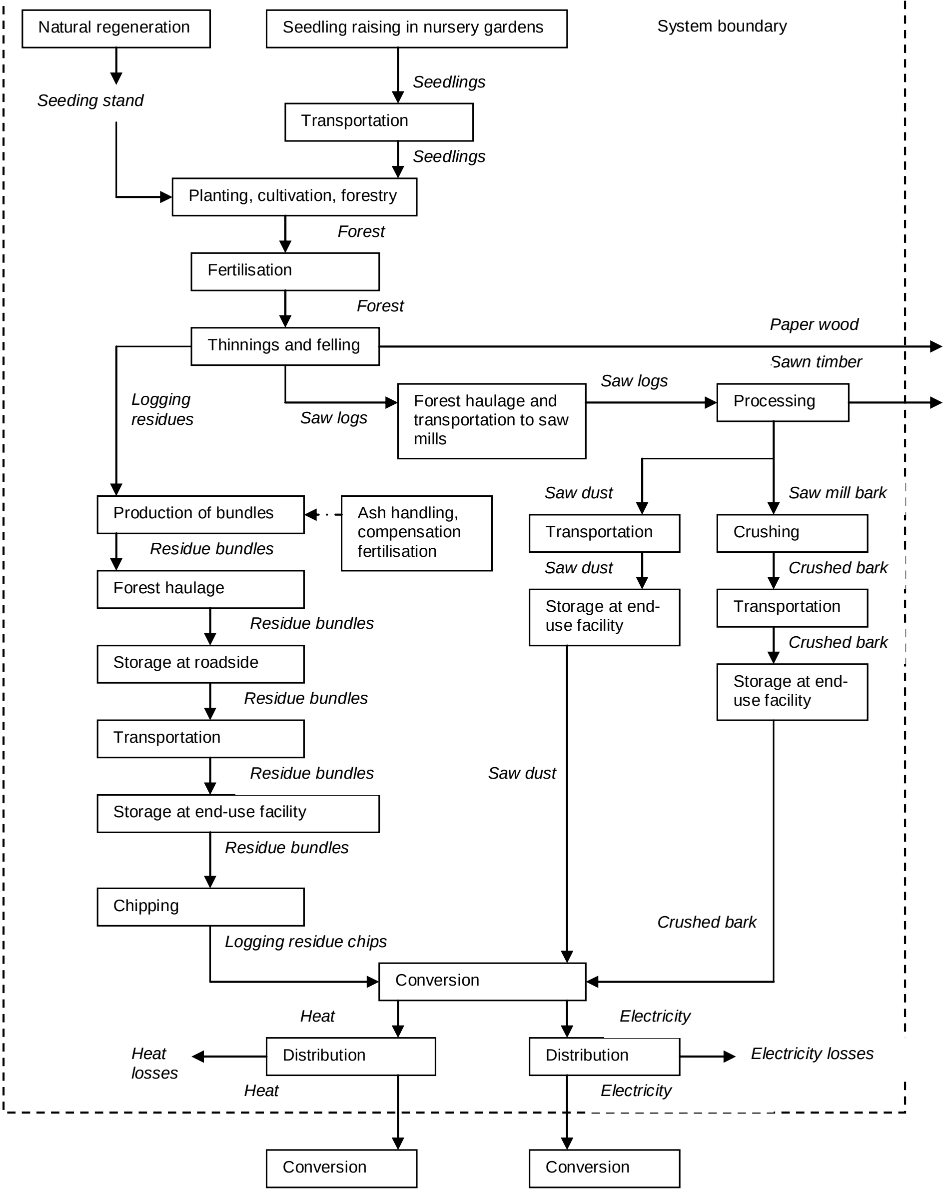
Transport and pre-processing module	
Dry matter loss after storage: 30%	*Emissions:*
Moisture content biomass: 40%	2000: 0.23 kg CO_2 eq./GJ_{del}
LHV biomass: 17.8 GJ/tdm	2020: 0.18 kg CO_2 eq./GJ_{del}

Conversion module		
Lifetime plant: 25 years	Efficiency CHP (BST) plant:	*Emissions:*
Efficiency CHP (BIG/CC) plant:	Total: 90%	(BIG/CC) plant:
Total: 86%	Efficiency electricity: 30%	0.9 kg CO_2 eq./GJ_{del}
Efficiency electricity: 42%	Efficiency heat: 60%	(BST) plant:
Efficiency heat: 44%	Net power CHP (BST) plant:	0.7 kg CO_2 eq./GJ_{del}
Net power CHP (BIG/CC) plant:	$MW_{electricity}$: 36	
$MW_{electricity}$: 65	MW_{heat}: 72	
MW_{heat}: 65	Efficiency stand-alone plant: 40%	

Distribution and end-use module	
Electricity loss distribution: 3.5%	*Emissions:*
Heat losses distribution: 15%	2000: 0 kg CO_2 eq./GJ_{del}
	2020: 0 kg CO_2 eq./GJ_{del}

* Case study is delivered by VTT Processes at the Technical Research Centre (Finland) and Mid Sweden University. References used are shown in table 3.

Figure 7: System boundary of the biomass energy system in the case study 'Combustion of forest processing residues under Finnish / Swedish conditions'.

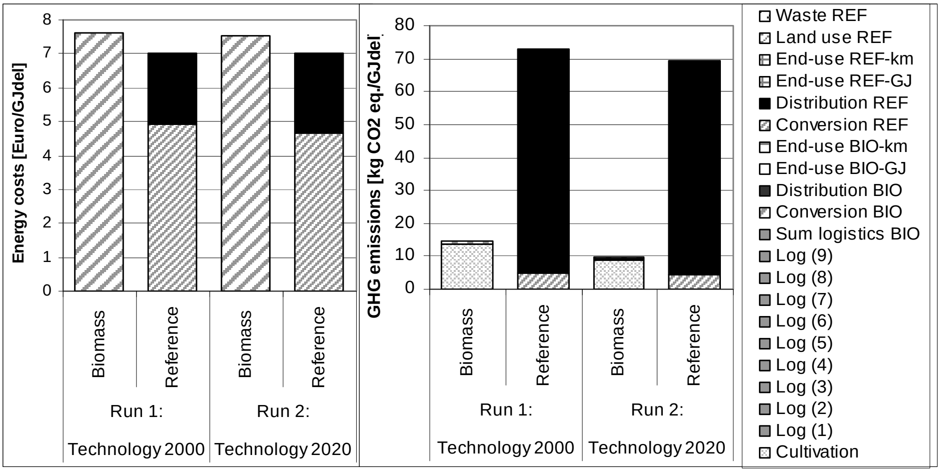


This case is selected as example to demonstrate 1) the relevance of the technology choice and 2) the selection of the time frame. The system boundary of the biomass energy system is shown in figure 7. The feedstocks for the Combined Heat and Power (CHP) plant are logging residues, saw dust and saw bark. Energy inputs, costs and emissions between the logging residues (main product) and saw logs (by-product) are allocated based on mass. This approach is also used for allocating inputs and outputs between the saw logs (by-product), saw dust and saw bark (main products). The case study assumes that two output products are generated: heat and electricity. Electricity and heat are produced in a natural-gas-fired stand-alone power plant in the reference energy system. The total net conversion efficiency of this natural gas plant is 88%. The lifetime is 25 years and its net power is 50 $MW_{electricity}$ and 50 MW_{heat} (based on references in table 3).

The energy costs and GHG emissions are calculated for two different runs. Run 1 is based on the CHP plant with BST technology, constructed in the year 2000. Run 2 is based on a CHP plant with (BIG/CC) technology, constructed in the year 2020. In Run 1, an extra stand-alone plant is used to produce the additional electricity generated in the reference system.

Figure 8 shows the GHG emissions and energy costs per GJ_{del} energy (sum of heat and electricity). The GHG emissions for the biomass energy and reference system in the first run are 15 kg CO_2 eq./GJ_{del} and 73 kg CO_2 eq./GJ_{del} respectively. The emissions decrease to 10 kg CO_2 eq./GJ_{del} for the biomass energy system and to 69 kg CO_2 eq./GJ_{del} for the reference system in 2020 (Run 2). For the biomass energy system, 91% (2000) and 92% (2020) of the total GHG emissions is generated during the cultivation phase. This includes GHG emissions due to soil carbon loss in the forest.

Figure 8: Energy costs (left) and GHG emissions of biomass energy and reference system per unit of delivered energy (sum of heat and electricity) for two defined runs for Case study 2 on 'Combustion of forest processing residues under Finnish / Swedish conditions, differentiated to various steps in the chain (log 1 to 9 showing different logistics steps).



The energy costs of the biomass energy and reference system for the two selected runs are also shown in figure 8. The conversion costs include the feedstock costs. A further specification of the feedstock costs to cultivation costs, transportation and pre-processing costs was not available for this case study. For Run 1 (technology based on year 2000), the energy costs for the biomass energy system are 7.6 €/GJ_{del} and for the reference system 7.0 €/GJ_{del}. For Run 2 (technology based on year 2020), the energy costs are 7.5 €/ GJ_{del} for the biomass energy system and 7.0 €/ GJ_{del} for the reference system. The emission avoidance costs for this case study are $1*10^{-2}$ €/kg CO_2 eq. for Run 1 and $9*10^{-3}$ €/kg CO_2 eq. for Run 2 per unit of delivered energy and thus remains, for this case study, more or less constant over time. The GHG emissions and energy costs for the biomass energy system and reference energy system, as presented in figure 8, show that the technology choice and time frame can have an impact on the results and should therefore be selected with caution.

5.3. Case study 3: Heat from Miscanthus in the UK.

Due to its simplicity, the UK case study 'Heat from Miscanthus', showing a first order calculation, is considered an appropriate example to demonstrate the impact of the selected reference land-use system and expected indirect land-use effects. The case study has one main output product, which is heat. The GHG emissions from the biomass energy system, unchanged over the various runs and excluding the GHG emissions from the reference land-use system, are 22 kg CO_2 eq./GJ_{del} (see also figure 9).

Table 7: Key data input for Case study 3: Heat from Miscanthus in the UK*.

Biomass resource module		
LHV biomass: 18 GJ/tdm	Energy use cultivation[a)]: 8870 MJ_{prim}/ha	*Emissions:*
MC biomass[b)]: 25%	Energy use harvesting: 1371 MJ_{prim}/ha	3.9 kg CO_2 eq./ GJ_{del}

Transport and pre-processing module		
LHV biomass: 18 GJ/tdm	Energy content diesel: 35.7 MJ/l	*Emissions:*
Moisture content biomass: 25%	Energy use: 42.8 MJ_{prim}/tdm	0.8 kg CO_2 eq./ GJ_{del}

Conversion module		
Thermal efficiency: 17.56%	Lifetime boiler: 25 years	*Emissions:*
LHV biomass: 18 GJ/tdm	Capacity boiler: 70 kW	19.6 kg CO_2 eq./ GJ_{del}

[a)] Energy use cultivation excludes harvesting, [b)] MC = Moisture content, * Case study delivered by Sheffield Hallam University. References used are shown in table 3.

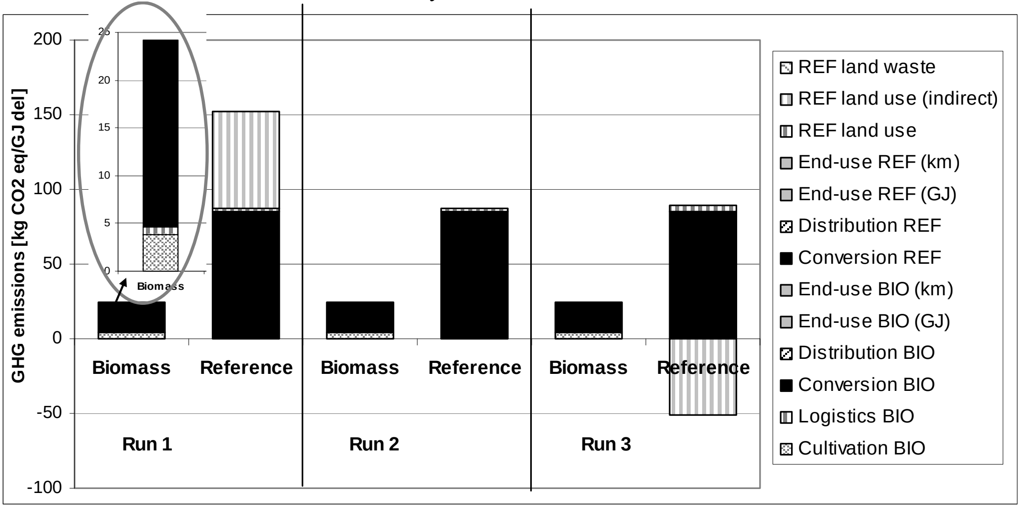
Key input data for this case study are shown in table 7. The large share of the conversion process to the total emissions is due to the high amount of nitrous oxide emissions from combustion per unit heat output. The following reference land-use and indirect land-use changes are investigated (see also figure 9):

- Run 1 shows mowing grassland as reference land-use with an emission factor of 84 kg CO_2 eq./ha (McCormack *et al.* 2000; Mortimer *et al.* 2001). It is assumed that the animal feed hay normally produced on this grassland with a yield of 5 tdm/ha per year, is replaced by soybean meal. The gross energy value (dry basis) of hay is 4.5 Kcal/g and for soybean meal 5.5 Kcal/g (WorldBank 1986). The emission factor of soybean meal use, as output from the crushing process (including the cultivation of soybeans) is 302 kg CO_2

eq. /ton product (JEC 2007). The LVH content of soybean meal is 19 GJ/t (Hamelinck *et al.* 2008);

- Run 2 shows rotational set-aside land' as reference land-use. The energy use is 922 MJ/ha, equivalent to 25.8 l/ha of diesel fuel, applied for the maintenance of set-aside land (Woods *et al.* 2005). This results in an emission factor of 94 kg CO_2 eq./ha. There are no extra GHG emissions from indirect land-use;
- Run 3 shows 'crop production from rapeseed' as reference land-use. Input data are used from case study 4 'Biodiesel from rapeseed in the UK.' (see also 5.4). The use of agrochemicals, fuel and machinery results in an emission factor of $18*10^2$ kg CO_2 eq./ha. It is assumed that the rapeseed would have been used for biodiesel production. Its replacements by miscanthus production results in an emission credit for the reference land-use system.

Figure 9: GHG emissions in kg CO_2 eq./GJ_{del} for the biomass energy and reference system for three selected runs*, as calculated for the case study 'Heat from Miscanthus in the UK'.



* Run 1: Mowing grassland, hay replaced by soybean meal, Run 2: Rotational set-aside land, Run 3: Rapeseed production.

The emissions of the reference energy system are 85 kg CO_2 eq./GJ_{del} for all three runs. The emissions from the reference land-use system range from 2 to 5 kg CO_2 eq./GJ_{del}. GHG emissions caused by indirect land-use (leakage effects) range from -51 to 65 kg CO_2 eq./GJ_{del}, resulting in a range of avoided emissions from 13 to 128 kg CO_2 eq./GJ_{del}. This example illustrates that the impact of direct and indirect land-use can contribute largely to the avoided GHG emissions and should therefore be taken into consideration.

5.4. Case study 4: Biodiesel from rapeseed in the UK.

One output is generated in case study 4, which is biodiesel from rapeseed in the UK. When producing biodiesel from rapeseed, several by-products (rapeseed straw, meal, glycerine) are generated as well. Allocating the emissions between the main product and by-products using the multifunctional and subtraction approach is not an appropriate option for this study for reasons mentioned in 3.2.7. The by-products generated make this study suitable to demonstrate the impact of 1) the selected allocation procedure and 2) the selected input data on the calculation of GHG emissions and production costs. In this study allocation plays a role during the production phase (raw rapeseed and straw), logistics (rapeseed oil and meal) and conversion phase (biodiesel and glycerine). The allocation can be based on fixed physical relationships (mass or energy content) or on market price (see also section 3.2.7).

Figure 11 shows the total GHG emissions in kg CO_2 eq./GJ_{del} for four runs using allocation based on price (Run 1-3) and on energy content. Market price data for the main products (raw rapeseed, rapeseed oil and biodiesel) and the by-products (straw, meal and glycerine) are presented in table 8. Table 8 also shows the input data for the biomass resource module of this case study. Energy content values[24] from the main products and by-products are from Hamelinck *et al.* (2008).

The fluctuation of market prices over time from the three by-products straw, meal and glycerine and the three main products raw rapeseed, rapeseed oil and biodiesel, produced during various steps in the bioenergy system, is taken into account by Run 1 to 3. Run 1 is based on original price levels of the produced main products and by-products, as provided in the case study (see also table 8). The second Run shows a 50% increase of the prices for the produced by-products compared to the original price levels. The prices of the main products raw rapeseed, rapeseed oil and biodiesel are similar to Run 1. The third Run assumes a 50% decrease of the prices for the produced main products compared to the original price levels.

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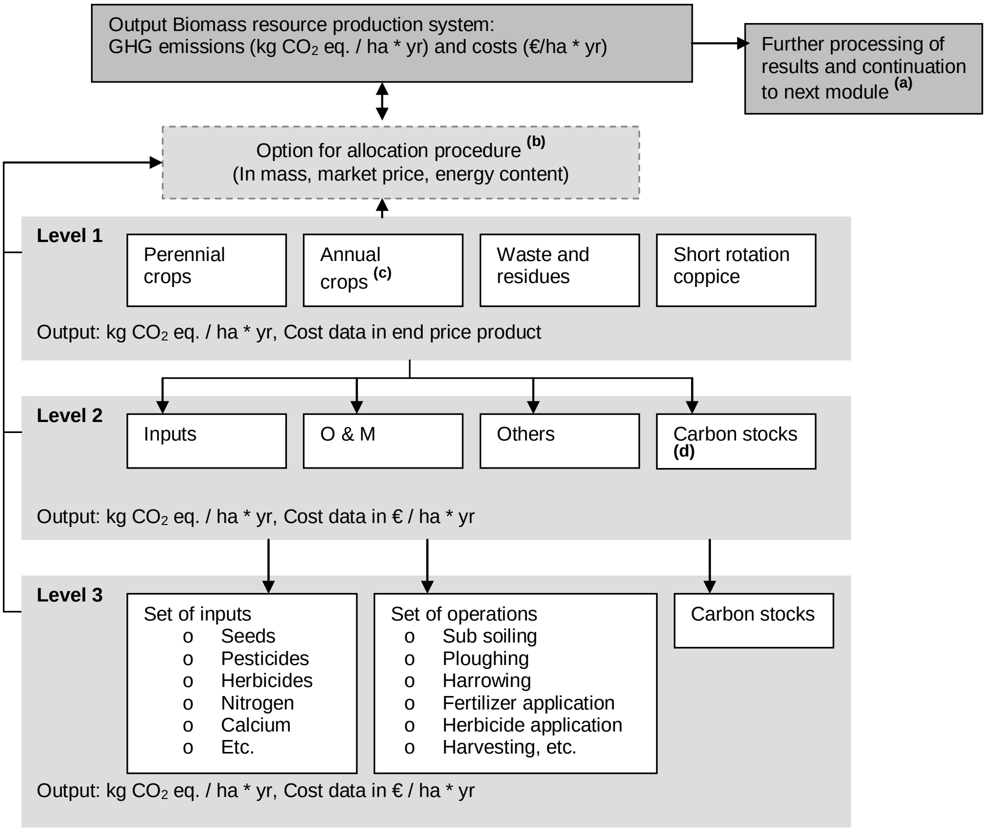
[24] Energy content (LHV) values are: raw rapeseed (22 MJ/kg dm), rapeseed oil (37 MJ/kg dm), biodiesel (37 MJ/kg dm), rapeseed straw (17 MJ/kg dm), rapeseed meal (19 MJ/kg dm) and glycerine (17 MJ/kg dm).

Figure 10: Data aggregation and distinctive data levels for the resource module software tool, presented for case study 4: Biodiesel from rapeseed in the UK.



(a) For functional unit and outputs of model, see section 3.2.1 and section 3.2.1.

(b) The case study ‘Biodiesel from rapeseed in the UK.’ uses an allocation based on price. Allocation takes place in the resource module (185 €/tdm main product, 30 €/tdm by-product), the extraction phase (395 € / tdm main product 103 € / tdm by-product) and in the conversion phase (327 €/tdm main product, 474 € / tdm by-product). This results in a percentage of GHG and costs (i.e. 86% for the biomass resource module), which can be attributed to the biomass chain. The user of the tool can select the allocation procedure and input data.

(c) For an example of the input data for the biomass production module for annual crops: see table 8.

(d) The annual soil loss factor in kg C/ha * yr is an input to calculate the change in carbon pools and can be calculated by using the broken-stick approach (see 3.2.5).

Table 8: Example of parameters used for calculation of GHG emissions for the biomass production module (annual crops) in case study 4: Biodiesel from rapeseed in the UK.*.

Biomass production module

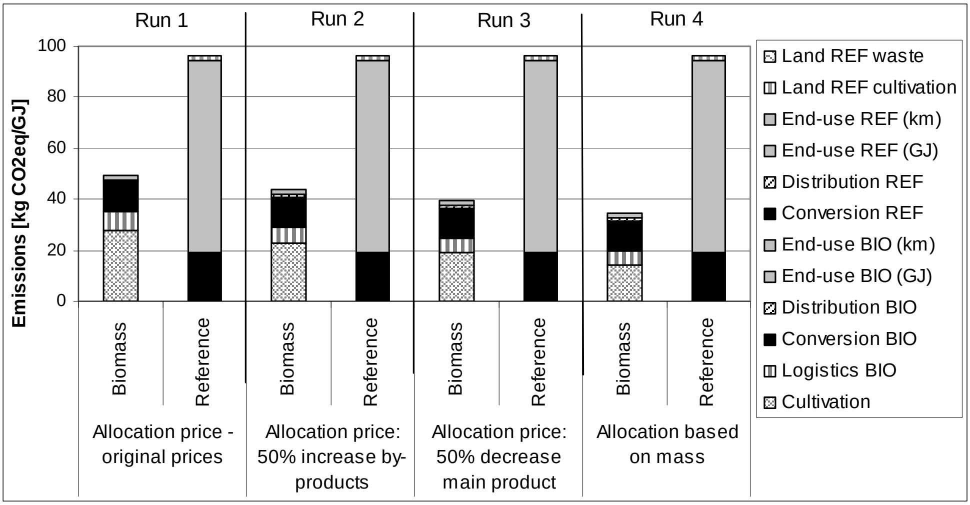
Level 1	
Total GHG emission biomass production	1757 kg CO_2 eq./ha * yr

Level 2	
Fuel	184.5 kg CO_2 eq./ha * yr
Inputs	1530.2 kg CO_2 eq./ha * yr
O&M	42.3 kg CO_2 eq. /ha * yr
Labour	0 kg CO_2 eq. /ha * yr
Land	0 kg CO_2 eq. /ha * yr

Level 3		**kg CO_2**	**kg N_2O**	**kg CH_4**
Diesel Fuel				
For all operations	2385 MJ_{prim}/ha	$8*10^{-2}$/MJ_{del}	$6*10^{-7}$/	$2*10^{-5}$
Machinery			MJ_{del}	/ MJ_{del}
Sub soiling	0.5 hrs/ha * yr - 150 MJ_{prim}/hr	11.1 / hr		
Ploughing	0.7 hrs/ha * yr -208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Harrowing	0.5 hrs/ha * yr -208 MJ_{prim}/hr	16.6 / hr	0/ hr	0/ hr
Sowing	0.4 hrs/ha * yr - 208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Fertilizer application	0.4 hrs/ha * yr - 208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Pesticide application	0.2 hrs/ha * yr - 208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Harvesting	0.9 hrs/ha * yr - 162 MJ_{prim}/hr	12.0 / hr	0/ hr	0/ hr
Maintenance			0/ hr	0/ hr
Sub soiling	$1*10^{-2}$ hrs/ha*yr -150 MJ_{prim}/hr	11.1 / hr		
Ploughing	$2*10^{-2}$ hrs/ha*yr -208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Harrowing	$1*10^{-2}$ hrs/ha*yr -224 MJ_{prim}/hr	16.6 / hr	0/ hr	0/ hr
Sowing	$1*10^{-2}$ hrs/ha*yr -208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Fertilizer application	$1*10^{-2}$ hrs/ha*yr -208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Pesticide application	0 hrs/ha*yr -208 MJ_{prim}/hr	9.6 / hr	0/ hr	0/ hr
Harvesting	$2*10^{-2}$ hrs/ha*yr -162 MJ_{prim}/hr	12.0 / hr	0/ hr	0/ hr
Labour			0/ hr	0/ hr
Labour input	15 hrs/ha * yr	0 / yr		
Sprays			0 / yr	0 / yr
All sprays	2.8 kg/ ha * yr	4.9 / yr		
Other Inputs			0 / yr	0 / yr
Seeds	5 kg/ha * yr	0.3 / yr		
N fertilizer (in kg N)	196 kg/ha * yr	1.9 / yr	0 / yr	0 / yr
P fertilizer (in kg P_2O_5)	50 kg/ha * yr	0.7 / yr	$2*10^{-2}$ / yr	0 / yr
K fertilizer (in kg K_2O)	48 kg/ha * yr	0.5 / yr	0 / yr	0 / yr
Lime (in kg CaO)	19 kg/ha * yr	0.2 / yr	0 / yr	0 / yr
			0 / yr	0 / yr

* This case study was delivered by Sheffield Hallam University (UK). References used are shown in table 3.

Figure 11: GHG estimations per GJ_{del} (in kg CO_2 eq./GJ_{del}) for the biomass energy and reference system for four selected runs for the case study 'Biodiesel from rapeseed in the UK.' (see text).



The prices of the produced by-products are similar to Run 1. Allocation based on energy content (LHV) results in a GHG emission of 35 kg CO_2 eq./GJ_{del} (Run 4) for the biomass energy system. Allocation based on price fluctuates between 39 kg CO_2 eq./GJ_{del} (Run 3) to 50 kg CO_2 eq./GJ_{del} (Run 1) depending on the market prices assumed for the main products raw rapeseed, rapeseed oil and biodiesel and the by-products straw, meal and glycerine.

The results in figure 11 show that the selection of the allocation procedure has an impact on the results and should be clearly defined.

6. Discussion and Conclusions

In the view of current policy developments, there is a growing need to get better insight in the GHG balance of biomass energy projects. Although various international protocols exist on how to calculate GHG emissions, current developments show a strong increase in initiatives developing methodologies and tools to calculate avoided GHG emissions (see section 2). The differences between these initiatives show the difficulty in achieving an internationally accepted methodology and default values to calculate the GHG balances. Although the economic feasibility and cost-effectiveness of bioenergy projects is of importance for both investors and policy-makers, cost-effectiveness of GHG emission reduction using bioenergy is not often considered.

A range of methodological issues should be solved when calculating the GHG balance and cost-effectiveness for biomass energy systems. These are: i) the functional unit, ii) outputs to be taken into account, iii) the system boundary, iv) the reference energy system, v) direct land-use and carbon changes, vi) indirect land-use change, vii) the allocation procedure, viii) timing issues, ix) cost measurements, x) site specificity and xi) uncertainty. This study proposes (see section 3) a unified methodology and approach to deal with each of these issues.

The current strong increase in investments in biomass energy projects in a wide range of regions in the world and the various requirements to demonstrate the GHG balance of biomass energy projects, also related to certification, requires a tool that enables transparent calculations and can be applied independently of the country and biomass energy technology used. The case studies, as presented in section 5, show that this software tool is able to accommodate a wide range of biomass energy systems. Its flexibility allows users from different regions to apply a standard methodology to calculate the cost-effectiveness of GHG emission reductions using different biomass energy systems, which improves the comprehensiveness and consistency in results.

The application of the software tool demonstrates that the core methodological issues, as discussed in section 3, can be accommodated in one tool. The case studies, discussing some of these issues, show that the user has to consider them with care as the choices made concerning these issues influence the results.

Biomass energy systems are developed for a wide range of biomass energy demand and supply options. This results in a large range of desired data input. The software tool is able to accommodate this diversity by allowing the user to make use of aggregated or disaggregated data. The quality of the results depends of course on the accuracy of the data used. Case study 1 on ‘Fuel production in the Netherlands from wood residues in Canada’ illustrates that the total GHG emissions and energy costs per GJ delivered from a detailed data level are respectively -137 kg CO_2 eq./GJ_{del} and 28 €/GJ_{del} (based on substitution) or 25 kg CO_2 eq./GJ_{del} and 32 €/GJ_{del} (based on allocation on energy content). In comparison, total GHG emissions and energy costs per GJ delivered are respectively -137 kg CO_2 eq./GJ_{del} and 12 €/GJ_{del} (based on substitution) or 25 kg CO_2 eq./GJ_{del} and 21 €/GJ_{del} (based on allocation on energy content) when using aggregated data. This difference (especially in costs) can be significant for investors, policy makers and other stakeholders. As more accurate input data will provide more accurate results, it is essential that the user is confident with the quality and appropriateness of the data used. The manual of this software tool (Dam *et al.* 2004b) gives further recommendations on this issue.

Case study 2 on ‘Combustion of forest processing residues under Finnish/Swedish conditions’ demonstrates that the selection of the reference system is important illustrating that the change from a current (2000) to more advanced technology (2020) lowers emissions from the bioenergy system from 15 to 10 kg CO_2 eq./GJ_{del} (sum of heat and electricity) while energy costs are more or less equivalent (7.6 versus 7.5 €/GJ_{del}).

The discussion whether and how to include indirect land-use change in the methodology to calculate GHG balances is currently ongoing. The case study ‘Heat from Miscanthus in the UK’ shows that the impact of assumptions on land-use changes can be large, illustrated by avoided GHG emissions ranging from 13 to 128 kg CO_2 eq./GJ_{del} depending on the reference land-use system assumed. Included references are mowing grassland, rotational set-aside land and crop production from rapeseed. This case study shows that the performance of a biomass energy system is site and time specific.

There is no general procedure to allocate the GHG emissions and costs to the main and by-products that can be accepted under all circumstances. Allocation using the multifunctional or subtraction approaches is preferred but has its limitations. The choice for allocation based on mass or energy content or market price of the different products should be taken with care as it can have a big influence on the outcomes. This is illustrated by Case study 4 ‘Biodiesel from rapeseed in the UK’, showing a variation of 35 to 50 kg CO_2 eq./GJ_{del} depending on the selected procedure and the underlying assumptions. Allocation based on energy content, which is currently (beginning 2009) proposed by the European Commission, is less sensitive for the variability in input parameters and underlying assumptions than allocation based on market price.

Based on the results of this study, the following conclusions are drawn:

- As outputs of GHG balances and costs can differ largely in space and time, site specific and disaggregated analyses are preferred;
- Data collection and the development of consistent databases are needed to keep track of the benefits and impacts of biomass energy production and trade from exporting regions, especially in developing countries. Data availability for greenhouse gas and cost calculations is often more limited in developing countries and the development of sufficient datasets, with a focus on the promising biomass producing regions, is highly desired;
- Including the cost-effectiveness of GHG emission reductions achieved by biomass energy systems will help decision makers to prioritize investments among available mitigation options and economic developments;
- The software tool can be useful for policy makers, market parties and certifying bodies, if appropriately used, to compare and screen GHG emission reductions and expected costs so as to further improve biomass energy systems and its technologies. For future steps, the user friendliness of the tool can be improved by the development of a user interface and the placement of the software tool on internet.

The complexity of biomass energy systems and the wide diversity of sources and geographical regions make regionally specific analyses desirable based on a standardized methodology. Therefore, reaching international agreement on both a detailed methodology and the data used for the calculations is important. Whether default values in the software tool are presented to the user as conservative, typical, or best practice values – or in a range – requires in this context extra attention.

Acknowledgements

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Chapter 7: Large-scale bioenergy production from soybeans and switchgrass in Argentina - Environmental and socio-economic impacts on a regional level[25]

Abstract

The feasibility of deploying a socio-economic and environmental impact analysis for large-scale bioenergy production on a regional level is analyzed, based on a set of defined criteria and indicators. The analysis is done for the La Pampa province in Argentina. The case study results in conclusions in how far the criteria can be verified ex ante based on available methodologies and data sources. The impacts are analyzed for two bioenergy chains (soybeans and switchgrass) for a set of defined land-use scenarios. The carbon stock change for switchgrass ranges from 0.2-1.2 ton C/ha per year and for soybean from -1.2 to 0 ton C/ha per year, depending on the scenario. The GHG emission reduction ranges from 88 to133% for the switchgrass bioenergy chain (replacing coal or natural gas) and from 16 to 94% for the soybean bioenergy chain (replacing fossil fuel) for various lifetime periods. The annual soil loss, compared to the reference land-use system is 2 to 10 ton/ha for the soybean bioenergy chain and 1 to 2 ton/ha for the switchgrass bioenergy chain. In total, nine sustainability principles are analyzed. In the case of switchgrass, most environmental benefits can be achieved when produced on suitable land of abandoned cropland. Soybean production for bioenergy shows a good overall sustainability performance if produced on abandoned cropland. The production of switchgrass on degraded grassland shows socio-economic and environmental benefits, which is not the case for soybean production. The production of bioenergy production on non-degraded grassland is not preferred. It is concluded that the scenario approach enables understanding of the complexity of the bioenergy chain and the underlying factors influencing the sustainability principles. It is difficult to give ex ante a final conclusion whether a bioenergy chain is sustainable or not as this depends not only on the previous land-use system but also on other factors as the selection of the bioenergy crop, the suitable agroecological zone and the agricultural management system applied. The results also imply that it is possible to steer for a large part the sustainability performance of a bioenergy chain during project development and implementation. Land-use planning plays a key role in this process.

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1. Introduction

Biomass is expected to play an important role in the future supply of modern energy (WEA 2000; OECD/IEA 2008a). To ensure that bioenergy is produced in a responsible manner, setting principles[26] (Lewandowski *et al.* 2006) and establishing certification schemes are possible strategies (Dam *et al.* 2008). Recently, national governments as the UK, the Netherlands and Germany and the European Commission have taken initiatives to develop sustainability principles and biomass certification systems. The need to ensure sustainable biomass production through proper procedures or policy tools is also acknowledged by various international bodies as the G8 Bioenergy Partnership, the WTO, the UNCTAD biofuels initiative and the FAO. In addition, various NGOs and companies have initiated pilot projects, policy papers or initiatives like the Roundtable on Sustainable Biofuels (RSB) to work on a more sustainable bioenergy production chain. Between them, there seems to be general agreement that it is important to include economic, social and environmental criteria when developing a certification system for sustainable bioenergy production.

Concrete initiatives to translate these criteria into operational indicators are, however, limited. Also, many uncertainties on the feasibility and implementation of sustainability principles remain (Dam *et al.* 2008). There are content matters to resolve, like the design of criteria and indicators in accordance with regional requirements, the avoidance of leakage effects, and the influence of land-use dynamics on the outcomes of sustainability assessments (Dam *et al.* 2008). Consequently, new standardized methodologies are needed to measure and valuate impacts of bioenergy production (Smeets *et al.* 2008). The complexity involved is enhanced by the large number of biomass resources, agricultural production systems, regional settings and conversion routes.

The first objective of this study is to get insights in the feasibility of deploying *ex ante* a socio-economic and environmental impact analysis on a regional level for large-scale bioenergy production, based on a set of defined principles and criteria. By implementing this analysis for a defined case study, conclusions can be drawn about in how far the criteria can be measured with indicators, based on available methodologies and data sources within a limited time period. The second objective of this study is to analyze the socio-economic and environmental performance of two selected bioenergy chains on a regional level for a defined set of land-use scenarios and also to get insight in possible consequences of sustainability principles for the potential of biomass energy and its economic performance

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[26] An important element of a certification system is the definition of standards or principles. Principles define the aim of certification and describe the requirements to be fulfilled for certification. Sustainability principles (e.g. the production of biomass must contribute towards the social well-being of the local population) are combined with sets of criteria (e.g. no negative effects on human right) that describe the requirements a sustainable product has to fulfil. To use criteria for the formulation of a certification standard they have to be operationalized and measurable. For this purpose, indicators are used. Indicators are measurable parameters (e.g. recognition of Universal Declaration of Human Rights).

on the short and longer term. In this study, a scenario is used as an imagined possible future situation placed in a defined time set.

2. The bioenergy chains and scenario parameters

The impact analysis builds on the results from part A of this paper (see chapter 3 of this thesis), which evaluated for the La Pampa province in Argentina the potential and cost performance of two defined chains to produce bioenergy for local use or for export. The two chains are summarized here:

I. Switchgrass is cultivated in the La Pampa province and, after harvesting, transported as bales by truck to the closest pellet plant. Pellets are exported by truck or train to the harbour Bahiá Blanca. From there, the pellets are shipped to Rotterdam in Europe to be converted into electricity in a power plant in the Netherlands or, alternatively, used in the local market in Argentina (Dam *et al.* 2008c).
II. Soybean is cultivated in the La Pampa province and, after harvesting, transported by truck to Junín for crude soybean oil extraction. After extraction, the crude soybean oil is transported by truck or train to Rosario to be converted to biodiesel. The (end) - product is exported by ship to Rotterdam or used in the local market. Alternatively, the crude soybean oil is converted into biodiesel in Rotterdam. (Dam *et al.* 2008c).

Calculations are done for the potential and costs of the bioenergy chains for the short and long term (2030) for the La Pampa province. Calculations for the current situation (CUR) present the performance of the bioenergy chains on the short term. A set of scenarios present the performance of the bioenergy chains on the long term (2030). Scenario A assumes a continuation of the current economic development. Scenarios B and C reflect a stronger economic development. Between them, scenario C is more export oriented while scenario B has a more environmental friendly orientation. Scenario C is also more open for competition and the application of advanced technologies. Quantitative scenario parameters that are relevant for assessing the sustainability performance of the bioenergy chains are shown in table 1. More information on the agricultural production systems and cost parameters assumed for the different scenarios can be found in Dam *et al.* (2008c) and USDA (2007).

Table 1: Scenario parameters for the current situation (CUR) and for scenarios A, B and C (for the year 2030) on suitable (S) and marginally suitable land (mS), relevant to assess the socio-economic and environmental impact and performance of soybean and switchgrass production in La Pampa province in Argentina.

	CUR		A2030		B2030		C2030	
	S	mS	S	mS	S	mS	S	mS
Reference land-use	Crop production (C)	Degraded grassland (D)	Crop production (C)	Degraded grassland (D)	Non-degraded grassland (G)	Degraded grassland (D)	Crop production (C)	Degraded grassland (D)
Available land for soybean bioenergy production in 10^3 ha	236	61	125	61	238	64	122	45
Available land for switchgrass bioenergy production in 10^3 ha	347	212	161	212	630	171	756	214
Feed conversion efficiency and division feed crops	Pastoral livestock production continues to be important.		Pastoral livestock production continues to be important.		Increase of mixed/landless production system		Highly intensified livestock management system	
Agricultural production system Switchgrass	- Intermediate agricultural production system. - No irrigation. - Lifetime plantation: 15 years - No-tillage system		- Intermediate agricultural production system. - No irrigation. - Lifetime plantation: 15 years - No-tillage system		- Mixed agricultural production system - No irrigation. - Lifetime plantation: 20 years - No-tillage system		- High input agricultural production system - No irrigation - Lifetime plantation:17.5 years - No-tillage system	
Agricultural production system Soybean	Direct seeding, intermediate input system, reduced tillage		Conventional cropping system (no direct seeding), reduced tillage		Direct seeding in combination with conservation measures, no tillage		Direct seeding, advanced technologies to improve efficiency, reduced tillage	
Yield soybean in tdm//ha	2.1	1.3	3.1	1.9	3.2	1	3.5	2.3
Yield switchgrass in tdm/ha	10	5	13.2	6.6	14.6	7.3	16.7	8.3
Environmental and economic priorities	Average environmental awareness due to economic constraints. Protection of the internal market and local producers.		Average environmental awareness due to economic constraints. Protection of the internal market and local producers.		High environmental awareness. Diversification of landscape and renewable energy sources is promoted.		Low to average environmental awareness. Economic growth is priority. Competition on the internal market.	
Technology level applied	Processing plants (e.g. pellet plant) are used on a small scale.		Processing plants are used on a small scale.		Making use of larger processing plants available in Latin American region.		Up-scaling of processing plants. Making use of state-of-the-art technology.	
Land rent switchgrass[27] (US$/ha/yr)	130	110	195	110	124	121	111	110
Land rent soybean[3] (US$/ha/yr)	150	130	225	163	150	130	225	195

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[27] Current land prices in Argentina are high, also in comparison with other countries (USDA 2007). Land rent fluctuates largely in Argentina per region and per land-use. The future land rents are based on the availability of S and mS land for bioenergy production and on the expected price trends for switchgrass and soybean and their end-products, see also Dam et al. (2008b)

3. Main characteristics of the selected region

La Pampa is a province of Argentina located in the centre of the country (INTA-Anguil 2008), having an area of $134*10^5$ ha (LaPampa 2006), covered for 7% with annual crops (i.e. wheat, sunflower, maize and soybean), mainly cultivated in the east of the province. More to the west, the land is mainly used for fodder and pasture. The largest part is, however, used for extensive grazing. The agricultural sector contributed 19% to the total GDP of La Pampa in 2006 (Verna *et al.* 2007).The contribution of the livestock sector to this figure was 54% in 2006. A further description of the economic characteristics of La Pampa province is given in Dam *et al.* (2008c).

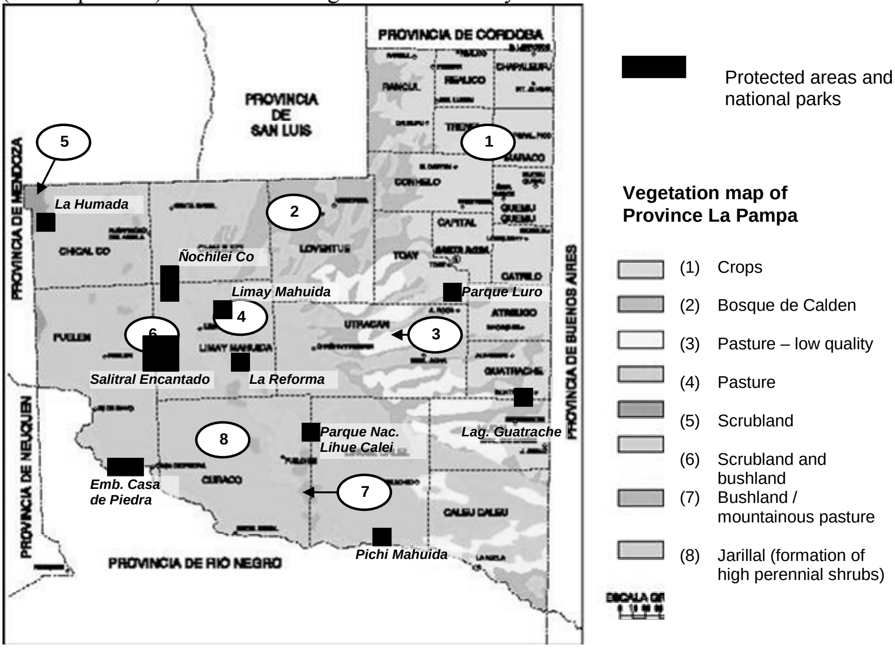
3.1. Biodiversity, flora and fauna in La Pampa province

Approximately 70% of La Pampa province is covered by natural vegetation and 30% by annual and perennial crops. The province is characterised by four main vegetation types: Bosque de Caldén, natural pasture lands, shrubs and the Matorral region. The ‘Bosque de Caldén’, having 2-3 layers of vegetation (trees, shrubs and grasses), is a unique ecosystem in the country. The system is also important because of protection against erosion and its forest production value (LaPampa 2008).

The primary economic activity in the ‘Bosque de Caldén’ is cattle production using natural vegetation. There are a few cultivated pastures or annual crop areas (Busso 1997). The total surface of the ‘Bosque de Caldén’ has diminished significantly in the last few decades because of extraction of trees, expansion of the agricultural frontier forest fires and inappropriate management of nature. Nowadays, the ‘Bosque de Caldén’ has a total area of around $2870*10^3$ ha in Argentina, from which around $750*10^3$ ha is suitable for sustainable cattle production or wood logging. The average annual rate of deforestation is around 2700 ha. The average amount of degraded land is around $300*10^3$ ha (LaPampa 2008). In the period 1998-2002, the loss of natural grasslands was around 3.6% in La Pampa (Bilenca 2005) but area losses of more than 10% are mentioned for other regions in Argentina. Forest exploitation combined with livestock intensification has led to degradation of natural grasslands, resulting in a general decrease of species with a high forage value as well as replacement to species with a lower or no forage value. This process, if continued, can result in severe erosion (CREA 2008).

The province has six protected areas, covering an area of over $36*10^3$ ha (see map 1), and the National Park Lihuel Cahel (LaPampa 2008). In Argentina 15% of the natural grasslands with a High Conservation Value (HCV) is protected compared to 4,6% of the natural temporary grasslands worldwide (FVSA 2007).

Map 1: Protected areas in La Pampa province based on (Busso 1997) combined with vegetation map (LaPampa 2008). The Caldenal region is indicated by number 2.

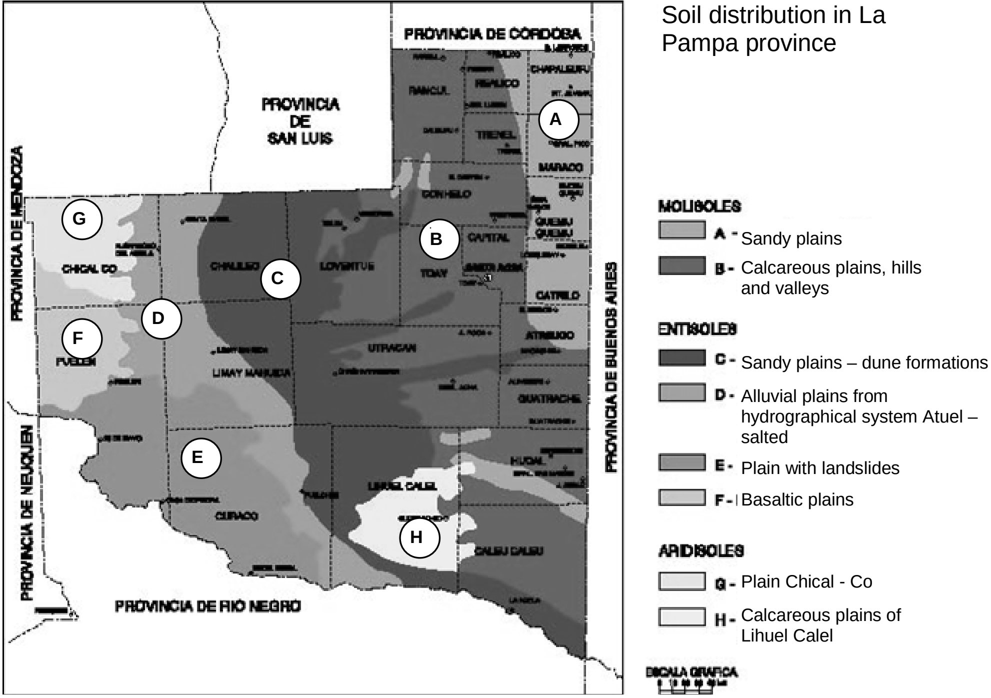


The protected areas in La Pampa province cover only a small part of its total area (see map 1). The 'Bosque de Caldén' is protected mainly by Provincial Law prohibiting extraction of native forest species in this area (DRN 2008). Other relevant legislations are Laws on the protection of areas (LaPampa 1995) and native forests (Congreso 2007).

3.2. Soil types in La Pampa province

The prevailing soil types in La Pampa province can be divided into semi-arid and arid soils. The soil profiles are characterised by sandy to loamy-sandy soils with little to average organic matter content and moderate to high sensitivity for wind and water erosion. This sensitivity increases to the west where rainfall is less (LaPampa 2008). The so-called Molisols, also classified as Kastanozem soil (Moscatelli *et al.* 2000), cover $66*10^5$ ha of the province. Within the Molisols, a further differentiation can be made into soil type A and B (see map 2). The land-use on soil type A, the '*sandy plain*', is characterised by a mix of agricultural land-use. Crop production dominates over cattle production. Although these lands have a low sensitivity to erosion, there are signs of severe erosion in the past. The rest of the *sandy plain* is represented by less developed soils, sensitive for wind erosion, with good permeability and average fertility. In these areas, agricultural land-use is mixed. Cattle dominates over agriculture (LaPampa 2008). The second soil type B is the '*calcareous plains, hills and valleys*'. These soils are drier than the soils in the arid plains and developed from mid-sandy to sandy sediments. The majority of the soils present a gradient of average erosion because of its characteristics (limestone content, drier) and because of over-use from grazing. Several locations show severe erosion (LaPampa 2008). The province has introduced a program 30 to 40 years ago to promote the establishment of Weeping Lovegrass to improve the quality of the soil in eroded areas. This is an area of around $3*10^5$ ha (INDEC 2002). A disadvantage of this grass species is, however, its low forage quality (Petruzzi 2008a).

Map 2: Distribution of the soils in La Pampa province (LaPampa 2008).



3.3. Water resources in La Pampa province

The province has limited superficial water sources. The Rio Colorado, with a basin of $70*10^5$ ha, forms the southern border of the province. The second main river (Salado-Chadileuvú) goes from north to south in the west of the province and is characterised by various tributaries and lakes (LaPampa 2008). The water quantity of the latter is deteriorating due to overuse of the water upriver in its side rivers. There are some lakes in the province. A drying process is noticed at most of the lakes and some of them have disappeared. In the west of the province, some salty lakes can be found (LaPampa 2008). Also, the continental climate of the region with a wide thermic range promotes evapotranspiration, with negative results for the water balance in the soil, especially in the west. There are eight aquifers in the region with an area ranging from $7*10^3$ to $160*10^3$ ha (LaPampa 2008). Most of them are located in the east-centre of the province and are replenished during periods of rain. The hydrochemical composition of the water varies within and per aquifer, depending on the hydrogeology of the area (Giai *et al.* 2008).

Consequently, potable water is available in some of the aquifers (LaPampa 2008). The water in other aquifers shows, however, higher salinity levels than allowed for human consumption (Giai *et al.* 2008).

3.4. Climatic characteristics of the region

Average annual temperatures in La Pampa province range from 16 ºC in the north-west to 14 ºC in the west. Average temperatures range between 7-8 ºC in July to 22-24 ºC in January (INTA-Anguil 2002). In the last 70 years, the climatic pattern in La Pampa province is changing to a higher variability of rainfalls, lower maximum and higher minimum temperatures and a reduction of frost periods. This situation of inter-annual instability is expected to increase in the future (Stritzler *et al.* 2007).

The centre of La Pampa province receives around 500 mm of rain a year, diminishing towards the west. Low humidity results in high contrasts of temperature between day and night. Most rain falls in the months September to November and February to March (INTA-RIAP 2008). There is limited rainfall from May to August. Although the precipitation is low in winter time, it is usually adequate (due to low temperatures) for agriculture although it can be too limited for double-cropping systems. There are intermittent shortages of water in the summer months from two to six weeks, especially in January and February, which can be devastating to summer crops (Solbrig 1997).

3.5. Socio-economic characteristics of the region

The average population density in the province increased in the period 2001-2006 from 2.1 to 2.27 habitants (hab.) per km^2. The eastern part of the province (around 3 hab./km^2) is more densely populated. More to the west, the average population density is 1.3 hab./km^2. The rural population represents 23% of the total population in 2001 compared to 35% in 1991 showing a tendency towards urbanization (Verner 2005).

The unemployment rate in La Pampa province was on average 11% in the 1st semester of 2006, which is in line with the average unemployment rate in Argentina for that year (INDEC 2006). The underemployment rate[28] in La Pampa province in that period was 7.5% (INDEC 2006). According to Verner,(2005) only 20% of the household heads in dispersed rural areas are engaged in the formal labour market while 80% is engaged in the informal labour market. In 2003, more than 75% of the extreme poor households cited agriculture as their primary form of employment. The census from 2001 shows that in La Pampa province 9% of the interviewed private households have insufficient means to facilitate their basic needs (Verna *et al.* 2007).

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[28] Underemployment rate: proportion of employed persons who expressed desire to have additional hours of work in their present job or in an additional job or to have a new job with longer working hours. An additional 2.1% of the proportion of employed persons in La Pampa province is underemployed but have no desire for additional hours of work.

The total number of agricultural units in La Pampa province has decreased with more than 10% in the period 1998-2002. The number of small agricultural units has decreased while the amount of larger (> 500 ha) agricultural units has increased (Iturrioz 2005). The dominating size of agricultural units for cultivated land was 200-1500 ha (52%) in the period 1998-2002, while 12% had a surface area of $5*10^3$ to $20*10^3$ ha. For perennial fodder, 37% of the agricultural units have a surface area of 200-1500 ha and 21% has a surface area of $5*10^3$ to $20*10^3$ ha (Iturrioz 2005). The most common form of agricultural land ownership in La Pampa province is private ownership (64%), followed by land tenure (19%) and other forms of tenureship. Agricultural units are mainly privately owned (59%), followed by different forms of cooperatives (39%). A small percentage of the agricultural units (2%) is owned by governmental organizations or NGOs (Petruzzi 2008a; INDEC 2006).

4. Environmental and socio-economic performance of bioenergy chains

As already indicated, there are various initiatives to develop principles, criteria and indicators to measure and evaluate the environmental and socio-economic performance of bioenergy chains (Dam *et al.* 2008). In this study, the performance will be analyzed based on a testing framework developed by the Dutch project group ‘sustainable production of biomass’ (Cramer *et al.* 2007). This framework is at this moment one of the most extended ones, covering most of the principles also proposed in other initiatives. The principles used in this framework, nine in total, are shown in table 2. They are discussed and applied for La Pampa province in the following sections. At the end of each section, a conclusion is given about the relative performance of the bioenergy chains for the principle discussed.

Table 2: Summary of the Dutch framework for sustainability principles: The corresponding criteria, indicators and minimum requirements defined per criterion are not reported here. For details: see (Cramer *et al.* 2007)

	Principles
1	Biomass production must not be at expense of important carbon sinks in vegetation and in soil.
2	The GHG balance of the production chain and application of the biomass must be positive
3	Biomass production for energy must not endanger food supply and local biomass applications
4	Biomass production must not affect protected or vulnerable biodiversity
5	Soil and soil quality must be retained or even improved.
6	Ground and surface water must not be depleted and its quality must be maintained or improved.
7	In the production and processing of biomass the air quality must be maintained or improved.
8	The production of biomass must contribute towards local prosperity.
9	Biomass production must contribute towards social well-being of employees and local population.

4.1. Principle 1: Biomass production not at expense of carbon sinks

This principle states that the possible increase of GHG emissions, as a result of soil carbon changes due to the cultivation of areas for biomass energy production, must be neutralized by the reduction of GHG emissions from the biomass production chain. Areas in which the loss of above-ground carbon storage cannot be recovered in a ten year period of biomass productivity as well as areas with great risk of significant soil carbon losses are excluded (Cramer *et al.* 2007). Annual carbon stock changes are calculated according to the IPCC approach (IGES 2006) as recommended by Voet *et al.* (2008) and Hamelinck *et al.* (2008). The IPCC approach uses a three-tier approach distinguished by its required data input. Due to limited availability of local data on soil carbon stocks, the tier 1 approach (basic data inventory) is used for this study. The carbon stock change for a land-use category is defined as the sum of changes from above-ground biomass, below-ground biomass, dead organic matter (DOM), soils and harvested wood products. The latter is not relevant for the selected case studies. DOM stocks are zero for non-forest land-use categories under Tier 1 (IGES 2006). The annual carbon stock change, based on an average Molisol (see also table 3), is therefore (IGES 2006):

Formula (1) $\Delta Clu = \Delta Cab + \Delta Cbb + \Delta Cso$

Where:
ΔClu = the total carbon stock changes
ΔCab = carbon stock change in above-ground biomass
ΔCbb = carbon stock change in below-ground biomass
ΔCso = carbon stock change in soils

ΔCso is calculated with formula 2.24 from IPCC[29]. The net flux for inorganic C stocks is zero under the Tier 1 approach (IGES 2006). Drained organic soils (peat derived soils) are not present in the selected region and annual changes in carbon stocks are therefore zero. The annual change in carbon stocks in below-ground and above-ground biomass is based on the stock-difference method (IGES 2006). The available above-ground biomass is the sum of total above-ground biomass minus the harvested yield and the removal of a percentage of the residues. The remaining amount of residues is available for decay and to build up soil organic matter. The following formula[30] is used to calculate the available above-ground biomass:

Formula (2): $$G\ (above) = \left\{ \frac{Ycalc}{HI} - (Ycalc) \right\} * F_{man}$$

Where:
G (above) = Available above-ground biomass in tdm/ha*yr
Ycalc = calculated yield in tdm/ha*yr
HI = Harvest index[31] (dimensionless)
F_{man} = management factor in % for leaving residues on ground (dimensionless)

The calculated bioenergy crop yields are shown in table 1 (Dam *et al.* 2008c). It is assumed that the plant, cultivated on the reference land-use ‘cropland’ (C), is soybeans.

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[29] $\Delta C_{soils} = \Delta C_{mineral} - L_{organic} + \Delta C_{inorganic}$, where Δ is annual change, C_{soils} is carbon stocks in soils, $C_{mineral}$ is organic carbon stocks in mineral soils, $L_{organic}$ is annual loss of carbon from drained organic soils and $C_{inorganic}$ is inorganic carbon stocks from soils.

[30] IPCC provides default values for annual crops and forestry to calculate $G_{(above)}$. As default values for switchgrass (and perennial grasses in general) are not available, own calculated data are used.

[31] Harvest index is the ratio of yield biomass to the total cumulative biomass at harvest.

Corresponding yields are shown in table 1 for the current situation and for scenarios A, B and C for 2030. The yield levels for the reference land-use 'non-degraded grassland' (G) correspond with the yield levels for switchgrass. It is assumed that the yield levels for the reference land-use 'degraded grassland' (D) are 50% of the yield levels for non-degraded grassland. The data sources used for the calculation of formula 1 and 2 are shown in table 3 (IGES 2006; Fischer *et al.* 2000; Tolley-Henry *et al.* 1986).

A key pre-condition in the assessment of the potential of bioenergy in La Pampa province, under various scenarios, is that food and feed demand is met (Dam *et al.* 2008c). Leakage is thus explicitly avoided in the scenarios. A crucial point in the current debate around the net GHG impact of biofuels is induced land-use changes. Recent studies (Fargione 2008; Searchinger 2008) have debated that including GHG emissions from indirect land-use could drastically worsen or even revert the GHG emission balance of energy crop production mainly due to soil carbon stock changes.

How to include GHG emissions from indirect land-use changes in the calculation of GHG balances and soil carbon stocks is still under debate (Gnansounou 2008). One proposal (Fehrenbach *et al.* 2008a) is to make use of a so-called "risk adder" as not every increase of biomass leads automatically to indirect land-use change.

The risk adder (or a range) therefore describes an average share factor (in %), which is adopted for land-use change to get an indication of its impact on total carbon stock changes. Assume, for example, that half of the total biomass production (100 ha) is produced on abandoned cropland (50 ha) and the other half is produced on areas inducing displacement (50 ha). The risk adder in this example is 50%, which means that the carbon stock change from indirect land-use change is calculated for 50% (50 ha) of the total land area. In this study, two alternative scenarios (ALT) are defined to look at the consequences of leakage on the carbon stock changes based on the risk adder approach (Fehrenbach *et al.* 2008a), using a risk adder of 25% and 50% respectively. The (ALT) scenarios assume that the production of the previous land-use system, cropland, in (CUR-S-C) is partly displaced to an area not yet in use, which is natural grassland. To calculate the carbon stock changes due to this indirect land-use change, it is assumed that the yield for natural grasslands with limited management is 80% of the yield for non-degraded grassland.

Table 3: Default values used for calculating carbon stock changes based on IGES (2006) Default values are based on Fischer *et al.* (2000) if * is indicated in the table and calculated based on Tolley-Henry *et al.* (1986) if ** is indicated in the table.

Indicator	Default value
Climatic region	Warm, temperate, dry
Soil type	HAC soils (including Molisols)
Ecological zone	Subtropical steppe
Time dependence period	20 years (in line with rotation period switchgrass scenario B)
Management practice reference land-use on suitable land (S) area	CUR: Cropland, intermediate input, reduced tillage (C) Scenario A: Cropland, intermediate input, reduced tillage (C) Scenario B: non-degraded grassland (G) Scenario C: Cropland, high input, reduced tillage (C)
Management practice reference land-use on marginally suitable land (mS) area	CUR: degraded grassland, unimproved (D) Scenario A: degraded grassland, unimproved (D) Scenario B: degraded grassland, unimproved (D) Scenario C: degraded grassland, unimproved (D)
Management practice current soybean biomass chain (for S and mS land)	CUR: Cropland, intermediate input, reduced tillage Scenario A: Cropland, intermediate input, reduced tillage Scenario B: Cropland, intermediate input, no tillage Scenario C: Cropland, high input, reduced tillage
Management practice current Switchgrass biomass chain (for S and mS land)	CUR: Grassland, non-degraded Scenario A: Grassland, non-degraded Scenario B: Improved grassland Scenario C: Improved grassland
Carbon fraction (CF) annual crops	0.47 t C / tdm
Carbon fraction (CF) grassland	0.5 t C / t dm
Management factor $F_{(man)}$	50%
Harvest Index grassland systems*	0.5 for intermediate input system 0.65 for high input system
Harvest Index soybeans*	0.23 for intermediate input system 0.30 for high input system
Below-ground / total biomass grassland	74%
Below-ground / total biomass soybeans**	≈ 12%
Stock change factor land-use (F_{lu})	0.58 +/- 61% for cropland 1 for grassland (for all permanent grassland)
Stock change factor for management regime (F_{mg})	1.09 for reduced tillage cropland system 1.17 for no tillage cropland system 0.97 for moderately degraded grassland 1 for non-degraded grassland 1.17 for improved grassland
Stock change factor for input organic matter (F_i)	1 for medium input cropland 1.37 for high input cropland 1 for medium input grassland
Defined area	Calculated for 1 ha

4.1.1. Carbon stock changes in the switchgrass bioenergy chain

The carbon stock changes for the switchgrass production system are calculated in ton C/ha * yr with a lifetime period of 20 years for the different scenarios. Figure 1 shows that the current situation and scenarios A, B and C have a carbon benefit for switchgrass production compared to the reference land-use system ranging from 0.2 to 1.2 ton C/ha/year. The scenarios (CUR-mS-D[32], A-mS-D) have the lowest carbon benefits because of lower yields and limited differences with the land-use reference system. The soil carbon changes determine largely the total carbon stock changes (see figure 1) for almost all scenarios, except for (CUR-mS-D, A-mS-D).

The soil carbon stock benefit in scenario B can be explained by the difference in management factor (see table 3) between the reference land-use and the switchgrass production system. Lewandowski *et al.* (2000) confirm the influence of soil carbon on total carbon benefits for switchgrass production after land-use change, mentioning that switchgrass stores a considerable amount of carbon in the soil by increasing the humus content and by the formation of high amounts of subsoil rhizomes. The deep, productive roots of switchgrass cause an increase of the soil organic carbon (SOC) content (Liebig *et al.* 2005). Consequently, switchgrass is a bioenergy crop with the potential to increase soil C sequestration (Lee *et al.* 2007).

Figure 1: Carbon stock changes for switchgrass in current situation and for scenarios A, B and C for year 2030, for different lifetime periods (20, 50 and 100 years) combined with different HI (50 yrs: HI = 0.7-0.75 for switchgrass and 0.3 for soybean, 100 yrs: HI = 0.8-0.85 for switchgrass, 0.4 for soybean.

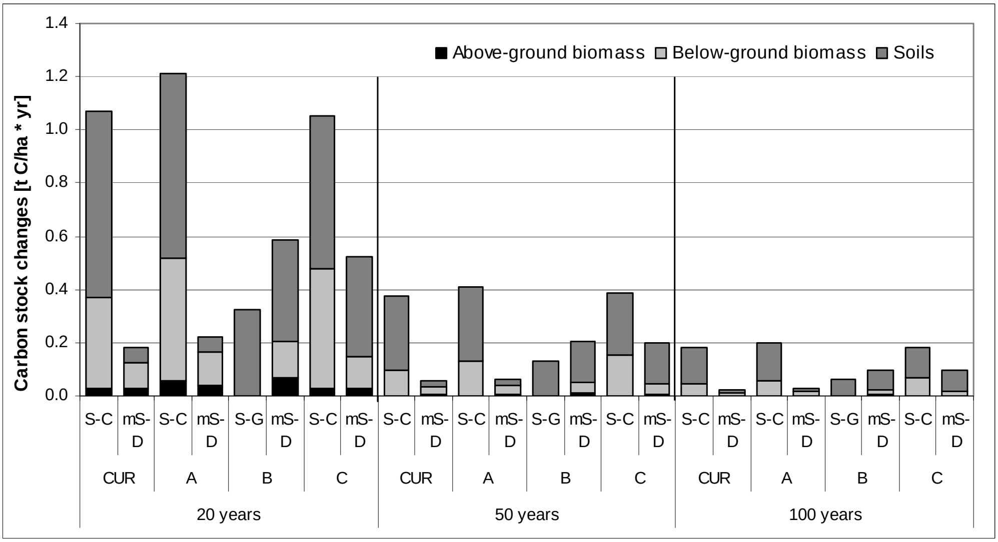

Figure 1 shows that the carbon stock benefit for switchgrass production diminish to lower, although still positive, values when a longer lifetime period is assumed combined with a higher value of the harvest index.

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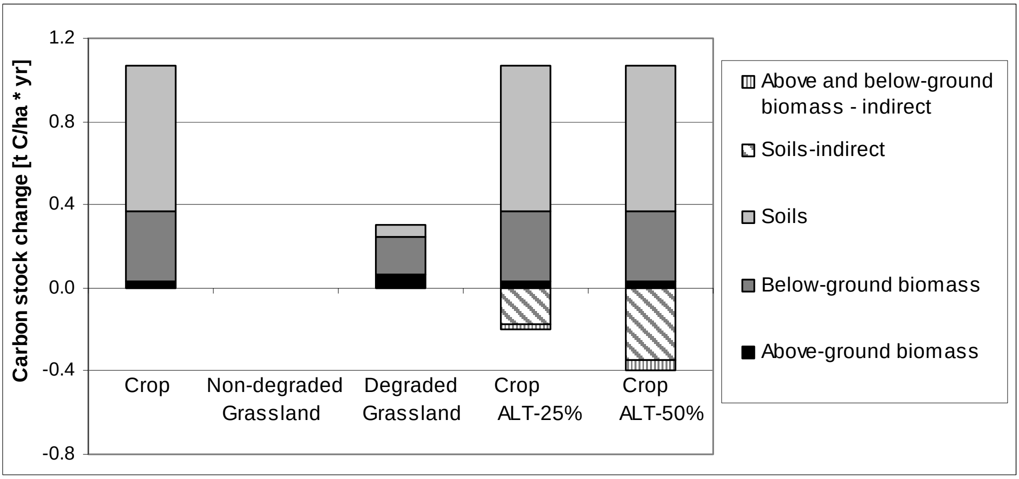
[32] The scenarios are presented by (in this order): i) indicator for scenario or current situation (CUR, A, B, C), ii) their land-use (mS or S land) and iii) their reference land-use (G, D and C). See also table 1.

The influence of different reference land-use systems and indirect land-use is shown in figure 2 for (CUR-S-C). In case Switchgrass production replaces non-degraded grassland, carbon benefits are zero as yields and soil carbon accumulation are assumed to be similar. Most benefits are achieved when cropland is replaced, followed by degraded grassland. Regional data from La Pampa province (Petruzzi 2008b) confirm the IPCC results with field data on root carbon content. The highest SOC content is found on the switchgrass field followed by forest land and cultivated land with root contents of 6760, 5760 and 420 kg/ha respectively. Similar results are found in the USA (Liebig *et al.* 2005; Bullard *et al.* 2001). In Bullard *et al.* (2001), it is estimated that 182 t CO_2/ha is mitigated and 1.8 t CO_2/ha is released by SOC when switchgrass replaces annual arable cropping in the USA. In case switchgrass replaces permanent grassland, no CO_2 is mitigated by SOC and 1.8 t CO_2/ha is released, showing more negative results than the outcomes for scenario (B-S-G). Mind that the results for carbon stock changes with reference land-use 'grasslands' are more positive than the results found by Bullard *et al.* (2001), possibly because this study uses the same yield levels for switchgrass production and for the reference land-use 'grasslands' (see 4.1.1).

Figure 2: Carbon stock changes for switchgrass production in (CUR-S) for different reference land-use systems (crop, non-degraded grassland and degraded grassland) and for the alternative scenarios (ALT), including the effect of indirect land-use change with a risk adder of 25% and 50%, assuming a lifetime period of 20 years.



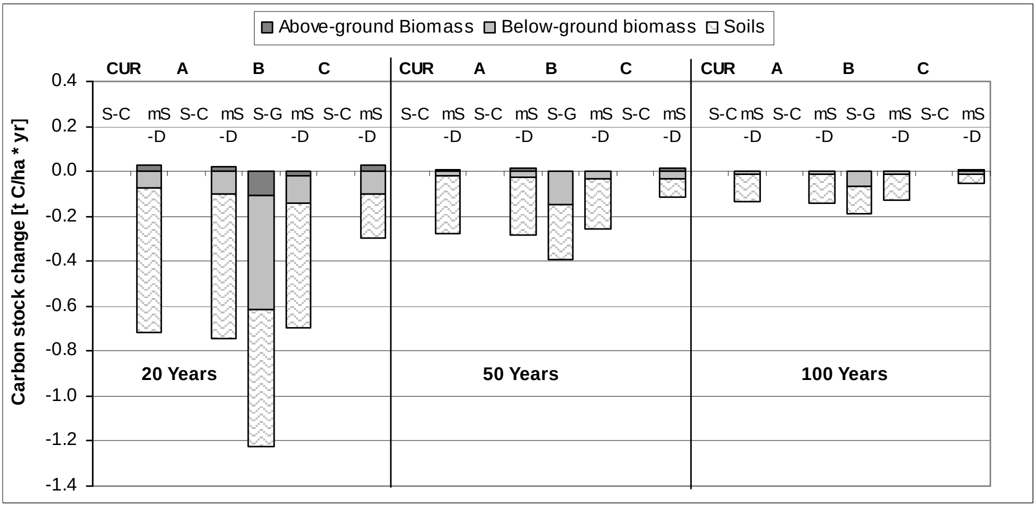
The two alternative scenarios (ALT) in figure 2 show that an indirect land-use change in scenario (CUR-S-C) results in a carbon loss due to changes in soil carbon, as well as the amount of above-ground and below-ground biomass.

Based on the results, a conclusion is given about the relative performance of the switchgrass bioenergy chain for this principle, based on a lifetime period of 20 years. The highest score (++) is for the scenarios with a carbon benefit of 0.6 t C/ha/yr or more within a period of 20 years. This score is achieved when switchgrass is produced on S land replacing abandoned cropland in CUR and in scenarios A and C. Relative high scores (+), with a carbon benefit of more than 0 and less than 0.6 t C/ha/year, are achieved in scenarios where degraded grassland is used for switchgrass production and in scenario (B-S-G).

4.1.2. Carbon changes for the soybean bioenergy chain

The carbon stock changes are also calculated for the soybean production systems assuming a lifetime period of 20 years. The outcomes for the different scenarios show a range of -1.2 to 0 ton C/ha/yr compared to the reference land-use. There are no changes in carbon content when soybean production replaces abandoned cropland. There is a carbon loss when soybean production replaces degraded and especially non-degraded grassland. The decrease in soil carbon can mainly be attributed to the difference in the IPCC default values for land-use (Flu) between grassland and cropland (see table 3).

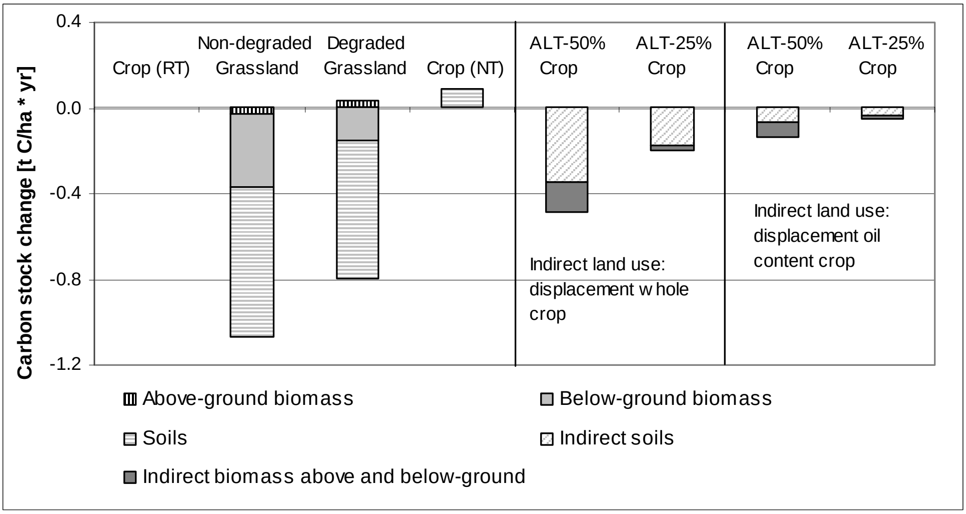
Figure 3: Carbon stock changes in t C/ha per year for soybean for current situation and for scenarios (A, B and C) to 2030 for different lifetime periods (20, 50 and 100 years) combined with different HI (50 yrs: HI = 0.7-0.75 for switchgrass and 0.3 for soybean, 100 yrs: HI = 0.8-0.85 for switchgrass, 0.4 for soybean).



The influence of the management system (Fmg) on soil carbon changes is limited as it is assumed that within one scenario both the reference and biomass production system practice the same kind of management. The negative carbon stock changes for soybean bioenergy production (whole crop) reduces when a longer lifetime period is assumed (the total carbon stock change is distributed over a longer time period) combined with a higher value of the harvest index.

Figure 4 demonstrates the influence of different reference land-use systems, management systems and indirect land-use change on carbon stock changes for one scenario (CUR-S-C). Replacing non-degraded or degraded grassland by soybean production, results in a carbon loss. The decrease in soil carbon content of crop land shifting from (natural) grassland is mentioned, among others, by Zach *et al.* (2006). This study in La Pampa province demonstrates that the highest C concentration was found under the natural Caldén savannah. Conversion of C_4 pasture to arable land caused a 33% reduction in the total topsoil carbon content after 13 years of conventional tillage. A second site showed that a 10 to 13 years cultivated crop area that replaced C_4 pasture land, lost 38% to 61% of its former C_4 carbon content after 10-13 years of cultivation of C_3 crops.

Figure 4: Carbon stock changes from soybean production in current situation (CUR-S) for different reference land-use systems (crop, non-degraded grassland and degraded grassland), management systems (RT=reduced tillage, NT=no tillage) and for alternative scenarios (ALT), including indirect land-use change with risk adder of 25% and 50%, assuming a lifetime period of 20 years.



Shifting from a reduced to a no-tillage system results in a net carbon stock benefit (see figure 4) assuming all other factors remain constant. This is confirmed by a study located in the west of Buenos Aires (Díaz-Zorita *et al.* 2002). Similar results are found for other sites in the region. Several researchers in Argentina have mentioned that IPCC standards hardly distinguish differences between agricultural practices commonly used in Argentina and more research is needed to get better insight in the impact of different agricultural systems on the net total GHG emissions (Lamers 2006; Hilbert 2008). Figure 4 shows that indirect land-use change from soybean production has an impact on the total carbon stock results changing the carbon balance from zero in (CUR-S-RT) to -0.5 t C/ha/yr when a risk adder of 50% is assumed. Mind that this risk reduces significantly when it is assumed that the feed (80% of whole crop) generated during soybean production is used to reduce the pressure on land-use conversion (see also 4.3 and 4.4)

Based on the results, a conclusion is given about the relative performance of the soybean bioenergy chain for this principle, based on a lifetime period of 20 years. The lowest score (--), with a carbon loss of 0.6 t C/ha/yr or more, is estimated for the scenarios where degraded grassland is used for soybean production and for scenario (B-S-G). No scenario has a negative score, with a carbon loss of 0.6 to 0 t C/ha/year. The scenarios in which soybean bioenergy production replaces abandoned cropland (CUR-S-C, A-S-C, and C-S-C) have a neutral score.

A small positive score could be obtained in case crop management improvements (as no tillage) are made compared to the reference management system. Leakage should strongly be avoided as this result in significant carbon stock losses.

4.2. Principle 2: GHG balance of bioenergy chains

The principles of Cramer *et al.* (2007) request a minimum GHG emission reduction of at least 30% for transportation fuels and of at least 50-70% (still under debate, the threshold of 60% is used in this study) for electricity. The European Commission (EC 2008) has agreed on a GHG emission reduction requirement of 35% for biofuels and this threshold will be further used in this study. The European Commission proposes to increase the threshold of 35% to 50% in 2017. Cramer *et al.* (2007) also considers making this criterion stricter on the longer term, suggesting a GHG emission reduction requirement of at least 80-90% (the threshold of 85% is used in this study).

The GHG calculation for the bioenergy chains is based on LCA methodology as suggested by Voet *et al.* (2008), Hamelinck *et al.* (2008), Fehrenbach *et al.* (2008a), EC (2008) and RPB (2007) and accounts for all GHG emissions that arise between initial land-use conversion up to the final use of bioenergy. The percentage of GHG emission reduction is calculated by dividing the difference in GHG emissions from the fossil and bioenergy chain divided by the emissions of the fossil reference system (Wicke *et al.* 2009).

The three most important GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are included in the calculation. For comparing the impact of the three gases, the concept of Global Warming Potential (GWP) is applied following the guidelines of IPCC (GWP CH_4 = 21 and GWP N_2O = 310 compared to CO_2). Other GHGs are not taken into account as they are insignificant in the bioenergy production chains (Voet *et al.* 2008; Hamelinck *et al.* 2008).

Nitrous oxide (N_2O) is produced in the soil from nitrogenous fertilisers and from natural mineralisation of nitrogen, by the parallel processes of bacterial nitrification and denitrification (RoyalSociety 2008). In this study, N_2O emissions are calculated with the tier 1 methodology from IPCC (IGES 2006). It must be noted that the IPCC methodology (tier 1) largely ignores the variability of emissions caused by differences in environmental conditions, crop type and agricultural management system (Smeets *et al.* 2008a). The default values from IGES (2006) indicate therefore a broad range of data insecurity. However, due to lack of more precise input data for the selected region, the IPCC approach is used for the calculation of direct and indirect N_2O emissions for the biomass system and the reference land-use system, as also suggested by Voet *et al.* (2008), Hamelinck *et al.* (2008) and Bauen (2007).

The total GHG emissions from the reference land-use system are GHG emissions coming from the use of inputs as fertilizers, seeds, diesel input and herbicides use. The amount of inputs for the reference land-use 'cropland' is the same as the amount of inputs calculated for soybean production for bioenergy for a defined scenario. The amount of inputs needed for the reference land-uses non-degraded and degraded grassland is the same as the amount of inputs calculated for switchgrass production. For degraded grassland, no fertilizer input is assumed, though.

Leakage due to biomass production is excluded in this study (see 4.1). The intensification of the reference land-use system in the various scenarios (according to the storylines) compared to the current situation results in a change in the amount of inputs needed for cultivation. This change in amount of inputs, and consequently in GHG emissions, of the reference land-use over time is allocated to the biomass system.

Bioenergy chains that involve the provision of more than one product or service require that the GHG emissions from inputs and outputs need to be subdivided between them, which is possible by a substitution approach or by allocation based on price, mass or energy content (Horne 2004). The switchgrass bioenergy chain does not have by-products in its chain. The soybean bioenergy chain has three by-products: pellets, glycerine and free fatty acids. There is an ongoing discussion which allocation or substitution method should be preferred or whether this decision should be upon the user. The draft Renewable Energy Directive from the European Commission proposes that allocation is based on energy content (EC 2008). This approach has been adopted by various national governments (Voet *et al.* 2008; Hamelinck *et al.* 2008; Fehrenbach 2007). Therefore, in this study, GHG emissions in the soybean bioenergy chain are allocated to the product based on energy content. Alternative scenarios (see 4.2.2) show the sensitivity results if other allocation options are used. The input data used for the GHG calculation of the two bioenergy chains are shown in table 4.

4.2.1. GHG balance of the switchgrass bioenergy chain

The GHG emissions from fuel use, K and P fertilizer input, seeding and herbicides input for switchgrass cultivation range from 15 (B-S-G) to 54 (CUR-mS-D) kg $CO_{2\ eq}$/ tdm per year. The main source of the GHG emissions is fossil fuel use, followed by P fertilizer input. In comparison, GHG emissions in an European situation are estimated to be 104-127 kg $CO_{2\ eq}$ / tdm in 2004 to 103-123 kg $CO_{2\ eq}$/tdm in 2030 for switchgrass production, storage, unloading and transportation (100 km distance) with the latter three items representing together around 20 kg $CO_{2\ eq}$/tdm (Smeets *et al.* 2008c).

Table 4: Key input data and references for calculating the GHG emissions of the switchgrass and soybean bioenergy chains for the current situation and for scenarios A, B and C to 2030.

General input data	Unit	Emissions				Reference
		CO_2	N_2O	CH_4	CO_2eq	
Production P_2O_5 fertilizer	G / kg P				714	(Smeets *et al.* 2008c)
Production Urea	kg / kg N				1.3	(Wicke *et al.* 2009)
Ammonium phosphate	kg / kg N				2.8	(Panichelli 2006)
Tuck, lorry 28 t	G / tkm				223	(Panichelli 2006)
Train, freight, rail	G / tkm				37.2	(Panichelli 2006)
Diesel truck / machinery	G / liter				3644	(Smeets *et al.* 2008c)
Ship transoceanic tanker	G / tkm				5.52	(Panichelli 2006)
Ship barge tanker, inland ship	G / tkm				42.4	(Panichelli 2006)
Electricity medium volt.ARG	G / kWh				629	(Panichelli 2006)
Natural gas, also for heating	G / MJ				62	(Smeets *et al.* 2008c)
Coal production and transport	g/MJe	20.9	0	0.34	28.0	(Damen *et al.* 2006)
Electricity production coal	g/MJe	248	$2.4*10^{-3}$	$2.9*10^{-3}$	$2.5*10^{3}$	(Damen *et al.* 2006)
Heat production natural gas(1)	G /MJ th				68.6	(SIMAPRO 2007)
Conversion boiler	g/ MJ th				2.5 (2)	(Damen *et al.* 2006)
Seeds (3)	kg / kg				105	(Panichelli 2006)
Metsulfuron (4)	kg / kg				8.8	(Panichelli 2006)
Master / Endosulfan (5)	kg / kg				5.8	(Panichelli 2006)
Cipermetrina (6)	kg / kg				28.3	(Panichelli 2006)
Roundup – glysophate (7)	kg / kg				15	(Panichelli 2006)
Curasemilla (fungicide) (8)	kg / kg				5408	(Smeets *et al.* 2008c)
Hexane,at plant	kg / kg				0.9	(Panichelli 2006)
Phosphoric acid, 85% H_2O	kg / kg				1.4	(Panichelli 2006)
Tap water, at user	kg / kg				$3*10^{-4}$	(Panichelli 2006)
Methanol at plant	kg / kg				0.7	(Panichelli 2006)
Hydrochloric acid, at plant	kg / kg				0.8	(Panichelli 2006)
EF wheat animal feed	kg / ton				744	(Donato *et al.* 2007)
EF synthetic glycerine	kg / kg				9.6	(Umweltbundesamt 2007)
EF fatty acids vegetable oil (9)	kg / kg				1.2	(SIMAPRO 2007)

(1) Based on Heat, natural gas, at boiler modulating >100kW, European situation, (2) based on GEMIS wood pelleting D 100% conversion, (3) (Panichelli 2006) uses pea seed (regional storage) from Ecoinvent database as reference for soybean seed, (4) Metsulfuron based on sulfonyl-urea compounds (at regional warehouse), (5) Endosulfan based on Master (commercial name), (6) Cipermetrina (commercial name Lorsban Plus) based on pyretroid and organophosphorus compounds, (7) Input data Roundup given in liter, converted based on density of 1.17 kg/liter for classical formula Roundup (Stuijt 2008), (8) EF curasemilla based on the general EF for herbicides from Smeets *et al.* (2008c) due to lack of more specific data, (9) Fatty acids, from vegetarian oil, at European plant.

Figure 5: Total GHG emissions of biomass and reference land-use system (left) and net GHG emissions from switchgrass cultivation for bioenergy (right) estimated over 20-year period in kg CO_2 $_{eq}$/tdm per year yr for current situation and for scenarios A, B and C to 2030.

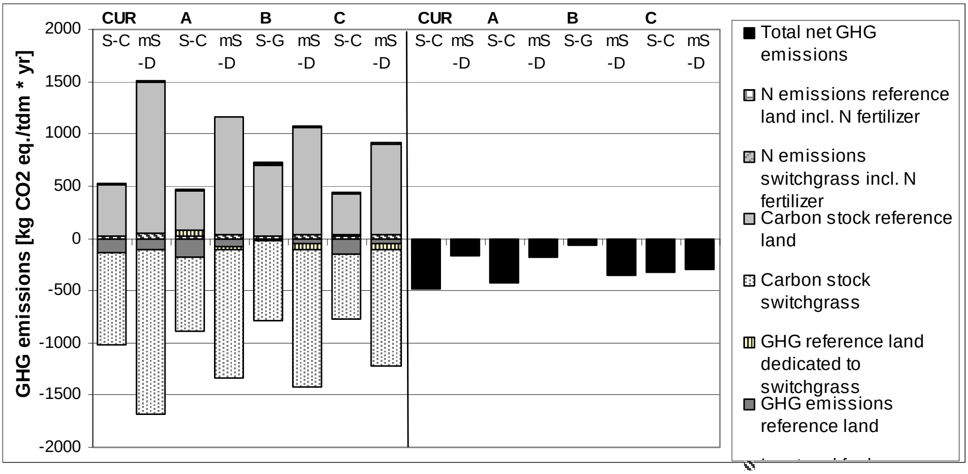


Figure 6: Total GHG emissions for switchgrass bioenergy production for electricity generation replacing coal in g CO_2 eq/kWh$_{el}$. The biomass is exported from Argentina to the Netherlands by truck or train (inland). Outcomes for the current situation and for scenarios A, B and C for year 2030 are presented.

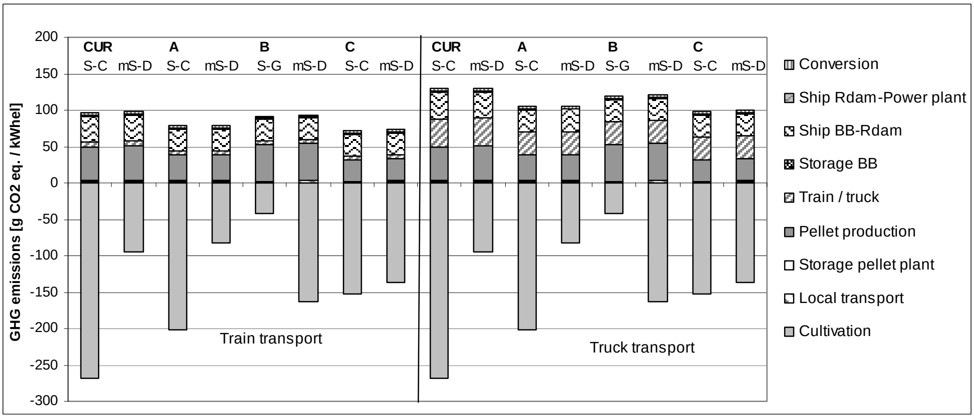


Figure 5 (left side) shows the total GHG emissions for switchgrass cultivation and its reference land-use system including carbon stocks, indirect and direct N_2O emissions and extra emissions of the reference land-use system due to intensified use of the land dedicated to bioenergy production. Total GHG emissions are largely determined by the carbon stock changes (see also 4.1). The inputs from switchgrass cultivation represent only a small part of it. The net GHG emission results for switchgrass cultivation range from -93 (B-S-G) to -484 (CUR-S-C) kg CO_2eq/tdm per year.

The GHG emissions for electricity production in the Netherlands from switchgrass pellets produced in Argentina transported by truck, range from -140 (CUR-S-C) to 76 (B-S-G) g CO_2eq/kWh$_{el.}$ GHG emissions decrease slightly when train transport is used for this route from -172 (CUR-S-C) to 49 (B-S-G) g CO_2eq/kWh$_{el}$. The total GHG emissions for heating in Argentina from switchgrass pellets range from -82 (CUR-S-C) to 16 (B-S-G) g CO_2eq/kWh $_{th}$. The contribution of the different process steps to total GHG emissions for the various scenarios (see figure 7) is 27-74% for the cultivation process, 12–37% for the pelleting process and 12–40% for transport. Table 5 shows the GHG reduction potential (in %) for switchgrass bioenergy production for electricity generation in the Netherlands (replacing coal) or for local heating (replacing natural gas). The GHG reduction of the switchgrass bioenergy chains (local use and export) ranges from 88 to 133% for varying lifetime periods (see also 4.1). The high GHG benefits on the short term of 95-117% reduce somewhat to 92-99% on the long term.

Table 5: GHG reduction (in %) for current situation and for scenarios A, B and C shown for switchgrass bioenergy production used for electricity generation in the Netherlands, replacing coal use, or for local heating in Argentina, replacing natural gas use. Inland transport is by truck or train. The results are differentiated to three lifetime periods.

Scenarios	CUR		A		B		C		REF* in g CO2eq/GJth-el
	S-C	mS-D	S-C	mS-D	S-G	mS-D	S-C	mS-D	
Export-train									
20 years	117%	100%	112%	100%	95%	107%	108%	106%	993.5 (in GJel)
50 years	103%	94%	102%	96%	95%	97%	101%	100%	993.5 (in GJel)
100 years	99%	93%	99%	95%	92%	96%	99%	98%	993.5 (in GJel)
Export-truck									
20 years	114%	96%	110%	98%	92%	104%	106%	104%	993.5 (in GJel)
50 years	100%	91%	99%	94%	90%	95%	99%	97%	993.5 (in GJel)
100 years	96%	90%	96%	93%	89%	93%	97%	95%	993.5 (in GJel)
Local use									
20 years	133%	103%	128%	104%	94%	117%	120%	116%	246.9 (in GJth)
50 years	109%	94%	107%	96%	89%	100%	106%	103%	246.9 (in GJth)
100 years	102%	92%	102%	94%	88%	95%	102%	99%	246.9 (in GJth)

* REF: Emission factor reference energy system

Based on the results, a conclusion is given about the relative performance of the switchgrass bioenergy chain for this principle. The highest score (++), with a GHG reduction potential of at least 85% for a lifetime period of 20 years, is achieved for all scenarios. As mentioned, there is a large insecurity range in the calculation of the GHG emissions, based on IPCC (IGES 2006). Hilbert *et al.* (2008) indicate for example a variation of 15% in the calculation of the GHG balance in Argentina which means a range of 30-60% for a calculated GHG reduction performance of 45%. Although a final comparison between the scenarios can therefore not be made, some indications can be given. Generally, the highest GHG reduction performance is estimated when switchgrass production replaces abandoned cropland (CUR-S-C, A-S-C, and C-S-C). Replacing non-degraded grassland (B-S-G), results in a relatively low GHG reduction potential. In absolute terms, most GHG emission is estimated when switchgrass pellets are exported to the Netherlands to replace coal. Also, from an economic perspective, the use of switchgrass pellets for energy conversion in the Netherlands is more attractive than for local use on the short term (Dam *et al.* 2008c).

4.2.2. GHG balance of the soybean bioenergy chain

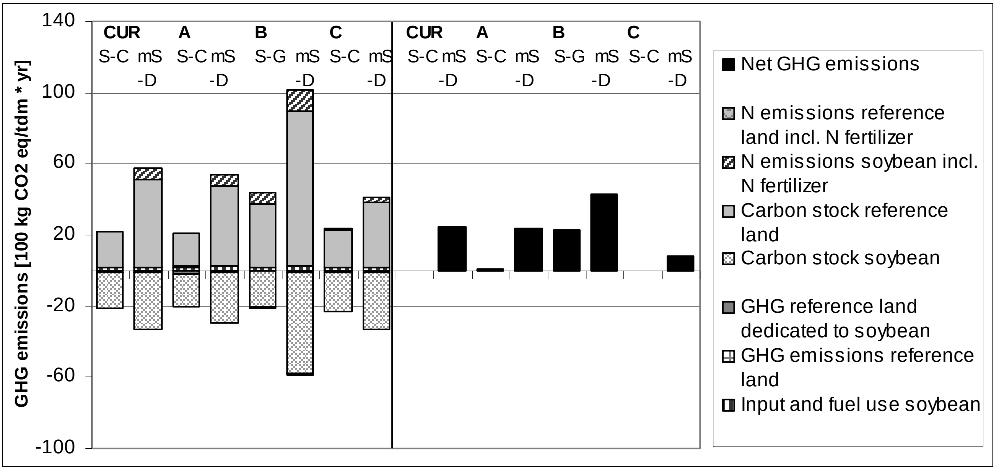
The GHG emissions coming from fuel use, K and P fertilizer input, seeding and herbicides input for soybean cultivation range from 133 (CUR-S-C) to 250 (B-mS-D) kg CO_2eq/ tdm per year. The higher emissions in kg CO_2eq/ tdm for scenario (B- mS-D) can largely be dedicated to the low yields assumed for this scenario (Dam *et al.* 2008c). Figure 7 (left side) shows the total GHG emissions for soybean cultivation (whole crop) and the reference land-use system including carbon stocks, indirect and direct N_2O emissions and extra emissions of the reference land-use system due to intensification of land-use that can be dedicated to the bioenergy system. The net GHG emission results for soybean cultivation are largely determined by carbon stock changes (see also 4.1).

Soybean is a biological nitrogen fixation (BNF) crop. The soybean crop can affect N_2O emissions by taking up water and NO from the soil, thus reducing N_2O emissions (Ciampitti *et al.* 2008). Crops with a low C/N ratio like soybean display on the other hand high decomposition rates, releasing soluble C and N, thus increasing N_2O emissions (Ciampitti *et al.* 2008; Aulakh *et al.* 1991). The total direct N_2O emissions in Argentina from 1990/91 to 2000/01 increased sharply by 85%. Lamers (2006) explains this increase by the percentual increase of BNF crops (with a strong increase in soybean production after 1996/1997) compared to legume crops and forages as well as by the burying of agricultural residues.

Soybean can be produced without or with nearly zero nitrogen, which is assumed for the current situation. Due to the expected imbalance of nutrients over time (see also section 4.5), an increased use of phosphate monoamonico (12% N, 52% P) is assumed for the future scenarios, see also (Dam *et al.* 2008c). The increase in N fertilizer combined with N emissions from mineralisation of soil organic matter (see section 4.1), results in an increase in the nitrogen emissions in some of the scenarios, especially in those replacing degraded grassland.

Mind that the tier 1 methodology from IPCC (IGES 2006) is based on general input data for N emissions from soybean cultivation. Large insecurities in results are discussed by various authors (Smeets *et al.* 2008a; Crutzen *et al.* 2008). Some first measurements in Mendoza, Argentina, indicate a N-content of below-ground residues of 0.74 kg N/kg DM (UTN 2008) compared to an IPCC-value of 0.008 kg N/kg DM. More accurate input data are needed on N_2O emissions and also on management practices, as the latter can reduce GHG emissions (lower energy input) and carbon stock changes.

Figure 7: Total GHG emissions from soybean and reference land-use system (left) and net GHG emissions of soybean cultivation (whole crop) for bioenergy (right) estimated over 20-year period in 100 kg CO_2eq/ tdm per year for current situation and for scenarios A, B and C to 2030.



The net GHG emission results (see figure 7, right side) results for soybean cultivation (whole crop) show a large variation ranging from 0.0 kg CO_2eq/ tdm*yr (CUR-S-C) to 4294 kg CO_2eq/ tdm*yr (B-mS-D). The GHG emissions from inputs for cultivation, as fuel or fertilizer use, are limited. The land-use reference system, and the resulting carbon stock changes, is the main determinant for the net GHG emissions for soybean cultivation.

The energy efficiency of the vehicles for fossil fuels and a blend of fossil fuels-biofuels are assumed to be the same, being 183.1 MJ/100 km in an European situation for both diesel and diesel mixed with 5% biodiesel according to JRC (2004). The GHG emissions for the bioenergy production chain from soybeans are therefore calculated until delivery of the fuel at the pump. Figure 8 shows the total GHG emission for biodiesel production for export to the Netherlands for the current situation and for scenarios A, B and C.

Figure 8: Total GHG emissions for soybean biodiesel production (produced in Rotterdam in the Netherlands or in Rosario in Argentina) in kg CO_2eq per liter for export from Argentina to the Netherlands with truck or train (inland), for current situation and for scenarios A, B and C in year 2030.

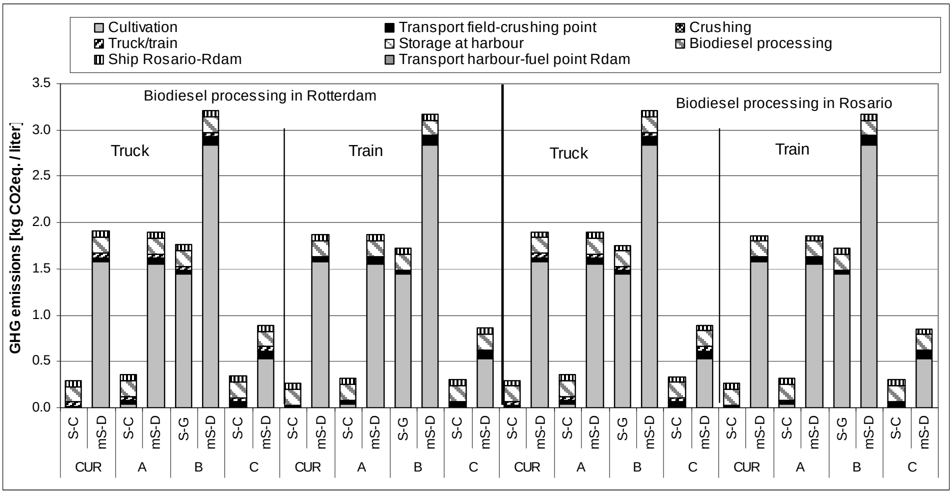
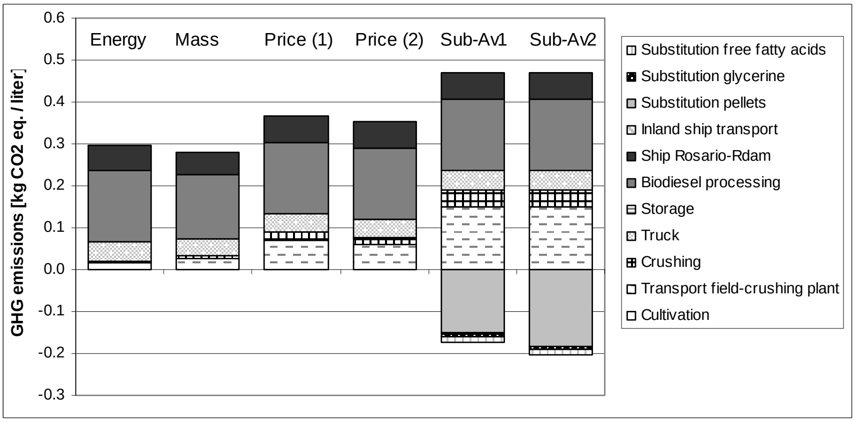


Figure 9: GHG emission results in CUR-S-C in kg CO_2eq per liter for varying possibilities of allocation choices and substitution[33] for biodiesel processing in Rosario with truck transport.



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[33] Price (1): based on pellet price 385 US$/ton, glycerine price 50 US$/ton, soy oil price 1390 US$/ton, biodiesel price ARG 583 US$/ton, Price (2): based on pellet price 214 US$/ton, glycerine price 0 US$/ton, soy oil price 615 US$/ton, biodiesel price ARG 583 US$/ton, Sub-av (1): pellets and glycerine biodiesel chain are replaced with soybean pellets feed / food chain, GE soybeans = 5.5, $EF_{average}$ = 67.2 kg CO_2eq/ ton product. Sub-av (2): pellets and glycerine biodiesel chain are replaced with maize for animal feed, GE maize = 4.4, $EF_{average}$ = 64.6 kg CO_2eq/ ton product.

The results range from 0.3 kg CO_2eq/l (CUR-S-C-train-ROS)[34] to 3.1 kg CO_2eq/l (B-mS-D-truck-ROT)[34] which is 0.3 and 3.5 kg CO_2eq/kg biodiesel respectively. In comparison, (Panichelli 2006) calculated a GHG emission for biodiesel transported to Switzerland (delivered at pump) of 1.7, 1.4 and 4.0 kg CO_2eq/kg biodiesel when produced in Argentina, USA and Brazil respectively. The GHG emission results for biodiesel (see figure 8) are largely determined by the impacts of land-use change (see 4.1). Transport and biodiesel processing contribute respectively 33% and 66% to the total calculated GHG emissions for the scenario (CUR-S-C-train-ROS). GHG emissions from biodiesel production for local use range from 0.2 kg CO_2eq/l (CUR-S-C-train-ROS) to 3.0 kg CO_2eq/l (B-mS-D-truck-ROS). GHG emissions are lower when the train is used for inland transport combined with biodiesel processing in Rosario.

Figure 10: GHG emission results in scenario CUR-S-C in kg CO_2eq per liter for different substitution choices[35], based on various literature sources, for biodiesel processing in Rosario with inland truck transport from the crushing to the biodiesel plant.

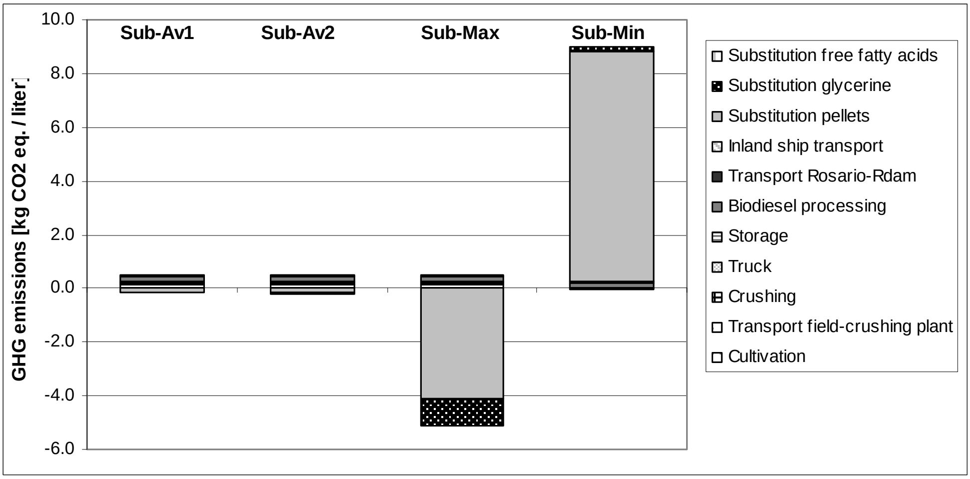

Figure 9 and 10 show the range in GHG emission results for scenario (CUR-S-C-truck-ROS) when different allocation methods (mass, price and energy) and substitution options are used. Variations in price data are based on Dam *et al.* (2008c) and SAGPyA (2008). Variation in the input data for substitution are based on data ranges of the replaced by-product derived from various literature sources (Wicke *et al.* 2009; SIMAPRO 2007; Umweltbundesamt 2007; Cramer *et al.* 2006; ARB 2008). The gross energy values (GE) for animal feed are based on (WorldBank 1986). The estimated range in results when different

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[34] The soybean bioenergy chain distinguishes between biodiesel conversion in Rosario (ROS) and in Rotterdam (ROT). Inland transport is by means of truck or train

[35] Sub-min and Sub-max reflect maximum and minimum EF found in literature. Sub-min: Soybean pellets are replaced by animal feed coming from extensive hay production. GE = 4.5, EF= -1553.3 kg CO_2eq / ton product. Sub-max: Soybean pellets are replaced by wheat bran, GE = 4.5, EF = 744 g CO_2eq / ton product. Glycerine in the biodiesel process is replaced by synthetic glycerine. GE = 4.3, EF = 9600 kg CO_2eq / ton product.

allocation methods are used is 0.3 to 0.4 kg CO_2eq per liter, which leads to a variation in GHG reduction performance ranging from 90% to 92%.

The estimated range in results when different input data (between minimum and maximum values found in literature) for substitution are used is -4.7 to 9.0 kg CO_2eq/l, which leads to a variation in GHG reduction performance ranging from -147 to 228%. The estimated range in results between options (Sub-av1) and (Sub-av2) is 0.02 kg CO_2eq/l. The results show that price allocation is quite sensitive to price fluctuations while results in substitution can vary according to the product replaced and the data sources used for that product. This creates a large uncertainty in the results. Allocation of GHG emissions based on energy content is therefore preferred.

Table 6 shows the GHG reductions (in %), based on allocation of energy, for the various scenarios for biodiesel production from soybean, ranging from 16% to 94% for varying lifetime periods (20-100 years). In comparison, Hilbert *et al.* (2008) have calculated the GHG balance for biodiesel from intensive soybean cultivation in Santa Fe province resulting in a GHG reduction of 74% (with a variation of 15%). This is in line with the results of this study. Typical values for biodiesel from soybean estimated by JRC (2008) are between 31-40%.

Based on the results, a conclusion is given about the relative performance of the soybean bioenergy chain for this principle. The scenarios replacing abandoned cropland (CUR-S-C, A-S-C, and C-S-C) have the highest score (++). A relative high score (+),with a GHG reduction requirement of more than 35% (EC 2008), is estimated for the scenarios replacing degraded grassland and for scenario (B-S-G). Scenario (B-mS-D) does not meet the GHG reduction requirement of 35%, based on a lifetime period of 20 years. Mind that the GHG reduction performance improves for the soybean bioenergy chain when longer lifetime periods are assumed. As table 6 shows, scenario (B-mS-D) would meet the GHG reduction requirement of 35% when a lifetime period of 50 years or more is assumed.

Table 6: GHG reduction (in %) for current situation and for scenarios A, B, and C for soybean bioenergy production, replacing fossil diesel use. Soybean is produced in La Pampa. Biodiesel processing is located in Rosario or in Rotterdam. The biodiesel is exported or locally used. The results are presented for three lifetime periods.

Scenarios	CUR		A-2030		B-2030		C-2030		REF* diesel in kg CO_2eq/liter
	S-CR	mS-D	S-CR	mS-D	S-GR	mS-D	S-CR	mS-D	
Export chain-inland transport by train –biodiesel processing in Rosario									
20 years	93%	49%	91%	50%	53%	16%	92%	77%	3.64
50 years	93%	75%	91%	74%	80%	62%	92%	85%	3.64
100 years	93%	83%	91%	82%	86%	75%	92%	87%	3.64
Export chain-inland transport by truck – biodiesel processing in Rosario									
20 years	92%	48%	90%	49%	52%	15%	91%	76%	3.64
50 years	92%	74%	90%	73%	79%	61%	91%	84%	3.64
100 years	92%	82%	90%	81%	85%	74%	91%	86%	3.64
Export chain-inland transport by train –biodiesel processing in Rotterdam									
20 years	93%	49%	91%	50%	53%	16%	92%	77%	3.64
50 years	93%	75%	91%	74%	80%	62%	92%	85%	3.64
100 years	93%	83%	91%	82%	86%	75%	92%	87%	3.64
Export chain-inland transport by truck – biodiesel processing in Rotterdam									
20 years	92%	48%	90%	49%	52%	15%	91%	75%	3.64
50 years	92%	74%	90%	73%	79%	61%	91%	84%	3.64
100 years	92%	82%	90%	81%	85%	74%	91%	86%	3.64
Local use of biodiesel – inland transport by train - biodiesel processing in Rosario									
20 years	94%	51%	93%	52%	55%	18%	93%	78%	3.64
50 years	94%	77%	93%	76%	81%	64%	93%	87%	3.64
100 years	94%	85%	93%	83%	88%	77%	93%	89%	3.64
Local use of biodiesel – inland transport by truck - biodiesel processing in Rosario									
20 years	93%	50%	92%	51%	53%	17%	92%	77%	3.64
50 years	93%	76%	92%	75%	80%	63%	92%	86%	3.64
100 years	93%	84%	92%	82%	87%	76%	92%	88%	3.64

* REF: Emission factor reference energy system

4.3. Principle 3: Biomass production must not endanger food supply and local applications

Principle 3 deals with land competition and the use of land for the production of energy carriers in state of food, feed or other applications. No defined methodology is yet established to map out the effects of the production of biomass for energy carriers on food security and other local applications and to evaluate these effects related to sustainability standards. Cramer *et al.* (2007) recommend that most aspects of this theme are monitored at macro level. For doing this, the following data on project level are needed: food prices, land prices, ownership of land and availability of food. In this study, we will use the reporting approach and parameters mentioned by Cramer *et al.* (2007). Also, we start from the assumption that in the reference case food and feed production meets the demand (Dam *et al.* 2008c). The following criteria are used:

I. Economic effects of land-use for bioenergy production with as indicators: impacts on land and food and feed prices;
II. Land-use change due to biomass production with as indicators: expected changes in land ownership, in vegetation and in crop pattern.

At present, no standardized methodology exists yet to assess these indicators. This study looks at ongoing price and land-use trends in the defined region to place the information in a macro perspective and to estimate impacts of bioenergy production following the selected indicators.

4.3.1. Economic effects of land- use for bioenergy production: land prices

Land prices increased strongly in the last few years in Argentina. Average increases of 10% in agricultural land rents in 2006/2007 compared to the previous year are mentioned by Bertello (2006). Similar increases (10-15%) are mentioned for 2007/2008 (Bertello 2007). This is caused by various factors (Bertello 2006). Land rents are pushed by high outputs and price levels for annual crops as soybean or maize. This creates good income perspectives for farmers, especially with the expectation of further increasing yields. Consequently, there is a high demand for renting suitable land for annual crop production and a supply that does not catch up. Also, the agricultural sector is seen as a secure financial investment. The increase in land rents as well as other costs and investment costs forces producers to select a crop with sufficient income (Bertello 2006). The land rental costs (see table 1) have been determined for the various scenarios, based on assumptions on demand and price of the harvested product and the availability of land for biomass production (Dam *et al.* 2008c).

Some first conclusions on the relative performance of the bioenergy chains for this criterion can be drawn but should be taken with caution. A negative score, with an increase in land price of 20% or more compared to the current situation, is estimated for scenarios A and C in the soybean bioenergy chain and for scenario (A-S-C) in the switchgrass bioenergy chain. A positive score, with a decrease in land price compared to the current situation, is estimated for scenarios (B-S-G) and (C-S-C) in the switchgrass bioenergy chain, due to a larger availability of surplus land from perennial fodder (Dam *et al.* 2008c).

4.3.2. Economic effects of land- use for bioenergy production: food and feed prices

Due to high inflation rates, food prices in Argentina have increased in the last few years although the government announces yearly a maximum price to avoid strong increases for the principal food products. The price of products falling in the category “oils and fats” increased strongly between 2002 and 2007 due to a strong international demand and insufficient production (Marelli *et al.* 2008). As the price increased 218% in the period 2002-2006, the government agreed to provide a subsidy to keep local price increases within a bandwidth. This agreement was ratified in June 2007. Related to this development, Marelli *et al.* (2008) mentions a shortage of vegetable oils (especially sunflower oil followed by other oil types), caused by limited production capacity and increasing (international) demand.

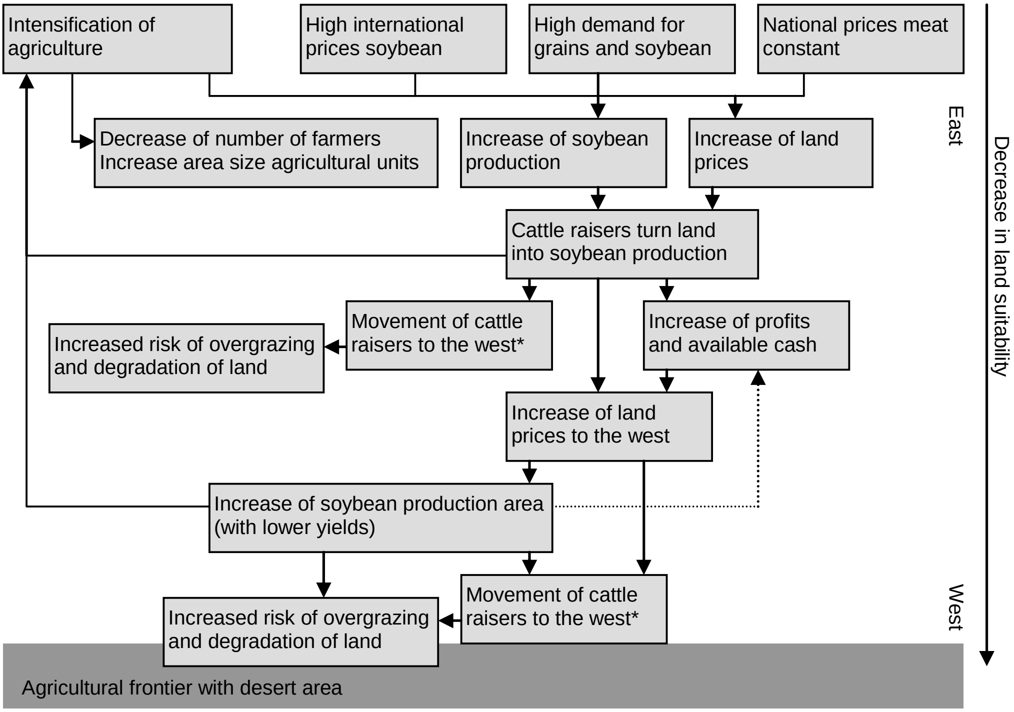
The demand on products from biomass for energy production increases as well over time, depending on the scenario, which is reflected in the price of these products. Assumptions about the price of switchgrass (pellets) and soybeans (meal, vegetable oil) are included in the various scenarios (Dam *et al.* 2008c). These prices are expected to increase over time with the highest price increase for scenario C. At present, these products are largely produced for export and not for internal demand. For example, more than 90% of the soybean meal is exported (Hilbert 2008). An increase in biodiesel production (around 20% of the harvested soybean production), will result in a stronger increase of valuable protein (around 80% of the harvested soybean production). This may result in a surplus of flour (Hilbert 2008) and consequently in a price decrease. The intensification of livestock in Argentina over time in the various scenarios in this study provides a growing market for this product, though. The required production from feed crops increases, for example, from $8*10^3$ tons in the current situation to $35*10^3$ tons in scenario C in 2030 (Dam *et al.* 2008c).

The dynamics of food and feed prices over time is influenced by a wide range of factors (demand for land, development of international markets, growth of economies, labour costs etc.) partly embedded in the storylines of the scenarios. A clear conclusion on the effect of a biomass energy production project in the region on food and feed prices can therefore not be drawn as this is beyond the limits of this study. A first indication can be given, though. Food and feed prices, as assumed in the scenarios, will increase. This increase goes hand in hand with economic growth (Dam *et al.* 2008c). Whether this increase shows a linear or non-linear relation with the expected economic growth cannot be said.

4.3.3. Land-use change due to biomass production

Human induced land-use changes are already happening in La Pampa province since the 1800s. Until 1980, the area of cropland and cultivated pasture has expanded displacing cattle production to the semi-arid, marginal lands of the western pampas (Viglizzo *et al.* 2001). The conversion of natural grasslands into cultivated grasslands was not homogenous. No single crop has expanded all over the region and livestock has not been removed from better lands in all areas. The process of overgrazing in the semi-arid region of La Pampa already started in the beginning of the 1900s (Fernández *et al.* 1997). Recently, a high profitability of annual crops, combined with an increase in precipitation and increased use of no tillage management (Hilbert 2007), has enlarged the area under agricultural rotation, which in return leads to increasing pressure on the west frontier of the semi-arid region of La Pampa province.

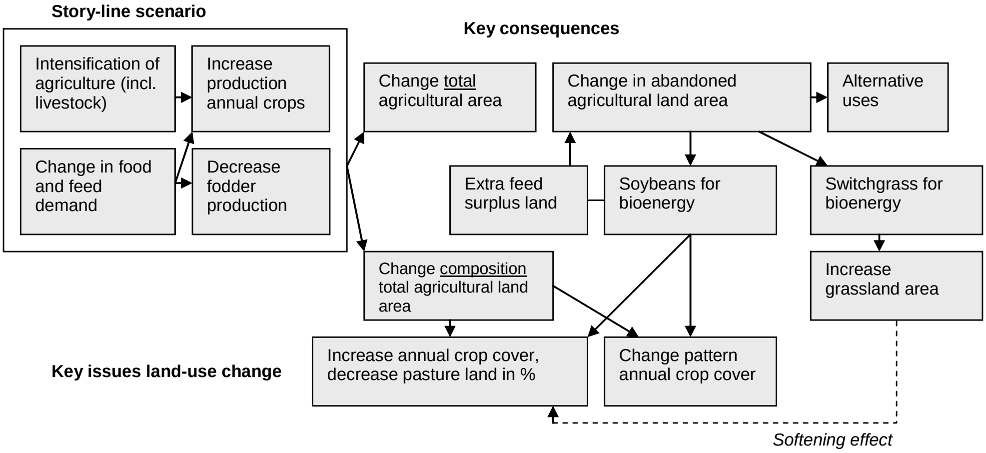
Figure 11: Schematic picture of the current land-use changes in La Pampa province. * Cattle raisers, moving to the west, in generally do not adapt their cattle load (number of livestock / ha) to the less productive areas.



The associated displacement of cattle generates a significant increase of the cattle load to the west, to areas dominated by natural pasture. This trend has already caused the loss and degradation of natural grasslands and severe erosion processes (Stritzler *et al.* 2007).

The recent land-use changes in La Pampa province are mainly caused by economic incentives for the farmer, receiving high prices for annual crops, and the possibility to extend the production of profitable crops to other areas within the region. Livestock production is traditionally characterized by low productivity, income and profit. The need for large areas and the low profit per area makes livestock production only viable in areas where land prices are low. Consequently, when infrastructure improves and more intensive land-uses as soybean production start to predominate, cattle production will be displaced, intensified or decreased. Displacement can lead to ecosystem degradation, as shown in Brazil (Sparovek *et al.* 2007).

Figure 12: Key consequences and expected direct land-use changes in scenarios according to story lines.



In this study, it is assumed that leakage, as the displacement of extensive cattle production due to biomass energy production, can and will be avoided (see section 4.1). Direct land-use changes that still can be expected in La Pampa province in the various scenarios are shown in figure 12. The contribution of bioenergy production to these land-use changes is, however, difficult to define. A clear conclusion on the impact of biomass energy production on land-use changes can therefore not be drawn, although some first indications can be given:

- Although leakage is not an issue in this study, it is an existing problem in the selected region. Therefore, care must be taken to further provoke the ongoing conversion of pasture areas, including natural habitats, to cropland areas. Bioenergy production on non-degraded grassland areas (B-S-G) may therefore be an undesirable action as it can cause important leakage effects;
- Soybean production for bioenergy will strengthen the already ongoing conversion of grassland areas to cropland areas and will contribute to an ongoing change in land ownership in the region. This impact is expected to be limited when soybean for bioenergy is produced on abandoned cropland areas (CUR-S-C, C-S-C and A-S-C). Switchgrass production is expected to soften the ongoing land-use changes;
- When pellets produced in the soybean bioenergy chain are used within the region for livestock production, surplus land will be generated (Dam *et al.* 2008c). As only a limited amount of this land meets the individual crop requirements for soybean production (Dam *et al.* 2008c), the remaining land may come available for alternative options (grassland, nature protection, switchgrass production), which will have a softening effect on the ongoing land-use changes in the region.
- The competition between the use of land for biomass energy production or for other annual crops is smaller for switchgrass than for soybeans as the agroecological area (taking into account the individual crop requirements) for switchgrass production is larger (Dam *et al.* 2008c).

Thus, switchgrass production may have a relative positive performance for this criterion, due to its softening impact on ongoing land-use changes, while soybean production may have a relatively negative performance.

4.4. Principle 4: Biomass production must not affect biodiversity

Cramer *al.* (2007) and EC (2008) propose that biomass plantations must not be located in protected areas or areas with a high conservation value (HCV). This neglects the effects from biomass energy production on biodiversity outside HCV areas. Dornburg *et al.* (2008a) recommend therefore including this aspect in a biodiversity impact analysis. The impact of biomass production on *total* biodiversity is estimated in this study by investigating:

I. The probability of biomass production in HCV areas;
II. the impact of biomass production on local biodiversity (agro-biodiversity).

Forest areas and protected areas (see map 2) are excluded from biomass production (Dam *et al.* 2008c) in this study. Consequently, the reduction of HCV areas due to biomass production should not happen. Therefore, this aspect will not further be discussed. The possible impact of large-scale biomass production on the agro-biodiversity in the region (Dornburg *et al.* 2008a), due to changes in the biodiversity value as a result of land converted to bioenergy crop production, is estimated by the 'Mean Species Abundance' (MSA). The MSA is used by Dornburg *et al.* (2008b) as an indicator for the short-term impact on the biodiversity on land converted from actual land-uses to bioenergy crop production. The possible impact of (increased) herbicides and pesticides use from biomass energy production on the local biodiversity in the region, as mentioned by (Berkum *et al.* 2006), is included in the MSA value. Available literature is used as an additional verifier for the MSA indicator.

Although a stakeholder consultation to designate biodiversity values in the region, as applied in the HCV methodology (Stewart 2008), would have been valuable for this study, this was not possible due to time limitations. The compliance of national and local regulations, as suggested by Cramer *et al.* (2007), is not further discussed as the protection of biodiversity is incorporated into national and provincial regulations (see section 3.1).

4.4.1. Possible impacts of bioenergy cultivation on the agro-biodiversity in La Pampa province

It can be concluded from sections 3.1 and 4.3 that the natural pasture land areas, including the 'Bosque de Caldén' should be protected to maintain its biodiversity. Important for the local biodiversity of biomass energy production areas are the crop type and the reference land-use system (Dornburg *et al.* 2008a). Whether a given biomass production system can contribute to biodiversity depends also on the prevailing local species and the type of habitats they require. Crop types should be favoured that match native ecosystem types (UNDP 2000). Table 7 shows the MSA values and the expected impacts of biomass production from soybeans and switchgrass on the biodiversity values in La Pampa province. As no MSA value is available for biomass production replacing extensive grasslands in the temperate zone (Dornburg *et al.* 2008a), the value for extensive grasslands in the tropical zone is used instead for scenario (B-S-G). Based on the results, a conclusion is given about the relative performance of the bioenergy chains for this principle.

Table 7: Expected impacts and MSA values for biomass production from soybeans and switchgrass replacing various land-use systems. A negative MSA value indicates a biodiversity decrease; a positive value indicates a biodiversity increase.

Reference land-use	MSA	Bioenergy system	Expected impacts
Existing grassland (intensive, in temperate region)	0	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors (Matteucci 2000).
	+0.2	Switchgrass	Positive impacts on biodiversity (Smeets *et al.* 2008c) due to increase in soil micro-organisms, soil fauna and niches for various species (Lewandowski *et al.* 2000)
Degraded grassland (marginal land)	-0.2	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors (Matteucci 2000).
	0	Switchgrass	Possibilities to restore biodiversity if sustainably managed
Existing cropland (intensive, in temperate region)	0	Soybean	No disruption of ecosystems
	+0.2	Switchgrass	Positive impacts on biodiversity (Smeets *et al.* 2008c) due to increase in soil micro-organisms, soil fauna and niches for various species (Lewandowski *et al.* 2000)
Extensive grassland (tropical region)	-0.2	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors (Matteucci 2000).
	-0.1	Switchgrass	Match to existing original ecosystem types (pasture, Caldenal region) in La Pampa province (limited disruption).
Natural vegetation	-0.4*	Soybean	Change in original natural vegetation and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors (Matteucci 2000).

* The conversion of existing cropland to natural vegetation has a MSA value of +0.4.

Relatively high scores, meaning the MSA indicator is positive, are estimated for the scenarios replacing abandoned cropland with switchgrass production (CUR-S-C, A-S-C and C-S-C), especially when cropland with a conventional management system (A-S-C) is replaced. Although switchgrass production on degraded grasslands has a neutral score, possibilities to restore biodiversity if sustainably managed may be possible. Negative scores, when the MSA indicator is negative, are estimated when biomass production replaces non-degraded grassland. Soybean production on non-degraded grassland also results in a negative score.

This effect can be minimized when the feed produced (80% of whole crop) is used within the region for livestock production. For example: $65*10^5$ ha of extra land (a 38% increase) with variable land suitabilities can be generated in scenario C in 2030 (Dam *et al.* 2008c). When we assume that with every hectare of abandoned cropland for soybean production, 0.4 ha of extra generated land is used for grass cultivation (MSA=+0.2) or for restoration of the natural vegetation (MSA=+0.4), the MSA value from scenario (C-S-C) could change from 0 to 0.1 (100%*0 + 38%*0.2) or 0.15 respectively.

4.5. Principle 5: Biomass production and processing and soil quality

This principle includes three criteria including no violation of national laws and regulations, the appliance of best practices and safeguarding that residual products must not be at variance with other local functions for soil conservation (Cramer *et al.* 2007). Cramer *et al.* (2007) propose, beside compliance with legislation and best practices, reporting on i) soil loss, ii) N, P and K nutrient balance and iii) soil organic matter and pH in the top layer of the soil. The compliance with legislation and best practices cannot be determined beforehand. The focus of this study is therefore on possible impacts of bioenergy production on soil loss, nutrient balance and soil organic matter (SOM). The soil loss is calculated using the so-called Universal Soil Loss Equation (USLE) as suggested by Smeets *et al.* (2008):

Formula (3): $A = R * K * LS * C * P$ Where:

A = soil loss (in ton ha^{-1}).
R = rainfall erosion index (in MJ mm ha^{-1} h^{-1})
K = soil erodibility factor (ton ha h ha^{-1} MJ^{-1} mm^{-1})
LS =Length of slope factor (dimensionless)
C = crop / vegetation management factor (dimensionless)
P = agricultural practice factor (dimensionless)

The USLE equation calculates the water soil loss (in ton/ha*yr) under various vegetation types. Soil loss by wind erosion is not included in the equation. Input data used are shown in table 8.

The nutrient and SOM balance of the soil are determined by the inflows and outflows in the soil over a defined time period. Nutrient budget and nutrient-balance models exist on a regional and national (Lesschen *et al.* 2007; Sheldrick *et al.* 2002) to farm level (Roy *et al.* 2003a). Applications of these methods (Lesschen *et al.* 2007; Sheldrick *et al.* 2002; Roy *et al.* 2003a) require a substantial amount of data, including field measurements for the collection of data on soil characteristics, material flows and crop nutrient requirements (Roy *et al.* 2003b). As this study looks beforehand at possible impacts from bioenergy production within a limited time frame, a more simplified approach is needed. The loss of nutrients from N, P and K is used as an indicator for the nutrient balance by Smeets *et al.* (2005). This approach requires data on the nutrient recovery efficient and on the mineral composition of the crops. The latter is affected by the composition of the soil, and thus by its location. A consistent data set for Argentinean circumstances for switchgrass and soybeans, required for this equation, is not available.

Table 8: Input data and references for factors used in USLE equation

Factors used in USLE	Input data		References
	S land	mS land	
Rainfall (mm / yr)	700	600	(INTA-RIAP 2008)
R (in MJ mm ha^{-1} h^{-1})	1839	1435	Calculated
K (ton ha h ha^{-1} MJ^{-1} mm^{-1})	0.03	0.04	(Stewart *et al.* 1975)
Slope length (m)	61	61	(Stone 2007)
Slope gradient (%)	4	5	(Stone 2007)
LS (dimensionless)	0.58	0.76	Calculated
P (dimensionless)	0.5 for contour farming		(Smeets *et al.* 2008)
C soybean (dimensionless)	* Soybean – conventional system : 0.45 Based on C data corn-soybean rotation for conventional tillage system (0.37-0.42) and for tillage system (0.25-0.48). * Soybean – no tillage system: 0.15 Based on C data corn-soybean rotation, ranging from 0.1 to 0.28. Note: soybean residue provides less protective cover than corn silage * Soybean no tillage – high input: 0.30 Based on C data for continuous soybean (20% cover, average yield, conservative tillage) C = 0.31		(Nelson *et al.* 2004; AGSA 2006; UIDAHO 2008)
C switchgrass (dimensionless)	* Intermediate agricultural input system: 0.05 * Mixed agricultural input system: 0.05 * High agricultural input system: 0.10		(Smeets *et al.* 2008)
C degraded grassland (dimensionless)	0.40		Estimation
C grassland full coverage (dimensionless)	0.02 for hay and pasture in general		(Stone 2007)

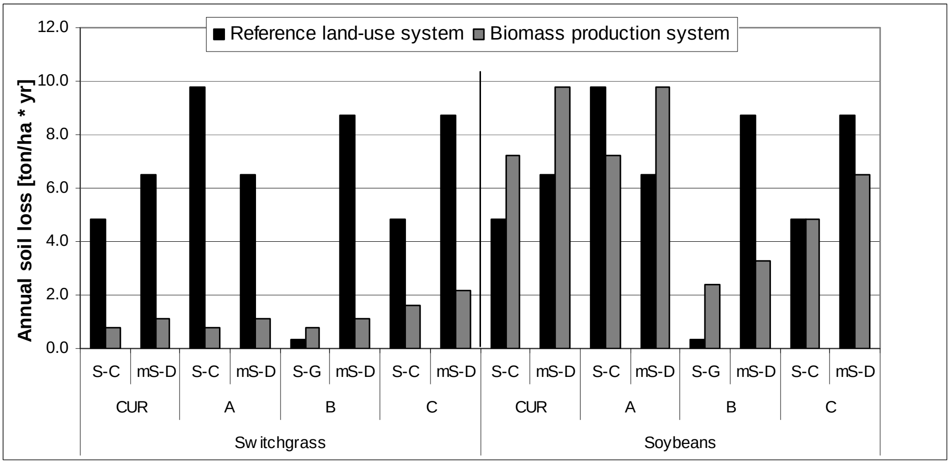
A reference indicator is therefore used in this study to analyze the SOM and nutrient balance of the soil, which is the net carbon stock change (as calculated in section 4.1) as changes in soil carbon and soil organic matter (SOM) are highly interrelated (Díaz-Zorita *et al.* 2002; UNDP 2000). La Pampa province is characterized by alkaline soils with pH values between 6 and 8.5 (DCA 2001a), which limits the risk for environmental acidity. Possible impacts of bioenergy production on the pH of the soil are therefore not further discussed in this study.

4.5.1. Soil erosion

The soil loss from soybean production varies from 2 (B-S-G) to 10 (A-mS-D, CUR-mS-D) ton/ha per year. The soil loss from switchgrass production is limited, ranging from 1 (CUR-S-C, A-S-C, B-S-C) to 2 (C-mS-D) ton/ha per year (see figure 13), as its permanent cover effectively controls surface water run-off. There is, however, an erosion risk for switchgrass production during its establishment phase as seedling growth rates of warm season grasses are often slow. This risk can be limited by using appropriate species and improved establishment systems that hasten attainment of the complete canopy cover (Kort *et al.* 1998).

Based on the results, a conclusion is given about the relative performance of the bioenergy chains for this criterion. The highest score (++), when the annual soil loss in the biomass production system is reduced with more than 2 ton/ha per year compared to the previous land-use system, is found when soybean production with a no tillage system (C-mS-D, B-mS-D) replaces degraded grassland. The use of no tillage or reduced tillage decreases soil erosion compared to repeated tillage (Kort *et al.* 1998) as there is a decrease in disruption of soil macro-aggregates and carbon turnover (Michelena *et al.* 2002) and an improvement of the physical and hydrological properties of the soil (Berkum *et al.* 2006). The highest score is found when switchgrass replaces abandoned croplands (A-S-C, CUR-S-C) or degraded grasslands.

Figure 13: Annual soil loss in ton/ha per year for switchgrass and soybean production for bioenergy for current situation and for scenarios A, B and C for the year 2030.



A relatively high score (+), when annual soil loss in the biomass production system decreases with 0 to 2 ton/ha per year compared to the reference system, is found for scenario (C-S-C). These findings are confirmed by Kort *et al.* (1998) mentioning an erosion reduction when cropland is converted to herbaceous biomass production in the US, especially in areas containing highly erodible land. There are no changes in annual soil loss when soybean production replaces abandoned cropland (CUR-S-C, A-S-C and C-S-C). A negative score (-), when annual soil loss increases 0 to 2 ton/ha per year compared to the reference system, is found when soybean production replaces degraded grassland. Replacing non-degraded grassland with biomass production (B-S-G) creates an annual soil loss increase of 0.5 and 2 ton/ha per year for, respectively, switchgrass and soybean bioenergy production.

The results show the possible risks of bioenergy production for water soil erosion, excluding possible risks for wind soil erosion. The latter can be substantial in La Pampa province though, as Fernández *et al.* (1997) mentions that approximately $16*10^4$ ha are moderately affected by wind erosion in ploughed areas at the eastern part of La Pampa province while $185*10^3$ ha have suffered severe damage.

4.5.2. Soil nutrient balance

Using carbon stock changes as an indicator (see 4.1), it can be assumed that most benefits in SOM can be achieved when switchgrass replaces cropland, followed by the replacement of degraded grassland. The results are confirmed by McLaughlin *et al.* (1998) mentioning a significant increase in SOM after four years of switchgrass production in the US. The results from section 4.1 indicate that a decrease in SOM can be expected when soybean production replaces degraded and non-degraded grassland.

According to the results from 4.1, there is no change in SOM content when soybean is produced on abandoned cropland. Various literature sources show, however, the risk for unbalance of nutrients when practising long-term intensive agriculture in Argentina. National research in 1999/2000 for vegetable oil and grain production estimated that only 50% of the consumed phosphor and 0.4% of the consumed potassium was brought back into the soil (Martellotto *et al.* 2001). Similar results are shown by Galarza *et al.* (2001). Castino (2006) mentioned that - in subsequent order - only 2%, 27% and 18% of the consumed nitrogen, phosphor and sulphur for soybean production was brought back into the soil. Explanations for these nutrient deficits are the high nutrient extraction from soybean (240 N, 27 P, 78 K kg/ha) compared to other annual crops and a further intensification of agriculture without sufficient inputs (Castino 2006). Soil nutrient deficits may result in a yield decrease (Berkum *et al.* 2006; UNDP 2000). The unbalance of nutrients for soybean for 2007/2008 in the region North Buenos Aires[36] was estimated to have an economic cost of 242 US$/ha (Miles 2007).

Based on the results, an indication is given about the relative performance of the bioenergy chains for this criterion. A final conclusion cannot be given though, as the results show a large insecurity because the carbon stock change is used as a reference indicator. The ratings of the scores for different scenarios and systems are presented and explained in section 4.1. Long-term intensive agriculture combined with no fertilizer use can result in nutrient deficits. For this reason, scenario (CUR-S-C) should have a more negative score for this criterion than indicated in section 4.1.

4.6. Principle 6: Biomass production and processing and water quality and quantity

Cramer *et al.* (2007) state that ground and surface water must not be depleted and that the water quality must be maintained or improved during the production and processing of biomass. This principle has been translated to a set of criteria stating that biomass production and processing must not be at the expense of water from non-renewable sources, or at the expense of ground and surface water quality, and that national legislation and regulations must not be violated. Cramer *et al.* (2007) propose to verify the risk for depletion of water sources by data on the use and origin of irrigation water and on water use efficiency. As the use of irrigation for bioenergy production is excluded in this study (Dam *et al.* 2008c), this will not be further discussed. Yet, the production of soybean and

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[36] Based on the 1st planting and an average yield of 4 tdm/ha

switchgrass may have an impact on the water balance in an area via changes in the evapotranspiration, runoff and percolation.

The possibility of water depletion due to biomass energy production is estimated by Smeets *et al.* (2005) with a simple water balance equation in which the evapotranspiration is compared with the effective rainfall.

Formula (4): $WS = -((ET_0 * Kc) - P)$

Where:

WS = water shortage (mm / month)
ET_0 = reference evapotranspiration (mm / month)
Kc = crop evapotranspiration coefficient (dimensionless)
P = effective precipitation (mm / month)

The same formula is used in this study to estimate the possibility for depletion of water resources. Monthly precipitation data are available from the weather station Anguil in 2006/2007 (INTA-RIAP 2008). Temperature data, required as input to calculate ET_0, are taken from a standardised data set for Santa Rosa (La Pampa) from the CROPWAT software tool (FAO/IIDS/NWRC 1999). The effective precipitation P and the reference evapotranspiration[37] ET_0 are calculated using CROPWAT (FAO/IIDS/NWRC 1999). The factor Kc[38] is the ratio between the actual non-water limited water demand to the reference evapotranspiration (Smeets *et al.* 2005). Kc data for various crops are shown in table 9.

The Water-Use Efficiency (WUE), also shown in table 9, is used as a second indicator in this study for evaluating the agricultural productivity and water resource utilization, as also suggested by (Dornburg *et al.* 2008a). The performance of the bioenergy chains in relation to water quantity focuses on use of water by the energy crops, in line with the studies from (Smeets *et al.* 2008c; Dornburg *et al.* 2008a). Water use related to the processing facilities is limited for the bioenergy chains investigated and will not be further discussed in this study.

Chemical contamination of water streams and underground aquifers with residues of agrochemical products and fertilizers can have a negative impact on the environment (Solbrig 1997). Cramer *et al.* (2007) propose to report on the responsible use of agrochemicals and to measure the impact of biomass production on the water quality with field tests in the area. The latter is not applicable for this study as we analyze the impacts beforehand.

The relative toxicity of agrochemicals is analyzed in Smeets *et al.* (2005) to determine the risk for pollution of agrochemicals from biomass production and, consequently, the environmental risks. The impact of fertilizers on the environment is not mentioned by

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[37] ET_0 is the evapotranspiration for a well-managed (disease free, well-fertilized) hypothetical grass species grown in large fields and for which water is abundantly available (Smeets *et al*. 2005)

[38] Note that the comparison based on the Kc, indicates the relative difference in water demand under non-water limited conditions, rather than the actual water use (Smeets *et al*. 2005).

Smeets *et al.* (2005) or Cramer *et al.* (2007), although this can have an eutrophication effect on the groundwater.

This criterion is therefore included in this study. This results in the following set of criteria to get insight in the possible impact of biomass production and processing on the water quality in the region:

- Limited use of agrochemicals combined with a low toxicity level with indicators: agrochemical input and their water solubility and toxicity level;
- Limited impact of fertilizers on the water quality with indicator: N_2O-N emissions from leaching

The risk for water contamination in the processing industry in the region is expected to be limited due to existing legislation (APA 1977; APA 1980; APA 1993) and will not be further discussed in this study.

Table 9: Crop evapotranspiration coefficient Kc (dimensionless) and Water-Use Efficiency (WUE) in product g DM / kg water transpired for selected crops

Crop	Kc	Reference	WUE		Reference
			g DM / kg water	GJ/ton water	
Soybean - Initial stage - Mid season - Late season	0.91 0.5 1.15 0.5	(Brouwer *et al.* 1986) (FAO 2008) (FAO 2008) (FAO 2008)	0.37-0.64 0.37-0.44	1.95 – 3.37[39]	(Dornburg *et al.* 2008a) (Yu *et al.* 2004)
Corn	1.0	(Brouwer *et al.* 1986)	0.7-1.41 0.75-1.23		(Dornburg *et al.* 2008a) (Yu *et al.* 2004)
Wheat	0.87	(Brouwer *et al.* 1986)	0.69-0.86		(Dornburg *et al.* 2008a)
Switchgrass	0.98	(Stroup *et al.* 2003)			
Miscanthus			1-9.5 4.1 - 22	18.5 - 175.8[40]	(Berndes 2002) (Dornburg *et al.* 2008a)
Pasture	0.98	(De La Torre *et al.* 2008)			
Pasture rotated grazing	0.95	(Smeets *et al.* 2005)			
Energy crops			0.3-14.2		(Jørgensen *et al.* 2001)
C3 crops			2-3		(Keulen van *et al.* 1986)
C4 crops			3.5-4.5		(Keulen van *et al.* 1986)

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[39] Based on 18% oil content, 0.93 kg oil/liter oil, 0.96 l biodiesel/l oil calculated per t DM.

[40] Calculated per t DM, energy content of 18.5 GJ/ton.

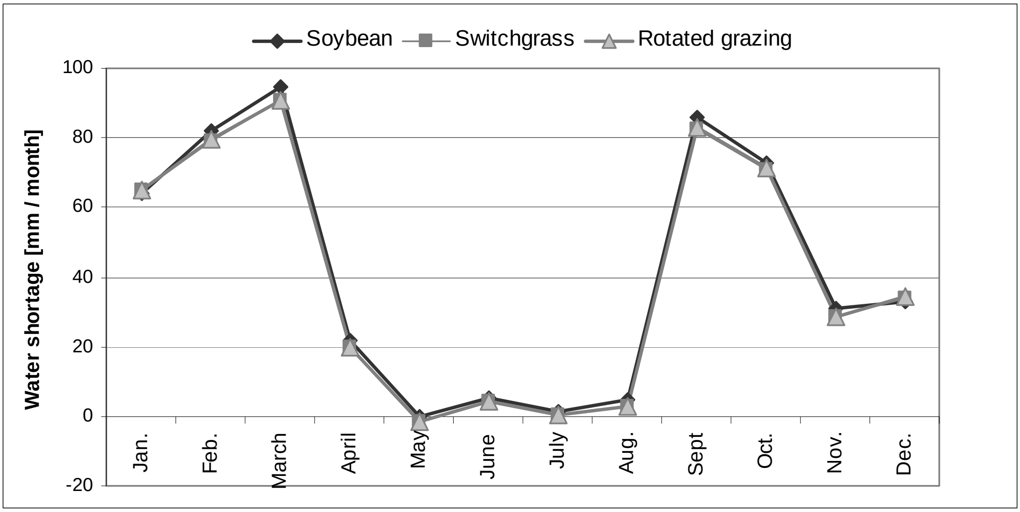
4.6.1. Performance of bioenergy chains in relation to water quantity

The Kc factors in table 9 show that switchgrass has a larger water need over its growing period compared to soybeans. This is confirmed by Hall (2003) mentioning that the evapotranspiration rate of switchgrass is expected to be higher compared to traditional annual crops due to its fast growth, large leave area and deep rooting system that leads to a higher rainfall interception.

As a result, deep percolation and runoff of water to groundwater reservoirs, streams and rivers from areas under energy grass cultivation is reduced compared to annual crops. This may lead to a reduction or depletion of these water bodies.

Figure 14 shows that the risk for water shortages in La Pampa province for soybean and switchgrass production is limited over the year. The seeding, growing and harvesting period for soybeans (SAGPyA 2007) and switchgrass (Petruzzi 2007) and the high water need of both crops (Petruzzi 2008b; FAO 2008) during the mid and late growing stage is in general in line with the precipitation pattern in La Pampa province. Intermittent periods of low rainfall can create, however, short water shortages.

Figure 14: Calculated monthly water shortages in mm/month, indicated as (WS), for soybean and switchgrass production for bioenergy and, as reference, for rotated grazing, a negative WS indicates a water shortage.



This may have an impact on the yields attained (Solbrig 1997; Petruzzi 2008b; Sinclair *et al.* 2007) and may increase temporarily the risk for water depletion in the drier areas.

Specific data for the WUE of switchgrass are not available. WUE data for miscanthus are therefore used as a reference. Miscanthus has the capacity for high yields on relatively poor quality sites, where water availability would prevent successful production of conventional crops (Lewandowski *et al.* 2003a). Lewandowski *et al.* (2003a) mention that switchgrass can be produced on similar areas as miscanthus or on areas that are too dry for miscanthus production, as switchgrass is considered more drought tolerant than miscanthus.

Although switchgrass uses per ha more water than soybean (see Kc factor), its Water Use Efficiency is significantly higher. Jørgensen *et al.* (2001) indicate that the WUE of C_4 crops (as maize or switchgrass) are about twice that of C_3 crops due to their higher efficiency of photosynthetic conversion. Yu *et al.* (2004) and McLaughlin *et al.* (1998) mention that C_4 plants produce 30% more food per unit of water than C_3 plants and are well adapted to more arid production areas (McLaughlin *et al.* 1999).

The WUE figures in table 9 imply good agricultural management and only a high WUE can be achieved if other factors (e.g. nutrient availability, incidence of pests and diseases, good management) do not limit crop production (Bessembinder *et al.* 2003). For example, the retention of crop residues combined with no-tillage management decreases the soil evaporation rate of soybeans that would normally occur from a bare soil (Sinclair *et al.* 2003). Combining an agricultural rotation system with direct seeding also promotes a higher WUE value (Martellotto *et al.* 2001).

Based on the results, an indication is given about the relative performance of the bioenergy chains for this principle. No final conclusion can be given as the risk for water shortages largely depends on rainfall and temperature dynamics in the La Pampa province over time. Some first conclusions can be drawn, though. Sufficient water seems to be available for bioenergy production during most months in the year in La Pampa province, especially in the S land areas receiving more rainfall than the mS land areas. Switchgrass uses the available water more efficiently than soybean. In case of limitation in water availability during the growing period, switchgrass causes a higher risk for depletion of water resources compared to soybean. However, a shortage in rainfall will also lead to a yield reduction, limiting the risk for water depletion. Proper management and adequate monitoring can further reduce this risk. Environmental friendly and advanced techniques for efficient water use are especially promoted in scenarios B and C.

4.6.2. Performance of bioenergy chains in relation to water quality

The fertilizers used for the bioenergy chains are nitrogen and phosphorus fertilizers (Dam *et al.* 2008c). Phosphorus is not very soluble and mobile in a soil solution, in contrast to nitrogen (León 2005). No N fertilizer is applied for soybean production in the current situation. A small increase in N and P fertilizer is assumed for the scenarios A, B and C in 2030 (Dam *et al.* 2008c). Switchgrass uses more fertilizers, especially N fertilizer, in the cultivation process compared to soybean cultivation (Dam *et al.* 2008c). The low fertilizer inputs for soybean production can however be questioned for the current situation, as discussed in section 4.5.

Figure 15 shows the change in N_2O-N emissions from biomass production compared to the reference land-use (see also 4.1). Emissions from nitrate leaching are lower for soybean production than for switchgrass production, when abandoned cropland is used (CUR-S-C, A-S-C, and C-S-C). Nitrate leaching increases significantly for soybean production when replacing degraded or non-degraded grassland due to changes in soil carbon, resulting in N_2O-N emissions. Emissions from nitrate leaching for switchgrass production are limited and mainly a result of nitrogen fertilizer inputs.

The risk of water contamination is higher for agrochemicals than for fertilizers as measurements show that only a limited percentage of the agrochemicals used reach the intended source and the rest spreads to other sources (León 2005). So far no such contamination has been recorded for the Pampas but research on this subject is limited (Solbrig 1997). Figure 16 shows that the agrochemicals use for switchgrass cultivation is limited as it is used only during the establishment period and removal of the plantation.

Figure 15: Change in N_2O-N (in kg/ha/yr) emissions from leaching from switchgrass and soybean production for bioenergy compared to the reference land-use system for current situation and for scenarios A, B and C for 2030.

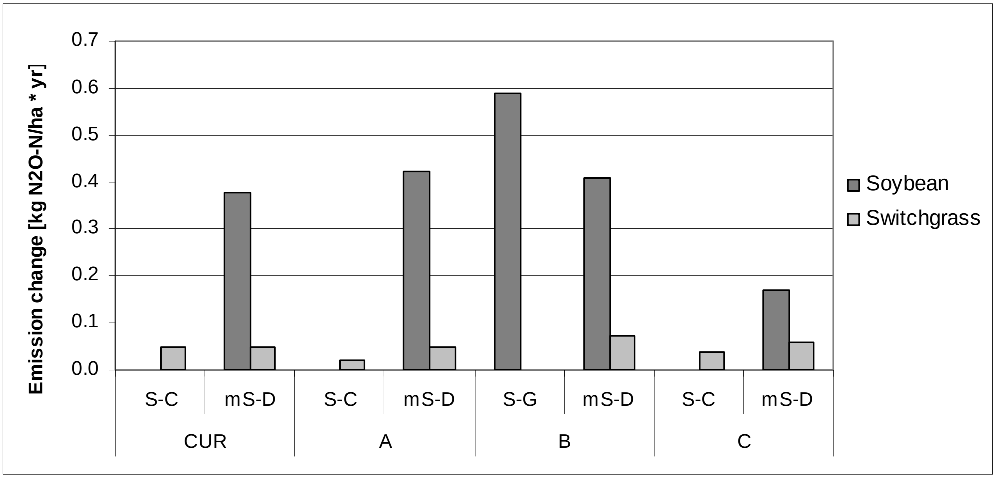


Figure 16: Change in agrochemical input for soybean and switchgrass production for bioenergy compared to reference land-use system in liter/ha or in kg/ha for current situations and for scenarios A, B and C for 2030.

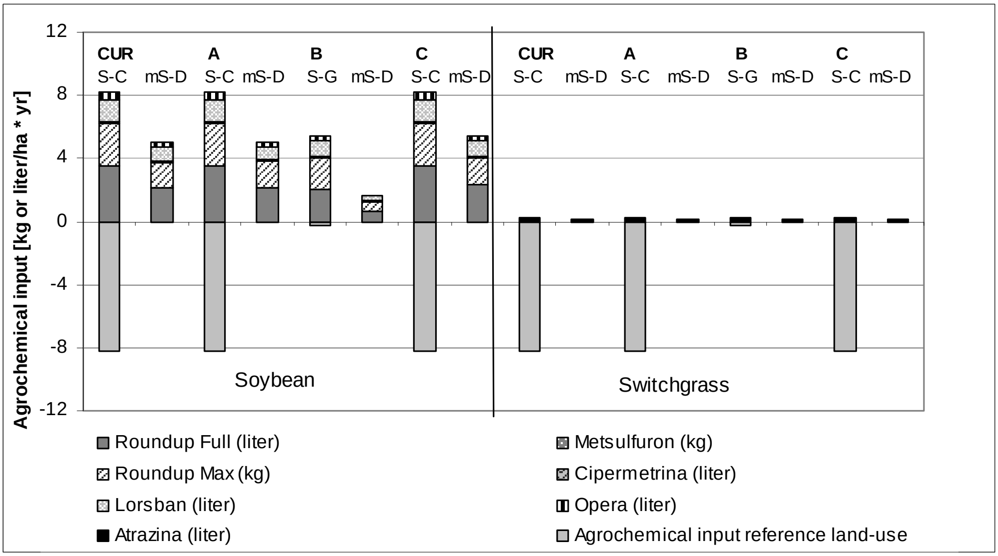


Table 10: Water solubility and possible environmental risks related to herbicides and pesticides use.

Product	Water Solubility		Environmental risks
	mg / liter	mg / liter	
Opera[a]	20 (PPBD 2008)		No information found
Metsulfuron	2790 (PPBD 2008)	9500 (NPIC 2008)	Low level of toxicity for fish and birds (León 2005). High to moderate toxicity for algae and aquatic plants (PPBD 2008)
Glysophate[b]	10500 (PPBD 2008)	900000 (NPIC 2008)	Virtually not toxic for bees, very little toxic for birds and fish (León 2005)
Cipermetrina	0.009 (PPBD 2008)	0.004 (NPIC 2008)	Moderately toxic for bees, not toxic for birds, highly toxic for fish (León 2005)
Lorsban[c]		4 (NPIC 2008)	Highly toxic to aquatic organisms on an acute basis in most sensitive species. Moderately toxic to birds on an acute or dietary basis (Dow Agrosciences 2004)
Atrazina	35 (PPBD 2008)	33 (NPIC 2008)	Low to average (depending on brand) toxicity on birds, fish, bees and aquatic plants (León 2005; PPBD 2008)

[a)] based on pyraclostrobin (main component), [b)] main component of Roundup, [c)] common name is Chlorpyrifos

The use of herbicides and pesticides for soybean production, used on an annual basis, is substantially higher. Several studies mention that the increased weed resistance of soybeans leads to an increased use of glysophate, combined with other herbicides (Berkum 2006).

Table 10 shows the water solubility and possible environmental risks related to herbicides and pesticides used for soybean and switchgrass cultivation. Highly soluble pesticides (e.g. metsulfuron and glysophate) are more likely to be removed from the soil by runoff or by moving below the root zone with excess water (NPIC 2008). Glysophate has no risk to disturb the fauna (León 2005). Metsulfuron, used on limited scale for soybean production, may have an average to high risk to disturb aquatic plants (PPBD 2008). Atrazina, used for switchgrass production, has a low water solubility and, a low to moderate risk to disturb the fauna (León 2005; PPBD 2008).

The change in N fertilizer and agrochemicals use are indicators for measuring the relative performance of the bioenergy chains for this criterion. Within this context, agrochemicals use has in this study a higher rating (1.2:1) than fertilizer use due to its higher risk for water contamination. The highest[41] score, defined as an annual decrease in fertilizer and agrochemicals use of 5 units/ha or more compared to the reference system, is estimated when switchgrass is produced on abandoned cropland. The lowest score, with an annual increase in fertilizer and agrochemicals use of 5 units/ha or more compared to the reference system, is estimated when soybean production replaces degraded or non-degraded grassland, with the exception of (B-mS-D).

4.7. Principle 7: Biomass production and processing and air quality

This principle aims to minimize air emissions with regard to biomass production, biomass processing and waste management. Compliance with national law and regulations is required (Cramer *et al.* 2007). The risk for air and waste contamination in both bioenergy chains is limited as no dangerous materials or rest products are produced or emitted to the air during the processing stages. Beside, national laws and regulations (Gobierno 1973; Gobierno 1991; DCA 2001b) are in place. The risk for undesirable air emissions due to bioenergy production and processing is therefore considered insignificant.

4.8. Principle 8: Production of biomass and local prosperity

The starting point of this principle is that biomass production contributes to the local economy. Cramer *et al.* (2007) propose to report on this principle according to the following indicators of the Global Reporting Initiative (GRI):

- EC1: Direct economic values that have been generated and distributed (revenues);
- EC6: Policy, methods and part of expenditure with respect to locally based suppliers;
- EC7: Procedures for local staff recruitment and share of the top executives originating from the local community at significant locations of operation;

Choices on expenditure of income (EC6) and human resource management (EC7) largely depend on the company to be established. It is therefore not possible to analyze these

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[41] Other scores: +: annual decrease in fertilizer and agrochemicals use of 0-5units/ha compared to reference system. -: annual increase in fertilizer and agrochemicals use of 0-5 units/ha compared to reference system.

indicators beforehand. It is, however, possible to give beforehand an indication of the generated revenues from bioenergy production to the local economy (EC1).

The socio-economic impacts of export-oriented bioenergy production in Argentina have been analyzed by Wicke (2006) with the use of an input-output model and focusing on the variables GDP, trade and employment (direct and indirect). Smeets *et al.* (2005) looked at the contribution of bioenergy production to local employment by analyzing historical trends in employments and wages with the use of statistics.

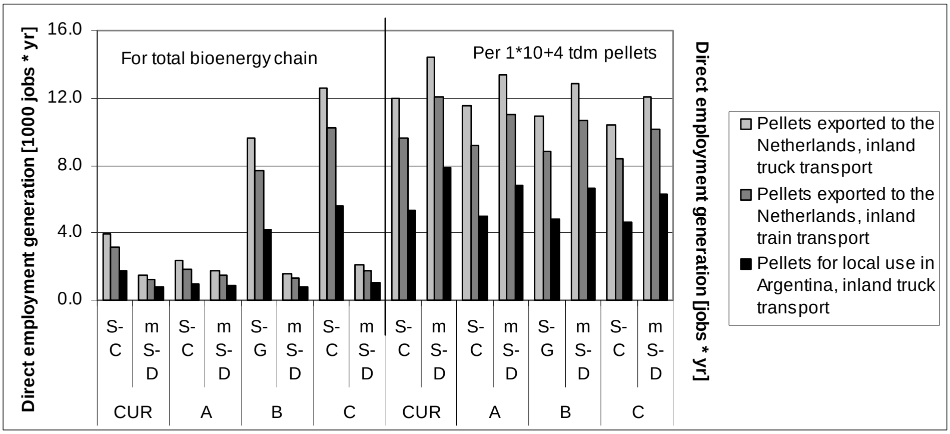
In this study, the following indicators are used to analyze the impact of biomass production on local prosperity: i) direct and indirect employment generation in the bioenergy chains and ii) GDP impact of bioenergy production. The direct employment generation can be calculated with labour input data (Dam *et al.* 2008c) for the different processing steps in the bioenergy chain for the current situation and for scenarios A, B and C for 2030. Scenarios B and C assume an increase in labour efficiency compared to the current situation, with the strongest increase for scenario C. An indication of the indirect employment and GDP generation from bioenergy production is based on literature sources and on data from Wicke (2006).

4.8.1. Local prosperity generated in the switchgrass bioenergy chain

Figure 17 (left) shows the estimated total direct employment generation generated for the switchgrass bioenergy chain. This ranges from $1.5*10^3$ jobs per year for (CUR-mS-D), with $1.0*10^6$ tdm pellets generated per year, to $12.6*10^3$ jobs per year for (C-S-C) with $12.1*10^6$ tdm pellets generated per year. Although scenarios (B-S-G) and (C-S-C) generate a high level of direct employment in case the available potential is fully utilized in the bioenergy chain (figure 17 left), the agricultural intensification and higher yields in these scenarios results in a decrease in jobs (in jobs / tdm pellets) compared to the current situation and scenario A (see figure 17 right). The same reasoning can be followed when comparing the direct employment generation on S land and on mS land. As shown in figure 17, inland transport by truck creates more employment than inland transport by train.

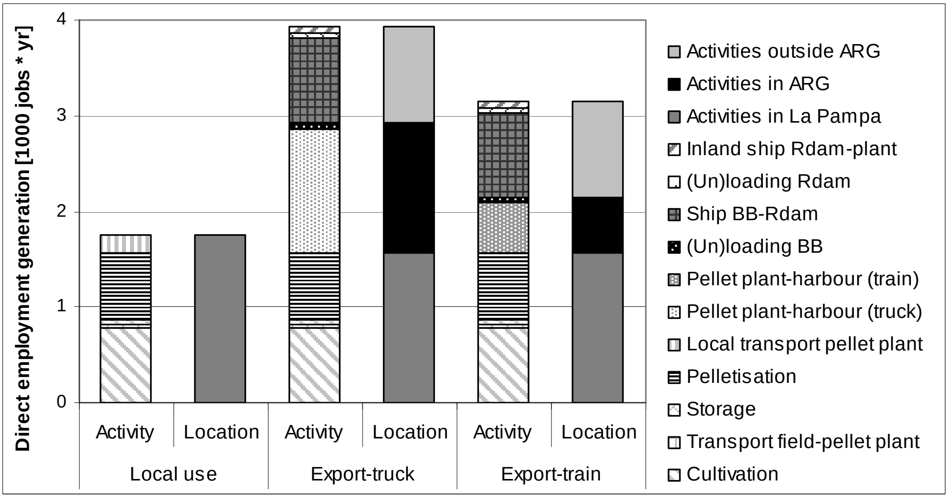
Wicke (2006) has estimated the total employment generation (direct and indirect) for a Eucalyptus pellet production chain (chain 1) and a Eucalyptus pellet FT production chain (chain 2). The results show that, beside the direct employment generation from these chains (23%), a substantial amount of extra jobs can be generated by indirect employment (30-31%) and induced impacts (46-47%). The high share of indirect impacts is explained by the large amount of machinery and equipment needed for pellet production. When using these percentages (Wicke 2006) for the switchgrass bioenergy chain, an additional indirect employment generation of $1.9*10^3$ (CUR-mS-D) to $16.4*10^3$ (C-S-C) jobs/year can be expected.

Figure 17: Left: Estimated direct employment generation in 1000 jobs per year in the total switchgrass bioenergy chain*. Right: Estimated direct employment generation in jobs per year per $1*10^4$ tdm pellets. The results are calculated for the current situation and for scenarios A, B and C for 2030.



* Total biomass potential in tdm pellets/yr: (CUR-S-C) $3.3*10^6$, (CUR-mS-D) $1.0*10^6$, (A-S-C) $2.0*10^6$ (A-mS-D) $1.3*10^6$, (B-S-G) $8.8*10^6$, (B-mS-D) $1.2*10^6$, (C-S-C) $12.1*10^6$ (C-mS-D) $1.7*10^6$

Figure 18: The distribution of the jobs generated per activity and per geographical location for the total estimated direct employment generation in 1000 jobs per year for the switchgrass bioenergy chain for (CUR-S-C) for local use and for export of pellets to Rotterdam (with train or truck for inland transport) for total pellets produced.



The export bioenergy chains generate for (CUR-S-C), with $3.3*10^6$ tdm pellets generated per year, 40-49% of the total direct employment in La Pampa province (see figure 18). The remaining employment, mainly generated in the transport sector, is located in Argentina (predominantly in Buenos Aires province) and outside the country. When the switchgrass pellets are used for local conversion, all direct employment is generated within La Pampa.

The intensification of agriculture in the future may lead to a decrease in jobs[42]. Wicke (2006) has estimated that $96*10^3$ jobs are lost in chain 2, due to agricultural intensification. This loss of jobs in the traditional agricultural sector is, however, by far compensated by an increase of $296*10^4$ jobs in the new economic activity of bioenergy production from Eucalyptus pellets.

Within the export chains for (CUR-S-C), cultivation, pelletisation and transport from the pellet plant to the harbour contribute respectively 20-44%, 18-39% and 17-33% to the total employment generated. Switchgrass cultivation and truck transport generate many jobs because of the high volumes of biomass produced. Large inland distances are another factor for employment generation. Employment generation in the conversion step is not included in this study. The FT/pellet sector contributes in Wicke (2006) around 3% to the total employment generation in the bioenergy chain. Employment generation in the conversion process is therefore expected to be limited.

Switchgrass bioenergy chains, including the required infrastructure and pellet plants, are not yet developed in Argentina (Dam *et al.* 2008c). Investments in this field therefore contribute to the development of a new economic activity. Wicke (2006) estimated that the percentual increase in GDP in 2015 (the moment when the bioenergy chains are fully developed) is 21% for chain 1 and 27% for chain 2 compared to the reference situation in 2001. Imports increase with 24% and 44% for chain 1 and 2. Although the imports are large compared to the reference situation in 2001, they are small related to the exports. Exports in chain 1 are more than four times higher than the imports. Exports in chain 2 are more than 12 times higher than the imports.

Based on the results, an indication can be given about the relative performance of the switchgrass bioenergy chain for this principle which is based on the direct employment generated. It is assumed that the relatively changes in direct employment are in line with expected contributions of the bioenergy chain to GDP and to indirect employment. The highest score, with more than 2000 extra generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when switchgrass is produced on S land. A relatively high score, with more than 200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when switchgrass is produced on mS land. Note that the number of jobs generated depends to a large extent to the amount of pellets produced in the switchgrass bioenergy chain, which varies per scenario.

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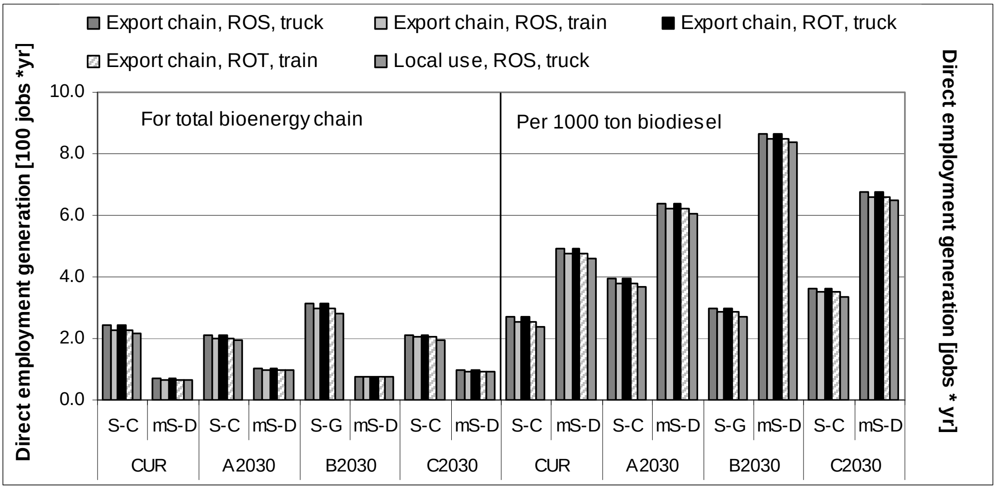
[42] As example: a yield increase from 3.7 to 8.9 tdm/ha is assumed for grain production from 2001 to the year 2015. An increase of feed crops use of 6% to 17.5% from 2001-2015 is assumed for the mixed livestock system.

4.8.2. Local prosperity generated in the soybean bioenergy chain

Figure 19 (left) shows the estimated total direct employment generation generated for the soybean bioenergy chain. This ranges from 58 jobs per year for (CUR-mS-D), with $1.4*10^4$ ton biodiesel generated per year, to 312 jobs per year for (B-S-G) with $10.4*10^4$ ton biodiesel generated per year. Although (B-S-G) generates a high level of direct employment in case the available potential is fully utilized in the bioenergy chain (figure 19 left), agricultural intensification and higher yields results in a decrease in jobs (in jobs per ton biodiesel) compared to the current situation (see figure 19 right). The same reasoning can be followed when comparing the direct employment generation on S land and on mS land. Inland transport by truck creates more employment than inland transport by train. The soybean bioenergy chain (whole crop) for export generates slightly more employment (3-12% for truck chains) than the chains for local use. This extra employment is generated outside the country (see figure 20).

Figure 19: Left: Estimated direct employment generation in 100 jobs per year in the total soybean bioenergy chain*. Right: Estimated direct employment generation in jobs per year per $1*10^3$ ton biodiesel. The results are calculated for the current situation and for scenarios A, B and C for 2030. Biodiesel processing is in Rosario (ROS) or in Rotterdam, the Netherlands (ROT). Inland transport in Argentina is by truck or by train.

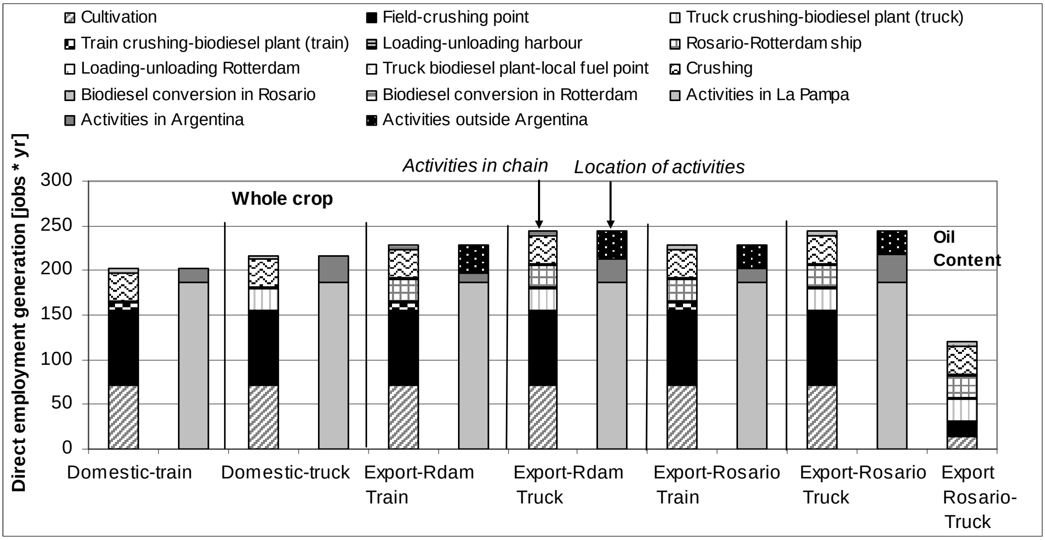


* Total biomass potential in ton biodiesel * yr: (CUR-S-C) $9.0*10^4$, (CUR-mS-D) $1.4*10^4$, (A-S-C) $5.3*10^4$ (A-mS-D) $1.9*10^4$, (B-S-G) $10.4*10^4$, (B-mS-D) $0.9*10^4$, (C-S-C) $5.8*10^4$ (C-mS-D) $1.4*10^4$

Llach *et al.* (2004) have estimated that the chain ‘vegetable oil and subproducts’ generated around $288*10^3$ jobs in Argentina in 2004, compared to $230*10^3$ for the milk chain and $543*10^3$ jobs for the meat chain. The Ministerio de Economía (1997) has estimated that every direct job generated in the soybean value chain multiplies to 17.7 indirect jobs. In comparison: One direct job in the petroleum, meat or milk sector multiplies to 10.6, 5.5 and 6.1 indirect jobs respectively.

Cultivation contributes 14 to 32% (whole crop) to the total direct employment in jobs per year in the export chain (truck-Rosario). This contribution is 29% in (CUR-S-C-truck-ROS) for the whole crop and 17% when employment is allocated to the soybean oil content, used for biodiesel production. The labour input (in hours per tdm) in the cultivation process (whole crop) is limited, ranging from 0.5 (CUR-S-C) to 0.8 hours/tdm (CUR-mS-D). This number fluctuates per scenario because of differences in yield and in efficiency. The required labour input for soybean production is discussed by Berkum *et al.* (2006), mentioning that large agricultural farms in Argentina with highly mechanized soybean production combined with direct seeding, generate around 1 labour place for every 200 hectares. In comparison, small traditional farms practicing rotation with two crops generate around 1 labour place for every 8 hectares.

Figure 20: The distribution of jobs generated per activity and per geographical location for the total estimated direct employment in jobs per year for the soybean bioenergy chain for (CUR-S-C) for local use and for export (with biodiesel processing located in Rosario or in Rotterdam) for inland truck or train transport, for total biodiesel produced.



The low labour input for intensive soybean production compared to more traditional production systems generates a process of rural out-migration, destabilization of livelihoods and scarcity of jobs in the agricultural sector in the Pampas region (Verner 2005; Berkum *et al.* 2006).

The contribution of processing activities to the direct employment generation in the soybean bioenergy chain is limited, namely 15-18% (whole crop) for the scenarios shown in figure 19. The biodiesel plants do not need many operators. They do, however, generate a demand in services that are supplied by regional companies. The biodiesel sector employed around $5*10^3$ people in 2008 (direct and indirect labour) and the sector is estimated to create $60\text{-}70*10^3$ jobs in the coming 15 years (Télam 2008). Truck transport from the field to the crushing plant contributes significantly to the total employment generation when looking at the whole crop (45-58% for scenarios in figure 19) due to the large product volumes that need to be handled in the beginning of the chain. This contribution reduces, however, significantly when only the soybean oil content, used for biodiesel production, is considered (see example in figure 20).

The soybean chain is an existing activity in Argentina. A value of 13.5 million US$ was exported in 2007, from which the state received 4.4 million US$ (ACSOJA 2008). Investments reached 750 million US$ in the year 2005-2007. From 2006 onwards, the biodiesel industry contributed significantly to these investments (ACSOJA 2008). Companies have invested 585 million US$ in biodiesel projects in Argentina in 2007 and additional investments, which are used to increase the capacity of crushing and biodiesel plants, of 800 million US$ were expected end of 2007 (Mathews *et al.* 2008). Capital costs generated in the soybean bioenergy value chain are thus mainly invested in a further extension of the required infrastructure of an already existing chain.

Based on the results, an indication is given about the relative performance of the soybean bioenergy chain for principle 8. No scenarios have the highest score (see also 4.8.1). A high score, with more than 200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when soybean is produced on S land. Scenarios, with 0 to 200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, have a neutral score as this amount of jobs is considered to contribute relatively little to local welfare in the region.

4.9. Principle 9: Contribution to social well-being from biomass production

Cramer *et al.* (2007) translate this principle into five criteria. The criteria and indicators are shown in table 11. As criteria 4 and 5 largely depends on the company to be established, it is not possible to estimate the performance for the associated indicators beforehand. Criteria 1 (no negative effects on human rights), 2 (no negative effects on the working conditions of employees) and criteria 3 (the use of land must not lead to the violation of official property and use) will be discussed in this study.

Table 11: Criteria and indicators for principle ‘production of biomass and contribution to social well-being as proposed by Cramer *et al.* (2007).

Criteria	Indicator
1. No negative effects on human rights	Recognition Universal Declaration of Human rights
2. No negative effects on the working conditions of employees	Compliance of Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy
3. The use of land must not lead to the violation of official property and use	Guarantee of right indigenous people. Land-use must be regulated by state
4. Positive contribution to the social well-being of the population	Social indicator 1 of GRI: Nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities
5. Insight into possible violations of the integrity of the company	Social indicator 3 and 4 of GRI: Percentage of employees trained in organization’s anti-corruption policies and procedures and actions taken in response to incidents of corruption.

4.9.1. Social well-being for the switchgrass and soybean bioenergy chain

The Universal Declaration of Human Rights, criterion 1, is recognized by Argentina (OHCHR-UNOG 1996). Violations against human rights related to the working conditions of employees and child labour are not an issue in Argentina (Verner 2005).

The recognition of the Tripartite Declaration of Principles, criterion 2, by companies is stimulated by the Argentinean government (Tomada 2008). The Argentinean government itself has subscribed the OECD guidelines for multinational enterprises[43] (OECD 2001). The Ministry of Labour has established the "Network for Corporate Social Responsibility and Decent Work" to promote Corporate Social Responsibility. This network of companies signed a Commitment to Corporate Social Responsibility and Decent Work in 2007 (Tomada 2008).

Rural work conditions in Argentina are regulated by specific resolutions. The ‘Rural Worker License law’ aims at regulating different aspects of the hiring process of permanent, temporary and harvest workers in the agricultural sector. The National Record Office of Rural Employers and Workers is established in 2001 to combat informal employment and to increase protection of workers (Verner 2005). Literature sources show variable estimations about the amount of informal workers (with no to limited access to insurance) and formal workers in agriculture in Argentina. Accurate statistical data are difficult to obtain. Unofficial estimations range from 17.5% to 50% of the workers in the agricultural sector engaged in formal employment (Verner 2005; Brondo *et al.* 2001; Neiman 2003).

Land-use rights, criterion 3, are officially laid down and described in Argentina. Land property in La Pampa province is largely regulated through private ownership or tenure of

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[43] The OECD Guidelines for Multinational Enterprises are recommendations addressed by governments to multinational enterprises, providing voluntary principles and standards for responsible business conduct consistent with applicable laws.

land. Limited areas of land are publicly owned (see also 4.3). In case the land is rented there are basically two forms of contracts (Lema 2004). The first form is a contract in which the owner charges a fixed amount per year or per harvest. The second form is that the owner receives a certain percentage of the production obtained by the tenant.

Based on criteria 1 to 3, no negative impacts from biomass production on the social well-being can be expected and, if properly managed, positive impacts can be generated. The latter is more probable in scenarios B and C, characterized by a stronger socio-environmental awareness and economy.

5. Synthesis of the environmental and socio-economic performance of the bioenergy chains

The relative performance of the environmental and socio-economic impacts of the bioenergy chains is summarized in table 12, showing that the impacts can vary strongly between scenarios for both bioenergy crops depending on the underlying assumptions.

Some conclusions can be drawn:

- Most environmental benefits can be achieved when switchgrass is produced on abandoned cropland;
- Switchgrass production replacing degraded grassland, limiting the competition with food and feed production, also shows a good overall sustainability performance, especially for scenarios (B-mS-D) and (C-mS-D).
- Soybean production for bioenergy shows a good overall sustainability performance if produced on abandoned cropland (A-S-C, C-S-C, and CUR-S-C). The production of soybean on degraded grassland results in a relatively lower sustainability performance;
- Bioenergy production on non-degraded grassland, especially from soybean production, may result in negative environmental impacts;
- Excluding the non-sustainable scenarios, being (CUR-mS-D, A-mS-D, B-mS-D, C-mS-D) for soybean production for bioenergy and (B-S-G) for both crops, the potential availability of land for bioenergy crop production in La Pampa province on S and mS land ranges from 0 to $24*10^4$ ha (instead of 17 to $30*10^4$ ha) for soybeans and from 17 to $97*10^4$ ha for switchgrass (instead of 37 to $97*10^4$ ha) (Dam *et al.* 2008c). The upper limit for switchgrass production for energy remains constant as the scenarios with a high potential are also the scenarios with a good sustainability performance;
- When excluding the non-sustainable scenarios, soybean biodiesel production costs are competitive with fossil fuel costs when oil has a price of 80-183 US$/barrel for the export chains (instead of 80-238 US$/barrel) and a price of 55-122 US$/barrel for local use (instead of 55-176 US$/barrel), depending on the scenario. Ergo, the non-sustainable scenarios are also the more expensive scenarios for soybean bioenergy production;
- When excluding scenario (B-S-G), there are no changes in the economic competitiveness from electricity from switchgrass pellets with the cost price of electricity from coal in the Netherlands. The use of switchgrass pellets for local energy production on the short term is economically not viable due to current low natural gas prices (Dam *et al.* 2008c).

Table 12: Rough indication of relative sustainability performance of switchgrass and soybean bioenergy chain based on the expected environmental and socio-economic impacts of the bioenergy chains when developed in La Pampa province (Argentina) for the current situation and for scenarios A, B and C to the year 2030 (+ = high score, - = negative score, 0 = neutral score, ++ = very high score, -- = very low score, ≈ = expectation with significant range of insecurity).

	Switchgrass bioenergy chain								**Soybean bioenergy chain**							
Principles	CUR		A		B		C		CUR		A		B		C	
	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS
Reference land- use [a)]	C	D	C	D	G	D	C	D	C	D	C	D	G	D	C	D
1 - Soil carbon balance [b)]	++	+	++	+	+	+	++	+	0	--	0	--	--	--	0	-
2 - GHG balance [c)]	++	++	++	++	++	++	++	++	++	+	++	+	+	0	++	+
3 - Land-use change Change in land-use [d)] Rise land prices [e)] Rise food prices	 ≈0+ 0 ≈ 0	 ≈0+ 0 ≈ 0	 ≈0+ - ≈ 0	 ≈0+ 0 ≈ 0	 ≈0+ + ≈ 0	 ≈0+ 0 ≈ 0	 ≈0+ + ≈ 0	 ≈0+ 0 ≈ 0	 ≈0 - 0 ≈ 0	 ≈0 - 0 ≈ 0	 ≈0 - ≈ 0	 ≈0 - - ≈ 0	 ≈0 - 0 ≈ 0	 ≈0 - 0 ≈ 0	 ≈0 - - ≈ 0	 ≈0 - - ≈ 0
4 – Biodiversity [f)]	+	0	+	0	-	0	+	0	0	-	0	-	-	-	0	-
5 – Soil quality Soil erosion [g)] Soil nutrients [h)]	 ++ ≈++	 ++ ≈+	 ++ ≈++	 ++ ≈+	 - ≈+	 ++ ≈+	 + ≈++	 ++ ≈+	 0 ≈0/-	 - ≈ --	 0 ≈0	 - ≈--	 -- ≈--	 ++ ≈--	 0 ≈0	 ++ ≈-
6 – Water quality Water quantity [j)]	++ ≈ 0+	+ ≈ 0-	++ ≈ 0+	+ ≈ 0-	- ≈ 0+	+ ≈ 0	++ ≈ 0+	+ ≈ 0	0 ≈ 0	-- ≈ 0-	0 ≈ 0	-- ≈ 0-	-- ≈ 0+	-- ≈ 0-	0 ≈ 0+	-- ≈ 0-
7 – Air quality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 – Local prosperity [k)]	≈++	≈+	≈++	≈+	≈++	≈+	≈++	≈+	≈+	≈0	≈+	≈0	≈+	≈0	≈+	≈0
9 – Social well-being	0	0	0	0	+	+	+	+	0	0	0	0	+	+	+	+

a) Reference land-use: G = non-degraded grassland, C = cropland, D = degraded grassland, **b)** (++) carbon benefit > 0.6 t C/ha per year, (+) carbon benefit > 0 and < 0.6 t C/ha per year, (0) carbon benefit = 0 t C/ha per year, (-) carbon benefit < 0 and > - 0.6 t C/ha per year, (--) carbon benefit < -0.6 t C/ha per year, **c)** (++) GHG reduction potential is > 85%, (+) GHG reduction potential is >35% and <85%, for lifetime period of 20 years, **d)** (+) Expected softening effect on ongoing land-use change of conversion of pasture areas to cropland areas, (-) Strengthening effect on ongoing land-use changes. Ongoing land-use change, **e)** (+) Decrease in land price compared to current situation, (-) increase in land price compared to current situation, **f)** (+) Positive MSA value, (0) MSA value is zero, (-) Negative MSA value, **g)** In change annual soil loss in t/ha per year compared to reference land-use system (++) Soil loss decreases > 2 t/ha per year, (+) Soil loss decreases >0 and <2 t/ha per year, (0) no changes in annual soil loss, (-) Soil loss increases >0 an <2 t/ha per year, (--)Soil loss increases >2 t/ha per year, **h)** See footnote b), **i)** In change in fertilizer and agrochemical use compared to reference land-use system: (++) Annual decrease of 5 units/ha, (+) annual decrease of >0 and <5 units/ha, (0) No change (-) annual increase of >0 and <5 units/ha, (--) annual decrease of >5 units/ha**, i)** (+) Environmental friendly and advanced techniques for efficient water use are applied in scenario, (-) Possible risk for water depletion in drier areas, j) In extra generated jobs per year due to introduction of biomass energy chain (++) > 2000 extra generated jobs (+) >200 and < 2000 extra generated jobs, (0) >0 and < 200 extra generated jobs, **k)** (+) Expectation of possible positive impacts on social well-being in scenarios with stronger socio-environmental awareness and economy, (0) Recognition of Universal Declaration of Human Rights, Tripartite Declaration of Principles and land-use rights.

Table 13: Overview of the indicators, data needs and methodologies used to analyze - based on a set of nine principles - the socio-economic and environmental performance of bioenergy chains. Future needs and options for improvement are given in the last column.

Principle	Methodology used	Data		Performance indicator	Future needs and options for improvement
		Need	Availability		
1. Carbon stock changes	IPCC methodology (IGES 2006)	High	Yes (mainly default values)	Δ ton C/ha per year	Need for local data, better insight in relation carbon stock changes with management system, land-use changes, land suitability.
2. GHG balance	IPCC methodology (IGES 2006)	High	Yes (partly default values)	GHG reduction in %	Improvement insecurity default values (N_2O emissions); need to collect local data and EF by-products.
3. Changes in land-use, prices	Reporting on land prices, food prices, land ownership and expected land-use changes in relation with current ongoing trends	Average	Yes (statistics, expert knowledge)	Land price, Food price Land ownership Expected land-use change	Not possible to draw a final conclusion ex ante. Methodology for qualitative indicator needs to be developed further.
4. Biodiversity	Total biodiversity assessment: Exclusion HCV areas + contribution bioenergy production to agro-biodiversity	Average	Yes (maps, legislation, empirical data)	Exclusion HCV areas MSA values	Stakeholder approach (Stewart C. 2008) requires more time. Field studies on relation local agro-biodiversity and biomass production.
5a. Soil quantity	USLE equation	Average	Yes (partly default values)	Soil loss in ton/ha per year	More accurate data for management factor agricultural systems. Wind erosion is not included in USLE equation
5b. Soil quality	Carbon stock change, as an indicator for SOM	High	Based on calculated results section 4.1	Δ ton C/ha per year (indicative)	Lack of accurate local data (crop recovery, nutrient composition crop) for simple nutrient balance equation. Standardised nutrient balance model to be developed based on limited set of input data.
6a. Water quantity	Simple water balance and WUE	Average	Low (default values)	Water shortage (WS) in mm/month WUE in g dm/kg water	Not possible to draw conclusion ex ante. Insight in dynamics local factors, climate, and energy crop characteristics needed by data collection and local measurements.

Table 13 (continued): Overview of the indicators, data needs and methodologies used to analyze - based on a set of nine principles - the socio-economic and environmental performance of bioenergy chains. Future needs and options for improvement are given in the last column.

Principle	Methodology used	Data		Performance indicator	Future needs and options for improvement
		Need	Availability		
6b. Water quality	The water solubility and toxicity level of the inputs (fertilizers, agrochemicals) used for bioenergy production	Average	Yes (partly based on calculated results)	N_2O-N $_{leaching}$ / ha per year Agrochemicals input in unit /ha per year, their toxicity and solubility level in mg/liter	Local measurements needed for better insight in risk water contamination due to inputs. Standardised methodology and indicator needed based on limited set input data.
7. Air quality	Compliance with legislation	Low	Yes	Compliance legislation	Qualitative indicator and methodology desired if air contamination is expected.
8. Local prosperity	Expected direct employment in bioenergy chains	High	Based on own calculations	Jobs / year	More insight needed in contribution bioenergy production to GDP and indirect employment.
9. Social well-being	Reporting on land-use rights and recognition declarations based on current situation	Average	Descriptive	a) Recognition declaration of Human Rights, b) Recognition Tripartite declaration, c) Description land-use rights	Final conclusions cannot be drawn ex ante whether a biomass project itself will contribute or not.

The results in the various scenarios show that most socio-economic and environmental benefits can be achieved when a bioenergy production chain aims to use the most advanced agricultural production system available in technical and environmental terms, replacing the land-use system in the region with the lowest economic and environmental performance while preventing leakage.

The overall performance of the bioenergy chains is in general higher for switchgrass than for soybeans. It is possible to significantly minimize the environmental impacts (especially the risk of leakage in land-use and biodiversity changes) from the soybean bioenergy chain when the generated feed is used explicitly for livestock production in the region. The surplus land can then be used for alternative purposes such as nature regeneration or biomass production. Modernising simultaneously biomass production for energy and food to prevent competition for land is needed to attain most socio-economic and environmental benefits from bioenergy production (UNDP 2000). The need and possibilities to diminish competition on agricultural land in Argentina by e.g. intensification and introduction of new species is mentioned by various authors (Stritzler *et al.* 2007; Adámoli 2007; Huergo 2008; ISAAA 2008). Land-use regulation and planning by the government in cooperation with the actors involved is in this case desired (Adámoli 2007).

6. Summary and conclusions

A combination of quantitative and qualitative indicators has been used to get an indication of the socio-economic and environmental performance of bioenergy production in the province La Pampa in Argentina. Qualitative indicators were used for the principles 3 (not endanger food supply and local applications) and 9 (contribution to social well-being) that lack an appropriate methodology or dataset to quantify the performance.

The use of standardized methodologies is desired but not yet possible for all principles, as shown in table 13. No appropriate methodology was available to couple macro-economic drivers with micro-economic impacts. The available methodologies to assess impacts of biomass production on water depletion and on soil quality require further elaboration to be applicable on a regional level for a range of biomass resources.

A norm or standard has to be set for the criteria used to be able to interpret and score the obtained results in terms of absolute performance. This standard is available for biodiversity (the MSA values) and for the GHG emission reduction that should be achieved (e.g. at least 35% GHG emission reduction compared to the reference case) but is at present lacking for other criteria. In our assessments, the scores for other principles are therefore based on a relative and not absolute performance of the bioenergy chains.

The type (default data, local data, expertise, maps) and level of accuracy of input data that is available varies strongly between the principles investigated. This indicates that the results in table 12 should be used with caution.

The results in table 12 show, however, also that it is possible to give a rough indication which chains and scenarios are expected to perform more sustainable than others. The use of scenarios enables to show the wide range in results that can be obtained due to variations in agricultural management systems, land suitability, reference land-use systems, lifetime periods investigated, allocation of impacts and the impact of indirect land-use changes. The approach gives an understanding of the complexity of bioenergy chains and the underlying factors influencing the GHG balance and other sustainability issues. Note for example that the reference land-use system 'cropland' in this study is based on soybean production and that the choice for an alternative crop may significantly change the results. It is concluded that key determinants for the sustainability of bioenergy production systems are the reference land-use, the selection the bioenergy crop suitable to the agroecological zone, and the management system that is used.

This also implies that it is possible to steer for a large part the sustainability performance of a bioenergy chain during the project development and implementation phase. Demonstration projects that apply a learning-by-doing approach combined with strict monitoring can give more insight in the sustainability performance of bioenergy chains in different regions. Various ongoing initiatives, such as the Roundtable on Sustainable Biofuels or the Roundtable on Responsible Soy, may serve as a suitable international platform to extend the knowledge and experience needed for sustainable bioenergy production. The productive and environmental quality system, developed by AAPRESID (Hilbert 2007; AAPRESID 2008), provides on a national level a sound basis. This system certifies crop production in general based on soil health indicator values and Good Agricultural Practices.

Land-use planning plays a key role in this process by setting conditions for biomass production (which crop, land-use, management system) in a certain region. This also requires for decision-makers a consideration of the relative importance of each principle as the improvement of one principle can mean a deterioration of the other. The conclusions also lead to the following recommendations for research:

- Further development and testing of a scenario-based set of socio-economic and environmental impact assessment tools that enables stakeholders to monitor and steer the performance of bioenergy projects;
- Development of a robust approach to weigh the performance of individual criteria;
- Improvement of the analysis of the socio-economic and environmental principles for bioenergy chains on a regional level by field data collection, methodology improvement and insight in interrelations of key underlying factors on various sustainability criteria (see also table 13).

The need to meet sustainability standards for bioenergy production to compete on the international market is recognized in Argentina (Panichelli 2007).

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Chapter 8: Summary and conclusions

Ensuring energy security and mitigating human-induced climate change by reducing GHG emissions are key challenges for the coming decades and beyond — especially in rural areas. These challenges must be met without compromising other needs such as food and water security and maintenance of biodiversity (IPCC 2007a). Bioenergy is considered to be one of the most viable options for meeting the increasing demand for energy services while mitigating climate change (IEA Bioenergy 2007; IPCC 2007a; OECD/IEA 2008a; OECD/IEA 2008b). For these reasons, modern bioenergy features prominently in the energy policy of many countries and its use is projected to increase considerably in the next few decades (REN21 2008).

An important requirement for a secure, long-term supply of biomass energy is the certainty that sufficient resources will continually be available. Several categories of biomass resource can be considered for evaluation: residues from forestry and agriculture, various organic waste streams and, most importantly, dedicated production of different types of energy crops[44]. Projections indicate that in the short and long terms, energy crops will provide the majority of the potential biomass. Three promising regions for biomass energy production are C.I.S and Eastern European countries, the Caribbean and Latin America, and sub-Saharan Africa (Hoogwijk *et al.* 2005; Smeets *et al.* 2007; Dornburg *et al.* 2008b).

Biofuels such as rapeseed methyl-esther and ethanol from starch and sugar crops grown in moderate climate zones are unlikely to reach truly competitive price levels in the coming decades, despite continuing improvements in production efficiencies and yields (IEA 2004). In some countries, including Brazil, the costs of producing ethanol from sugar cane are approximately equal to or even less than the cost of producing gasoline (Goldemberg 2007). In the long term, the production of so-called second-generation biofuels – i.e. methanol, di-methyl esters (DME), hydrogen, methane via synthetic natural gas (SNG), Fischer-Tropsch liquids, and ethanol produced from lignocellulosic biomass – may also become competitive as a result of continuing technological improvements, learning-by-doing and large-scale production (IEA Bioenergy 2007).

The potential supply of energy from biomass depends largely on the amount of land that is available for growing energy crops, taking into account that the growing worldwide demand for food must be met, biodiversity protected, soils and water reserves sustainably managed and a variety of other sustainability requirements fulfilled. Because the greater proportion of the future availability of biomass resources for energy depends on all these conditions, it is impossible to present the future potential of biomass energy production as one simple figure (Dornburg *et al.* 2008).

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[44] The analysis in this thesis is restricted to forestry and agriculture residues and dedicated biomass production on land, the latter having the main focus.

Taken together, the issues indicated above imply that the increasing biomass energy demand and production will go hand in hand with growing concerns as to the performance of bioenergy chains, especially regarding their socio-economic and environmental impacts.

Sustainable production and use of biomass resources is now considered a key requirement for market access in a growing number of countries (Zarrilli 2006; Cramer *et al.* 2007). When investigating the sustainability of biomass energy production, the environmental and socio-economic impacts that are taken into account relate to GHG emissions, competition with biomass for food production, biodiversity, water use, nutrient balance of soils, (local) welfare and social well-being. Developing principles, criteria, indicators and standards, as well as establishing certification schemes, are generally recognised as strategies that can facilitate sustainable biomass energy production and trade.

Between the various envisaged frameworks for sustainability and between the approaches of various countries and stakeholder groups, differences are evident in the strictness, extent and level of detail of the proposed social, economic and environmental criteria. A range of content-related issues have yet to be resolved, including the precise formulation of sustainability principles and criteria and the selection of indicators. This process is highly complex, because many stakeholders are involved and a wide variety of biomass production systems and settings must be taken into account.

Against this background, this thesis aims to provide an understanding of how the feasibility and sustainability of large-scale production, supply and use of bioenergy can be determined *ex ante*. This is addressed in the context of bioenergy for local use or trading on a regional level, taking account of the complexities and variabilities of underlying factors such as food demand and land use.

To this end, the following **research questions** have been formulated:

I. How can areas be selected *ex ante*, within specific world regions, that offer good short- and long-term prospects for biomass energy production, taking into account biological and climatic limitations, human food and animal feed demand, the need to maintain forests and biodiversity, and agricultural, environmental and energy policy directions?
II. How can the economic performance of large-scale biomass energy production and trading systems be determined for specific regions?
III. What initiatives are currently being taken in biomass energy certification and, more specifically, in the development of principles, criteria, indicators and methodologies to determine impacts and guarantee sustainable biomass energy production for a wide range of regions and biomass sources?
IV. What are the possibilities and limitations of adopting a unified approach to defining sustainable biomass and bioenergy production for a wide range of regions and biomass sources, focusing on calculation of GHG emission reductions?
V. How can the environmental and socio-economic impacts of a particular bioenergy chain be assessed *ex ante* with respect to various land-use scenarios?

These research questions are addressed in Chapters 2 to 7. Question I is analysed in Chapters 2 and 3. Chapters 2 to 4 give an answer to Question II. Question III is discussed in Chapter 5. Chapters 5 and 6 analyse Question IV. Chapters 6 and 7 give an answer to Question V.

The main findings of the individual chapters are discussed below. The discussion is followed by overall conclusions and recommendations for future research and policy development.

Chapter 2 assesses the technical potentials and cost-supply curves of bioenergy resources on a regional level in Central and Eastern European countries (CEEC), including Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia. The assessment is made on a NUTS-3[45] (local or district) level. Five scenarios, in the timeframe to 2030, were built to illustrate the influence of various factors on biomass potentials and costs. The scenarios V1 to V5 characterise the main regional drivers related to agriculture and land-use. The key characteristics of these scenarios are:

- *V1:* Trade is liberalised and no trade barriers exist between the EU and the world market for agricultural products. The EU specialises in products that are competitive on the world market. The agricultural sector in the CEEC uses high input and advanced technology production systems.
- *V2:* Policies are regionally oriented. Trade barriers exist between the Western and Eastern European markets. Agriculture in the CEEC has difficulties competing with agriculture in Western European Countries (WEC). The agricultural sector in the CEEC uses production systems similar to those currently applied there.
- *V3:* There are no internal trade barriers within the EU. Trade between the EU and the world market is based on the current situation (1997-1999). The Common Agricultural Policy (CAP) regulates EU agriculture. The CEEC have completely adapted EU legislation and can compete freely and fully with WEC agriculture. The agricultural sector in the CEEC makes use of high input, state-of-the-art production systems.
- *V4:* There are no internal trade barriers within the EU. However, trade barriers do exist between the EU market and the world market, as Europe protects its own market strongly. The agricultural sector in the CEEC uses high input and advanced technology production systems.
- *V5:* The EU (WEC and CEEC) gives priority to sustainable development and nature conservation. Protection and maintenance of biodiversity, rural areas and forest and grassland vitality have high priority. A certain level of market protection is needed for this. The agricultural sector uses ecologically sound production systems.

In this thesis, the technical potential of bioenergy resources is assessed by means of detailed, bottom-up calculations. The total available bioenergy potential, calculated on a regional or district level, is the sum of biomass from energy crops, wood from surplus

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[45] Nomenclature of Territorial Units for Statistics (NUTS) are the statistical regions of Europe and the Accession Countries (EUROSTAT 2002). NUTS-3 regions are local or district levels within a country (EUROSTAT 2002).

production forest, and agricultural and forest residues. A pre-condition in the assessment is that domestic demands for food and feed should be met, which will require a certain area of agricultural land. The size of this area depends on the food and feed demands, on the productivity of the agricultural system and on allocation procedures for the production of food and feed, which determine the land most suitable for each crop on the basis of its requirements. The currently available land, excluding forest and protected areas, minus the land required for food, feed and livestock production gives the surplus land that can be used to cultivate energy crops. The technical potential of biomass energy derived from these crops is calculated by multiplying the available land area by the productivity of the crops. Cost-supply curves indicate at which cost levels the biomass energy potential will become available. Cost levels are estimated by calculating the biomass production costs that are specific to the scenarios evaluated in the assessment.

An area of 36 to 46 million ha – the latter being 36% of the total agricultural land area – may become available for energy crop production in the CEEC. The scenarios in which current levels of agricultural production predominate (V2) or in which the emphasis is on ecological production systems (V5) show the smallest biomass energy production potentials of 2.0 to 5.7 EJ for all the CEEC. The more favourable scenarios (V1, V3 and V4) show a maximum potential of 11.7 EJ (85% from energy crops, 12% from residues and 3% from surplus forest wood) and biomass energy potentials that are larger than the current primary energy use in the CEEC. The greater part of the potential (83–94%, depending on the scenario chosen) comes from energy crops. In these scenarios, it should be noted, national food and feed demands are met and forest and nature areas are preserved.

The countries with the largest land areas, Poland and Romania, have the highest potentials for biomass energy production. A region with a high biomass potential is generally characterised not only by large land areas but also by favourable eco-physiological production conditions, such as fertile soils. The most ecologically sound scenario (V5) shows a conflict between the expansion of ecological agriculture and large-scale biomass energy production. This is due to the lower yields that are obtained using ecological production methods.

In most of the CEEC, the majority of the biomass potential can be produced at costs below 2 €/GJ — a figure that is lower than that in the WEC and is competitive with fossil fuels. Perennial lignocellulosic biomass crops such as willow, poplar and miscanthus have the lowest biomass production costs, followed by sugar beet and rapeseed. Production costs for willow biomass range from 1.0 to 4.5 €/GJ in the scenario reflecting the current state of agricultural production (V2) and from 1.6 to 8.0 €/GJ in the scenario with the highest agricultural productivity (V1). The main reason for the cost increase indicated above is the assumed increases in land and labour costs. Inputs like fertilizer and agrochemicals are another important cost component. The highest biomass production costs are found in the scenario in which ecological agriculture prevails (V5). High production costs are also found in areas where the land is of low quality.

Chapter 3 analyses, for developing national and international markets, the potential and economic feasibility of large-scale production of bioenergy from soybeans and switchgrass cultivated in a selected area of Argentina — a MERCOSUR country with a promising potential for bioenergy production. Currently, soybeans are Argentina's principle export crop. For bioenergy production the cultivation of switchgrass, which is as yet largely unknown as an energy crop there, seems promising as well. These reasons, and the fact that bioenergy potentials have not yet been well studied in Argentina, make that country an interesting case.

Three scenarios with a timeframe up to 2030 illustrate how the main drivers influence the potential and costs of these bioenergy systems. The potential and costs are also evaluated for the current situation (CUR). Scenario A reflects a baseline of economic development. Scenarios B and C are characterised by stronger economic growth. Scenario C is more export-oriented, while Scenario B is more environmentally friendly and oriented towards developing domestic markets.

The biomass energy potential is assessed on a national and provincial level, using the bottom-up methodology applied in Chapter 2 of this thesis, though with more specific national and regional data input. An area of Argentina that is suitable for large-scale bioenergy production is chosen according to the following predefined set of criteria:

i) Sufficient land availability for bioenergy production under the assumed scenarios;
ii) Potential for production of soybeans and switchgrass in the defined area;
iii) Limited risk of competition for land between bioenergy production and food/feed production;
iv) Proximity of logistical infrastructure.

Bioenergy chains are defined to enable analysis of the economic performance of large-scale biomass production for local use or for export to the Netherlands. The costs are determined for each step in the bioenergy chain.

On a national level, $18*10^6$ ha (A2030) to $33*10^6$ ha (CUR) of land may become available for soybean bioenergy production, whereas $10*10^6$ (A2030) to $17*10^6$ ha (C2030) of land may become available for switchgrass bioenergy production. Switchgrass can reach the highest biomass energy potential of $243*10^6$ tdm[46] (4.5 EJ) per year in the scenario with a high input production system and application of more advanced technology (C2030), compared to $99*10^6$ tdm (1.9 EJ) per year in the scenario with continuation of current agricultural production methods (A2030). Based on its crude vegetable oil content, soybean production can reach potentials of $13.8*10^6$ tdm per year (0.5 EJ) in CUR and $12.6*10^6$ tdm per year (0.45 EJ) in C2030 compared to $7.1*10^6$ tdm per year (0.25 EJ) in A2030. Most bioenergy production is from a combination of suitable (S) and moderately suitable (MS) surplus land. Overall, it can be concluded that the bioenergy potential of switchgrass is substantially higher than that of soybeans. It should be noted that this study does not consider possible impacts of climate change (e.g. droughts or increased rainfall) on the biomass potential results.

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[46] tdm = tonne dry matter

Based on the predefined set of criteria (see list above), the area of Argentina that is most suitable for cultivating energy crops is La Pampa province, where $65*10^4$ (A2030) to $127*10^4$ ha (C2030) may become available for switchgrass bioenergy production and $28*10^4$ (C2030) to $42*10^4$ ha (B2030) for soybean bioenergy production. If production is restricted to suitable (S) and marginally suitable (mS) land, $17*10^4$ to $30*10^4$ ha may become available for soybean bioenergy production and $37*10^4$ to $97*10^4$ ha for switchgrass bioenergy production.

Switchgrass production costs in La Pampa province are 33 US$/tdm (22 €/tdm)[47] on suitable land in CUR to 91 US$/tdm (62 €/tdm) on marginally suitable land (mS) in B2030. Soybean production costs range from 182 US$/tdm (124 €/tdm) on suitable land in CUR to 501 US$/tdm (341 €/tdm) on marginally suitable land in B2030. Land use, machinery, fuel, fertilizer and agrochemicals (in the case of soybeans) are the main cost components for energy crop production.

It is assumed that switchgrass is converted to pellets for electricity generation in the Netherlands or for local heating in Argentina. The production and transportation costs of pellets produced in La Pampa province are 58 to 143 US$/tdm (40 to 97 €/tdm) for local use and 150 to 296 US$/tdm (102 to 201 €/tdm) for export (including delivery to the quayside at Rotterdam Europort).

In the Netherlands, electricity derived from switchgrass pellets imported from Argentina can be produced at a cost of 0.06 to 0.08 US$/kWh (0.041 to 0.054 €/kWh), whereas electricity derived from coal costs 0.05 to 0.09 US$/kWh (Ouwens 2006), the higher figure including costs for carbon capture and storage. The electricity production costs for co-firing pellets in the current situation (CUR) and in scenario A2030 are approximately equal to the electricity production costs for coal when carbon capture and storage costs are excluded.

Heating costs in Argentina, based on the use of switchgrass pellets to replace natural gas, range from 0.02 to 0.04 US$/kWh (0.014 to 0.027 €/kWh). Because of the current low natural gas prices (based on 2007-2008 levels), switchgrass pellets cannot compete with natural gas to generate heat in Argentina. If natural gas prices increase in the future, as is assumed in two of the scenarios (B2030, C2030-mS), switchgrass pellets may become competitive with natural gas.

It is also assumed that soybeans produced in la Pampa province are converted to biodiesel for local use or export to the Netherlands. In the various scenarios, biodiesel can be produced at a cost of 0.3 to 1.2 US$/liter (0.2-0.8 €/liter) for local use and 0.5 to 1.7 US$/liter (0.3 to 1.2 €/liter) for export to the Netherlands. At current cost levels, soybean biodiesel production and export to the Netherlands (0.46 to 0.54 US$/liter) can compete with fossil fuel at an oil price of 80 US$/barrel when the soybeans are produced on suitable land, and at an oil price of 94 US$/barrel when the soybeans are produced on marginally

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[47] Cost data from 2007 to the beginning of 2008 are used to evaluate the current situation. Throughout this study, conversions from € to US$ and vice versa are based on the February 2008 exchange rate of 1 € = 1.47 US$. This rate is also used to compare results from the CEEC and Argentina.

suitable land. Also at current cost levels, soybean biodiesel production for local use (0.32 to 0.39 US$/liter) can compete with fossil fuel at an oil price of 55 US$/barrel when the soybeans are produced on suitable land, and at an oil price of 67 US$/barrel when the soybeans are produced on marginally suitable land. Clearly, biodiesel is not competitive with fossil fuels at price levels such as those in January 2009, when the oil price hit a low of 40 US$/barrel (IEA 2009).

The IEA projection for the crude oil price in the period 2008-2015 is 100 US$/barrel, rising to over 120 US$/barrel in 2030. This projection takes account of oil price fluctuations in the period 2007 to 2008. The IEA outlook (2008) indicates that “while market imbalances could temporarily cause prices to fall back, it is becoming increasingly apparent that the era of cheap oil is over” and that “pronounced short-term swings are likely to remain the norm and temporary price spikes or sharp falls cannot be ruled out”. The IEA predicts upward pressure on oil prices beyond 2015 until the end of the projection period (2030), mainly because of necessary investments in (additional) capacity to increase supplies (OECD/IEA 2008a). For this reason, oil price increases are probable even in the short-to-medium term.

As Argentina needs large quantities of biodiesel by 2010 to comply with its Biofuels Law, local use of soybean biodiesel is a favourable option.

Key parameters for evaluating economic performance are cultivation costs, pre-processing and conversion costs, transport costs and the costs and prices of fossil fuels and agricultural commodities. If markets develop, bioenergy costs can be expected to decrease due to optimisation of logistics, research and development, and technical learning. Improving the logistics of train transport in Argentina can make existing agricultural areas that are far from seaports economically attractive for bioenergy production.

The high potential and favourable economic performance of the switchgrass bioenergy chain in La Pampa province makes it interesting to further develop switchgrass production there, especially on marginally suitable lands. Currently, local use of switchgrass pellets is not economically competitive when replacing natural gas. It might, however, be worthwhile to use (a proportion of) the switchgrass pellets locally in La Pampa for alternative applications; for example, to diversify the locally available energy resources or to meet the national target of 8% renewable electricity by 2016. As switchgrass is a new alternative for bioenergy production in Argentina, demonstration projects should be developed, with possible integration of other perennial grasses for livestock production.

Chapter 4 assesses whether the market for, and trading of, biofuels can be profitable enough to realise a supply of biofuels from the Central and Eastern European Countries (CEEC) to the Western European market. This question is addressed by estimating the cost performance of the energy carriers delivered. A modular spreadsheet model is used to perform an economic analysis of a wide variety of long distance bioenergy chains.

This analysis was based on the scenario characteristics and calculated biomass potential results on a NUTS-2[48] regional level of the V3 scenario (see Chapter 2 of this summary).

Within the CEEC, five NUTS-2 regions in the Czech Republic, Hungary, Poland and Romania offer good prospects for producing biomass energy feedstocks in the short and long term. They are selected as key regions in this study. The selected Western European destinations for the biomass are Duisburg, Marseille and Rotterdam. Three options are analysed. In the first option, willow produced in the source areas is transported as pellets to the selected destinations. In the second option, willow is transported as pellets for large-scale ethanol conversion at the selected destinations. In the third option, willow pellets are converted to ethanol in the source areas and the ethanol is transported to the selected cities.

Pellets produced in the CEEC can be supplied to the selected destinations at a cost of 105 to 220 €/tdm. Compared to current pellet production costs of 74 to 119 €/tdm in Sweden and Austria, the production and export of pellets from the CEEC can be competitive only for a limited number of source regions, due to higher transportation costs.

Ethanol can be produced at 12 to 21 €/GJ if the biomass conversion is performed at the selected destinations in Western Europe or at 15 to 18 €/GJ if the conversion takes place (on a smaller scale) where the biomass is produced. The calculated ethanol production costs coincide with indicated ethanol production costs in the short term (22 €/GJ) and the long term (11 €/GJ) as cited by Hamelinck *et al.* (2005a). Based on an estimated cost range for oil of 13 to 19 €/GJ, assuming an oil price of 100 to 150 US$/barrel and an €/US$ exchange rate of 1.35, ethanol production costs can be economically attractive, in both the short and the long term. Ethanol may not be competitive when the price for oil is 11 €/GJ (approx. 85 US$/barrel) or lower, as in early 2009. Oil prices are, however, expected to increase in the short to medium term (see also Chapter 3), which will improve the competitiveness of ethanol.

Further reductions in ethanol costs can be achieved by reimbursement (based on 0.048 €/kWh) of the surplus electricity, which is cogenerated during the conversion process. If the electricity reimbursement increased to 0.06 €/kWh, total conversion costs of a 400 MW plant would decrease by 9%. If electricity reimbursement decreased to 0.04 €/kWh, total conversion costs of a 400 MW plant would increase by 5%. The level of reimbursement is often policy-related and can differ strongly from country to country and over time.

The cost performances of the CEEC bioenergy chains show that it is important to choose favourable source and destination areas in order to minimise transportation costs. In general, for long distance trading of biomass, the selected areas of Romania and Poland show better economic performance than the areas in the Czech Republic and Hungary. This may partly be due to the geographical position of the source areas and the destinations that are selected. CEEC areas with marine shipping options are most suitable for delivering biofuels or their feedstocks to international long distance markets.

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[48] A NUTS-2 region is a combination of NUTS-3 regions (see also Chapter 2 of this summary) and is often the provincial level within a country.

Biofuels from CEEC areas that lack connections to favourable transport options will mainly be put on local markets.

Chapter 5 provides an overview of current initiatives in biomass certification (until October 2007) and, more specifically, in the development of principles, criteria, tools and methodologies to guarantee sustainable biomass production for a wide range of regions and biomass resources.

Some national governments, such as those of Belgium, Germany, the Netherlands and the UK, and the European Commission have taken the initiative of developing a policy framework to guarantee sustainable biomass for energy production. In addition, various NGOs including WWF, FBOMS and a Dutch NGO alliance have published position papers expressing key concerns relating to sustainable biomass production. Other NGOs (including Solidaridad) have launched pilot studies or play an active role in forum debates on this issue.

The type of initiatives launched by companies that are active in developing biomass certification systems (e.g. DaimlerChrysler and Shell) depends on the company's role and interest in the bioenergy chain.

Table 1: Summarised overview of sustainability principles proposed or considered by various countries and stakeholder groups1) based on the situation in October 2007.

Principles related to:	Countries and the European Commission (EC)2)								NGOs3)			4)
	NL	B	UK	BR	Ca	GE	US	EC	SA	FB	N	E
Origin of biomass	●		●		●	●	●	●	●	●	●	●
Socio-economic issues 6)	●		●? 5)	●				●?	●	●	●	
Economic prosperity	●								●	●	●	
Working conditions	●			●						●	●	
Human rights	●			●						●	●	
Property rights	●			●					●		●	
Well-being	●									●	●	
Integrity										●		
Environmental issues 6)			●?					●?				
GHG, energy balance	●	●	●			●	●	●	●	●	●	●
Soil carbon	●							●			●	
Land competition	●								●	●	●	
Biodiversity	●					●			●	●	●	
Waste	●								●			
Agrochemicals use	●									●		
Farming practices	●			●	●	●			●	●	●	
Sustainable land use	●			●		●	●		●	●	●	
Soil	●			●					●	●	●	
Water	●								●		●	
Air emissions	●				●				●			
GMO use									●	●	●	

1) Not all initiatives by NGOs, companies and international bodies are shown in this table. For a complete overview, see Chapter 5. 2) NL = the Netherlands, B = Belgium, UK = United Kingdom, BR = Brazil, Ca = Canada, GE = Germany, US = United States (California), EC = European Commission. 3) SA = South African NGOs, FB = Brazilian NGOs, N = Dutch NGOs. 4) EL = Electrabel Company. 5) ? = Inclusion of this principle is under discussion. 6) There is a willingness to include socio-economic or environmental principles, though which principles are to be included is as yet undefined.

Initiatives by international bodies are focused on a wide range of activities, such as providing financial and knowledge support to developing countries or establishing forums for information exchange. International bodies, including UNEP and the Global Bioenergy Partnership (GBEP), have formulated specific projects to gain insight into the question of how to develop a biomass certification system. International networks and roundtables, such as those for soybeans (RTRS), palm oil (RSPO) and biofuels (RSB), are voluntary in approach and should also result in the development of a certification system for their specific commodity.

Concrete initiatives to translate sustainability principles into operational criteria and indicators, and to monitor and verify them through an established biomass certification system, are more limited. In October 2007, two certification systems for biomass were in operation, initiated by energy companies (GGL and Electrabel). The Belgian, Dutch and UK governments, as well as the RSPO, have also launched initiatives to develop biomass certification systems. The function of these systems varies from developing to testing sustainability criteria.

Several issues impede the development of biomass certification systems. The overview of initiatives presented in Chapter 5 demonstrates that differences are evident in the strictness, extent and level of detail of criteria, due to differences in interests and priorities. A proliferation of individual standards and systems may lead to a loss of efficiency and credibility. Also, there are many unresolved uncertainties regarding the feasibility, implementation and costs of international biomass certification systems and their compliance with international laws and agreements on trade. Therefore, in this preliminary phase it is worthwhile to consider which approaches can be taken to developing a reliable, efficient biomass certification system.

In the various possible approaches to developing, implementing and governing a biomass certification system, the two main distinctions are whether the system is voluntary or mandatory and whether it is internationally or nationally oriented. Each published approach has its own strengths and limitations. Nevertheless, it is true of all the initiatives that the following urgent actions must be taken if they are to be further developed:

I. Better international coordination between initiatives is required in order to improve coherence and efficiency in the development of biomass certification systems. Various international organisations can take the lead, including the European Commission (for the European region), UNEP, FAO and UNCTAD. This should give a clearer direction to the approach taken on a national and a local level.

II. Existing WTO agreements, such as the Technical Barriers to Trade Agreement, the Most Favoured-Nation Principle or the Code of Good Practice, and related jurisprudence already inform the role of the WTO with respect to the development of a biomass certification system. As yet, however, no precedent has been established in this area. A process of negotiation between WTO members is necessary to reach further agreement on, and gain more insight into, this topic.

III. Certification is not a goal in itself, but a means to an end. It can be one of the policy tools to secure the sustainability of biomass production and use. Setting up good practice codes and integrating sustainability safeguards into global business models may also be effective ways to ensure this. It is important to keep an open mind on (a combination of) alternative policy tools in order to identify the most suitable options for securing sustainable biomass production and trade.

IV. Currently, there is only limited experience in making several criteria operational. The design of specific criteria and indicators in relation to the requirements of a region, as well as questions such as how to include the avoidance of leakage effects and the influence of land-use dynamics, requires the development of new methodologies and integrated approaches. This may take several years to achieve. On the other hand, there is already a short-term need to secure the sustainability of biomass in a fast-growing market. A gradual development of certification systems, involving a learning process (through pilot studies and research) and expansion – linked to the development of advanced methodologies – can provide valuable experience and further improve the feasibility and reliability of biomass certification systems. This stepwise approach offers possibilities for coherence, monitoring and adjustment of activities.

Chapter 6 discusses in greater detail the GHG balance of bioenergy systems — considered to be one of the most important issues in a certification system. Current developments include a strong increase in initiatives to develop GHG methodologies and tools. The differences between these initiatives illustrate the difficulty of achieving an internationally accepted methodology, as well as default values to calculate the GHG balances. Although the economic feasibility of bioenergy projects is of importance for both investors and policy-makers, the cost-effectiveness of bioenergy to mitigate GHG emissions is seldom considered.

A range of methodological issues have to be taken into consideration when calculating the GHG balance and cost-effectiveness of biomass energy systems. These issues include leakage effects, allocating emissions to the main- and by-products, carbon stock dynamics, up-stream energy inputs, and efficiency of the energy systems. In Chapter 6, a unified methodology is developed to evaluate GHG balances and the cost-effectiveness of biomass energy systems. This methodology serves as the basis for the framework of a user-friendly software tool to analyze GHG balances and the cost-effectiveness of GHG mitigation.

The main features of this tool are the flowchart design and the concept of working with different tiers of calculation and data input. The five case studies presented show that the tool is able to accommodate a wide range of biomass energy systems. Its flexibility allows users from different regions to use this methodology, which significantly improves the comparability and consistency of results.

These case studies demonstrate that, in order to calculate the GHG balance and the cost-effectiveness of biomass energy systems, the core methodological issues can be accommodated in one single tool. These are the functional unit, mitigation parameters, the system boundary, the reference energy system, direct land-use and carbon changes, indirect land-use change, allocation procedures, timing issues, cost measurements, site specificity and uncertainty.

Biomass energy systems cover a wide range of biomass energy demand and supply options. The software tool is able to accommodate this diversity by allowing the user to make use of aggregated or disaggregated data. Of course, the quality of the results depends on the accuracy of the data used. The case study on ‘Fuel production in the Netherlands from wood residues in Canada’ assumes that one output product is generated: FT-diesel. Electricity is generated as a co-product. Allocation of energy inputs, emissions and costs between the generated fuel and electricity in the conversion process is based on substitution and, alternatively, on allocation of energy content. In this summary, the results for allocation based on energy content are given. The case study illustrates that the total GHG emissions and energy costs per GJ delivered (GJ_{del}) from a detailed data level are respectively 25 kg CO_2 eq./GJ_{del} and 32 €/GJ_{del}. In comparison, total GHG emissions and energy costs per delivered GJ are respectively 25 kg CO_2 eq./GJ_{del} and 21 €/GJ_{del} when using aggregated data. This difference (especially in costs) can be significant for investors, policy makers and other stakeholders.

The case study ‘Combustion of forest processing residues under Finnish/Swedish conditions’ demonstrates that the selection of the reference energy system is important. This case illustrates that the change from current (2000) to more advanced technology (2020) lowers emissions from the bioenergy system from 15 to 10 kg CO_2 eq./GJ_{del} (sum of heat and electricity), while the energy costs are more or less equivalent (7.6 versus 7.5 €/GJ_{del}).

For allocating GHG emissions and costs to the main product and by-product of the biomass projects, there is no general procedure that is acceptable under all circumstances. Allocation using the multifunctional or subtraction approach is preferred but has its limitations. The choice of allocation based on mass or energy content or market price of the different products should be treated with caution, as it can have a major influence on the outcomes. This is illustrated by the case study on ‘Biodiesel from rapeseed in the UK’, which shows a variation of 35 to 50 kg CO_2 eq./GJ_{del}, depending on the selected procedure and the underlying assumptions. Allocation based on energy content, which is currently (early 2009) proposed by the European Commission, is less sensitive to the variability in input parameters and underlying assumptions than allocation based on market price.

The discussion of whether and how to include indirect land-use change in the methodology for calculating GHG balances continues. The case study ‘Heat from Miscanthus in the UK’ shows that the impact of assumptions on land-use changes can be large; this is illustrated by avoided GHG emissions ranging from 13 to 128 kg CO_2 eq./GJ_{del}, depending on the reference land-use system assumed. Included references are mowing grassland, rotational set-aside land and crop production from rapeseed. This case study shows that the performance of a biomass energy system is site- and time-specific.

As more accurate input data gives more accurate results, the user must be confident about the quality and appropriateness of the data used. Site-specific analyses using disaggregated data are preferred. To keep track of the positive and negative impacts of biomass production and trading, it is necessary to collect further data and to develop consistent databases with a focus on promising biomass energy producing regions.

Chapter 7 analyses the feasibility of conducting *ex ante* a socio-economic and environmental impact analysis for large-scale bioenergy production on a regional level, based on a set of defined criteria and indicators. The analysis is done for large-scale bioenergy production from soybeans and switchgrass in La Pampa province in Argentina. The results are calculated for the current situation (CUR) and for scenarios A, B and C in the year 2030 (see also Chapter 3). Switchgrass and soybeans are produced on suitable (S) and marginal suitable (mS) land areas. The reference land-use systems are cropland (C), degraded grassland (D) and non-degraded grassland (G). The availability of data and methodologies is discussed for each sustainability principle that is formulated and applied for La Pampa province. In our sustainability assessment, a total of nine sustainability principles are used.

A combination of quantitative and qualitative indicators is used to indicate the socio-economic and environmental performance of bioenergy production in La Pampa province. Qualitative indicators were used for Principle 3 (which states that biomass production for energy must not endanger food supply and other local biomass applications) and Principle 9 (which states that biomass production must contribute to social well-being). Both principles lack an appropriate methodology or dataset to quantify the performance.

The use of standardised methodologies is desirable but not yet possible for all principles. At the time of writing, no appropriate methodology was available to couple macro-economic drivers with micro-economic impacts. The available methodologies for assessing impacts of biomass production on water quantity and soil quality require further elaboration to be applicable on a regional level for a range of biomass resources.

A norm or standard has to be set for the criteria used in order to be able to interpret and score the obtained results in terms of absolute performance. This standard is available for biodiversity (MSA values) and for the GHG emission reduction that should be achieved (e.g. at least 35% GHG emission reduction compared to the reference case), but is currently lacking for other principles. In our assessments, the scores for other principles are therefore based on a relative rather than an absolute performance of the bioenergy chains. The type (default data, local data, expertise, maps) and level of accuracy of input data that is available varies strongly between the criteria investigated.

The carbon stock change for switchgrass ranges from 0.2 to 1.2 ton C/ha per year and for soybeans from 1.2 to 0.0 ton C/ha per year, depending on the scenario. The GHG emission reduction ranges from 88 to 133% for the switchgrass bioenergy chain (replacing coal or natural gas) and from 16 to 94% for the soybean bioenergy chain (replacing fossil fuel) for various lifetime periods. The MSA value, an indicator of the impact of biomass production on biodiversity, ranges from +0.2 (conversion of intensive cropland production to switchgrass production) to -0.2 (conversion of extensive grassland to soybean production). The water use efficiency (WUE) of biomass production ranges from 0.4 to 0.6 g dm/kg water for soybean production and from 1 to 22 g dm/kg water for switchgrass production. The annual soil loss, compared to the reference land-use system, is 2 to 10 ton/ha for the soybean bioenergy chain and 1 to 2 ton/ha for the switchgrass bioenergy chain.

Most environmental benefits can be achieved when switchgrass is produced on abandoned cropland. Switchgrass production replacing degraded grassland, and limiting the competition with food and feed production, also shows good overall sustainability performance, especially for scenarios (B-mS-D) and (C-mS-D). Switchgrass production on non-degraded grassland may result in negative environmental impacts.

Soybean production for bioenergy shows a good overall sustainability performance if produced on abandoned cropland (A-S, C-S, and CUR-S). The production of soybeans on degraded and non-degraded grassland results in a lower sustainability performance.

Excluding the non-sustainable scenarios (i.e. CUR-mS-D, A-mS-D, B-mS-D, C-mS-D for soybean production and B-S-G for the production of both crops), the potential availability of land in La Pampa province for bioenergy crop production on S and mS land ranges from 0 to $24*10^4$ ha (instead of 17 to $30*10^4$ ha, see Chapter 3) for soybeans and from 17 to $97*10^4$ ha for switchgrass (instead of 37 to $97*10^4$ ha, see Chapter 3). The upper limit for switchgrass production for energy remains constant because the scenarios with a high potential are also the scenarios with good sustainability performance.

As soybean production for biodiesel for export and local use is cost-effective for all scenarios, this chain remains economically viable when excluding the non-sustainable scenarios. Large-scale switchgrass production remains economically viable for export in the short and long terms when excluding scenario B-S-G. The use of switchgrass pellets for local energy production in the short term is economically unviable (see Chapter 3).

In general, the overall performance of the bioenergy chains is higher for switchgrass than for soybeans. It is possible to significantly reduce the environmental impacts of the soybean bioenergy chain (especially the risk of leakage in land-use and biodiversity changes) when the generated feed is used explicitly for livestock production in the region. The surplus land can then be used for alternative purposes such as nature regeneration or biomass energy production.

The results in the various scenarios show that most socio-economic and environmental benefits can be achieved when a bioenergy production chain aims to use the most advanced agricultural production system available in technical and environmental terms, replacing the land-use system in the region with the lowest economic and environmental performance while preventing leakage.

It is possible to roughly indicate which chains and scenarios are expected to perform more sustainably than others. The use of scenarios enables us to show the wide range of results that can be obtained, due to variations in agricultural management systems, land suitability, reference land-use systems, lifetime periods investigated, allocation procedures and the impact of indirect land-use changes. This approach facilitates an understanding of the extent to which the underlying factors influence the GHG balance and other sustainability issues. Note, for example, that in this study the reference land-use system of ‘cropland’ is based on soybean production. The choice of an alternative crop may significantly change the results.

Final conclusions and recommendations for policy developments and research

The research presented in this thesis illustrates that it is possible to select *ex ante* promising areas for biomass energy production in the short and long term, taking account of biological and climatic conditions, food and feed demand, and the need to maintain forests and biodiversity — all in different (policy) scenarios. Promising regions can be selected according to pre-defined sets of criteria, as demonstrated in Chapter 3 (Research question I). The technical potential of bioenergy resources can be evaluated by means of bottom-up calculations (see Chapters 2 and 3), which clarify the levels of improvement in agricultural management at which land can be released for biomass production, without causing indirect land-use change. The analysis, for the selected areas, of the economic performance of large-scale biomass energy production and trading systems (Research question II) builds on this approach: the cost calculations take account of spatial variation in yields, land-use and prices, as well as subsequent logistical operations.

This thesis also demonstrates that international trade patterns and the prices of fossil fuels and agricultural commodities can have a significant impact on the potential and performance of bioenergy chains at micro-level. It is therefore recommended that top-down and bottom-up approaches should be coupled. Furthermore, the possibilities and limitations of improving the efficiency of agricultural and livestock production systems within a definite timeframe merit further analysis.

In an increasing number of countries, the sustainable production and use of biomass resources is now considered a key requirement for their further deployment. In recent years, national governments, NGOs, companies and international bodies have launched a wide range of initiatives in the field of biomass certification. These include the development of principles, criteria, tools and methodologies to guarantee sustainable production of a wide range of biomass resources in diverse regions (Research question III). So far, however, there is a general lack of concrete initiatives aimed at translating sustainability principles into operational criteria and indicators, as well as monitoring and verifying bioenergy projects through an established biomass certification system.

Several unresolved issues impede the development of biomass certification systems (Research question IV). These include uncertainties as to the feasibility, implementation and costs of international certification systems, and their compliance with international laws and agreements on trade, such as the Technical Barriers to Trade Agreement, the Code of Good Practice and the Most Favoured Nation Principle.

The following aspects are important when considering approaches to analysing the environmental and socio-economic impacts of bioenergy chains and evaluating their overall sustainability:

- To enable both a transparent analysis and a comparison of results for various countries, biomass resources and biomass energy technologies, it is essential to take a unified approach. This is necessitated by the current sharply increasing implementation of bioenergy projects in many world regions and the range of requirements for demonstrating the sustainability of biomass energy projects. Therefore, using one standard approach for a criterion is vastly preferable to using different approaches, which generally yields divergent results. The elaboration of a unified methodology for calculating GHG balances is moving in the right direction, though there is still room for improvement. The software tool described in Chapter 6 makes it possible for users from different regions to use the same methodology to calculate the GHG balance and cost-effectiveness of different biomass energy systems.

- Various socio-economic and environmental criteria require the development of new or improved approaches and performance indicators. For example, the influences of food, feed and land prices on direct and indirect land-use changes are still poorly understood. In addition, although the Universal Soil Loss Equation is a robust methodology for calculating the annual soil loss due to water erosion, it takes no account of wind erosion. Several indicators (e.g. overall nutrient balance, the balance of a key nutrient, and the organic matter content) can be used to assess the impact of biomass production on soil quality. However, when it comes to defining and quantifying this impact, there is no (standardised) performance indicator.

- There is also a lack of standards (or thresholds) per criteria, which complicates the evaluation of a bioenergy chain's sustainability. Although the water use efficiency (WUE) of switchgrass and soybeans can be roughly estimated in order to assess the impacts of biomass production on a region's water quantity, the spatial level at which water use results in water depletion that may be unsustainable remains undefined. Furthermore, no standard is available for assessing the absolute decrease or increase in annual soil losses that results in unsustainable soil erosion rates.

- The accuracy of the data input determines the exactness of the predictions regarding the potential and performance of bioenergy chains in the short and long term on a regional level. Accurately mapping the potential for biomass production and trading requires better land-use data and the development of transparent databases. For example, more site-specific data are needed to reveal the impact of agricultural management systems on soil carbon default values. Furthermore, data on marginal and degraded land is generally of limited quality. Regionalised input data, among others, are needed for hydrological analyses and biodiversity impact assessments. Often, for obvious reasons, data availability is more limited in developing countries; there is a great need for adequate and sufficient datasets from these countries, with a focus on promising biomass producing regions.

Despite the current limitations, the environmental and socio-economic impacts of a particular bioenergy chain in various land-use scenarios can be assessed *ex ante*, in order to determine which bioenergy chains are promising in the short and long term (Research question V). Chapter 7 shows that, on the basis of the criteria, indicators, standards and methodologies that are currently available, it is possible to predict, with a reasonable degree of certainty, which bioenergy chains will perform more sustainably than others. With regard to the potential of bioenergy chains, as well as their economic and sustainability performance, the scenario-based approach used in various chapters of this thesis clarifies the range of results that can be achieved if the underlying factors are altered. The chosen bottom-up approach enables scenario parameters to be translated into changes in the key variables that determine the impacts of the biomass production systems analyses. This gives insight into the bioenergy development pathways that should be pursued or avoided in order to obtain sound environmental and socio-economic performance.

In this context, the following factors are important:

- The development of more efficient and productive agricultural and livestock management systems should be supported. This development should be based on optimal use of agricultural inputs, modern crop varieties and efficient technologies.
- Biomass production should be allocated to areas where synergies in the potential and the socio-economic and environmental performance can be achieved. A key example analysed in this thesis is the production of perennial grasses on more marginal lands with benefits in terms of reducing soil erosion, protecting soil carbon contents and maintaining biodiversity. In order to achieve such aims, accurate and specific geographical information systems and land-use data are required.
- A suitable energy crop (or combination of crops) should be selected by matching and optimising the regional agro-ecological conditions to the crop requirements. Generally, when high energy yields, low biomass production costs and environmentally friendly production methods are to be combined, the production of perennial lignocellulosic crops is preferred. This is especially true when marginal lands are used.
- Land-use planning and monitoring of land-use changes on a macro-level are necessary, excluding areas with a high biodiversity value from biomass production. Areas with a low biodiversity value can be allocated for biomass production, as this may contribute to their rehabilitation.
- Logistics should be optimalised by choosing favourably connected export regions, means of transport and destination areas. Generally, ocean transport is preferable for long distance international transport, followed by, in decreasing order, short sea shipping, inland waterway shipping, rail transport and truck transport. Costs are further reduced when pre-processing or conversion plants are located within or near the biomass producing region and when economies of scale of (final) conversion to energy carriers are used.

In conclusion, the combination of all the work presented in this thesis demonstrates that the feasibility and sustainability of large-scale biomass production (for local use or trading) can be assessed *ex ante*. Embedding impact analysis in a scenario-based approach is an effective way of dealing with the great spatial and temporal variations that are possible in the performance of biomass production and supply chains. The use of regional analyses and the availability of sufficiently disaggregated data (on land-use and water availability, etc.) are indispensible if sufficiently reliable results are to be achieved. Furthermore, the work presented demonstrates that the factors listed above are interrelated. For example, the improvement of one sustainability principle (e.g. employment generation) can mean a deterioration of another (e.g. the balance of GHG emissions), though synergies can also be achieved. That is why this thesis is entitled *Sustainability of bioenergy chains: the result is in the detail*s.

On the basis of these conclusions, the following policy recommendations are made:

- Sound potential, economical and sustainability performance analyses, examples of which are presented in this thesis, are needed to guide policy and market activities aimed at the (further) development of biomass production potentials.
- Solid and regionally specific data are required for a sound regional analysis of the potential, costs and sustainability of bioenergy chains. This thesis has demonstrated that such an analysis is feasible to a reasonable level of detail.
- Reaching international agreement on suitable approaches to analysing impacts and collecting data of the required quality is crucial to internationally credible certification and monitoring efforts. It is highly desirable to harmonise efforts towards certification and related development of indicators and analysis tools.
- This thesis shows that the potential and performance of bioenergy chains vary with time. Therefore, monitoring and repeated evaluation are necessary.
- Demonstration projects that take a learning-by-doing approach can provide the knowledge that is needed for the further development of bioenergy production. The gradual development of a biomass certification system linked to the development of advanced approaches (e.g. to evaluating impacts on soil quantity, land-use changes and relations to macro-economic drivers) can improve the feasibility and reliability of the assessments in a stepwise approach.
- Clear and coherent policy strategies have to be formulated in order to further develop sustainable large-scale biomass production for bioenergy in specific regions. Policymakers should consider that multiple objectives (i.e. employment generation, biodiversity rehabilitation and reduction of GHG emissions) can be achieved when implementing bioenergy systems. The process of prioritising the impacts and objectives of biomass production for energy should involve all regional stakeholders.
- In doing so, it is necessary to establish interlinkages between different policy arenas and the incorporation of bioenergy in policies on land use, agriculture and (rural) development.

In addition, the following recommendations for research are made:

- Scenario-based tools should be further developed and tested in order to accurately assess socio-economic and environmental impacts so that stakeholders will be able to monitor and steer the performance of bioenergy projects. In combination with this development work, the quality of land-use data should be improved.
- Appropriate approaches should be developed in order to weigh individual (sustainability) criteria, based, for example, on (informed) stakeholder perspectives in a regional setting.

- The linkages between macro-economic drivers and regional land-use changes should be improved by linking bottom-up approaches to top-down modelling approaches.
- Better insights should be gained into how agricultural (and livestock) management can be improved in relation to (macro-) economic drivers, land-use policies and targeted strategies in order to increase efficiency and improve environmental performance.
- More detailed datasets on biomass production and supply systems should be collected for various settings, especially developing countries, marginal and degraded lands, and perennial cropping systems. In addition, substantial efforts are required to demonstrate the feasibility of such production systems in practice and to progressively optimise them.
- Finally, the impacts that climate change could have on the global, regional and local potential and sustainability of biomass energy production should be further investigated.

Hoofdstuk 8: Samenvatting en conclusies

Een stabiele energievoorziening, toegang tot energie - vooral in rurale gebieden in ontwikkelingslanden - en het beperken van de klimaatverandering door menselijk handelen zijn prioriteiten voor duurzame ontwikkeling in de komende decennia. Deze prioriteiten moeten worden bereikt zonder afbreuk te doen aan andere behoeften zoals het veilig stellen van de beschikbaarheid van voedsel en water en het behoud van biodiversiteit (IPCC 2007a). Bio-energie wordt beschouwd als één van de opties die kunnen worden toegepast om te voldoen aan de stijgende energievraag en om klimaatverandering ten gevolge van menselijk handelen te beperken (IEA Bioenergy 2007; IPCC 2007a; OECD/IEA 2008a; OECD/IEA 2008b). Moderne bio-energie is daarom een belangrijke optie in het energiebeleid van vele landen. De verwachting is dat het gebruik van bio-energie in de komende decennia aanzienlijk zal toenemen (REN21 2008).

Een belangrijke eis voor het gebruik van bio-energie is, dat de beschikbaarheid en de aanvoer op zowel de korte als lange termijn zeker kunnen worden gesteld. Diverse categorieën van biomassabronnen spelen hierbij een rol: bos- en landbouwresiduen, organische afvalstromen en, wat het belangrijkst is, verschillende typen geteelde biomassa[49]. Projecties wijzen erop, dat het grootste deel van het beschikbare biomassapotentieel op korte en lange termijn uit energiegewassen zou moeten komen. Drie veelbelovende regio’s voor biomassaproductie voor energie zijn de voormalige Sovjet Unie en de Oost-Europese landen, de Caraïben en Latijns Amerika en Afrika ten zuiden van de Sahara (Hoogwijk *et al.* 2005; Smeets *et al.* 2007; Dornburg *et al.* 2008b).

Biobrandstoffen als methyl-esthers van koolzaad en ethanol van zetmeel- en suikerhoudende gewassen in gematigde klimaatstreken zullen hoogstwaarschijnlijk geen concurrerende prijsniveaus bereiken in de komende decennia, ondanks continue verbeteringen in de productie-efficiëntie en opbrengsten (IEA 2004). In sommige landen, waaronder Brazilië, liggen de productiekosten van ethanol uit suikerriet dichtbij of onder de kosten om benzine te produceren (Goldemberg 2007). De productie van methanol, di-methyl esters (DME), waterstof, Fischer-Tropsch brandstoffen, methaan via SNG (synthesegas) productie en ethanol, geproduceerd van lignocellulose biomassa – ook wel tweede-generatie biobrandstoffen genoemd - kunnen op termijn waarschijnlijk concurrerend worden door middel van voortgaande technologische verbeteringen, leereffecten, en grootschalige productie (IEA Bioenergy 2007).

De mogelijke levering van energie van biomassa hangt grotendeels af van de hoeveelheid land dat beschikbaar is voor de teelt van energiegewassen. Hierbij moet rekening worden gehouden dat moet worden voldaan aan een wereldwijd groeiende vraag naar voedsel, gecombineerd met bescherming van biodiversiteit, duurzaam beheer van bodems en waterreserves en het voldoen aan diverse andere duurzaamheidseisen.

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[49] In dit proefschrift beperken we de analyses tot bos- en landbouwresiduen maar voornamelijk tot geteelde biomassa voor energietoepassingen.

Aangezien een belangrijk deel van de toekomstige beschikbaarheid van biomassabronnen voor energie van deze voorwaarden afhangt, is het niet mogelijk om het toekomstige potentieel van biomassaproductie voor energie in één enkelvoudig cijfer weer te geven (Dornburg *et al.* 2008).

De vermelde kwesties duiden er al op dat de toename in de productie van en de vraag naar biomassa voor energie zal samengaan met een groeiende bezorgdheid over de prestaties van bio-energieketens. Die zorg betreft vooral de sociaal-economische en milieueffecten van deze ketens.

Het duurzaam produceren en gebruiken van biomassabronnen wordt tegenwoordig beschouwd als een belangrijke eis voor toegang tot de markt in een groeiend aantal landen (Zarrilli 2006; Cramer *et al.* 2007). Milieu- en sociaal-economische effecten van biomassaproductie en –gebruik, die voor de duurzaamheid van biomassa energieproductie in beschouwing worden genomen, zijn o.a. de concurrentie met biomassa voor voedselproductie, de effecten op de uitstoot van broeikassen, de biodiversiteit, het watergebruik, de nutriëntbalans van bodems en de effecten op (lokale) welvaart en welzijn. Het ontwikkelen van principes, criteria en indicatoren, evenals het opstellen van certificeringschema's, worden gezien als strategieën die kunnen bijdragen aan het waarborgen van een duurzame productie van en handel in bio-energie.

Er zijn tussen de duurzaamheidkaders, die worden voorgesteld door diverse landen en door stakeholdergroepen, verschillen zichtbaar in het detailniveau, de striktheid en uitgebreidheid van de voorgestelde sociale, economische en milieucriteria. Een scala aan inhoudelijke kwesties die nog moeten worden opgelost of uitgewerkt zoals de precieze formulering van duurzaamheidprincipes en -criteria en de selectie van indicatoren. Dit proces is zeer complex vanwege het aantal betrokken stakeholders en de grote hoeveelheid en verscheidenheid aan biomassaproductiesystemen en settings waarmee rekening moet worden gehouden.

Vanuit deze context streeft dit proefschrift ernaar om inzicht te krijgen in de manier waarop de haalbaarheid en duurzaamheid van grootschalige productie, aanvoer en gebruik van bio-energie *ex ante* op een regionaal niveau kan worden bepaald. Dit wordt bepaald voor bio-energie voor lokaal gebruik of voor handel, waarbij rekening wordt gehouden met de complexiteit en de veranderlijkheid van de onderliggende factoren zoals de voedselvraag en het landgebruik.

Daartoe zijn de volgende **onderzoeksvragen** geformuleerd:

I. Hoe kunnen *ex ante* gebieden binnen wereldregio's worden geselecteerd die in potentie goede vooruitzichten bieden op zowel de korte als de langere termijn voor biomassaproductie ten behoeve van energie, waarbij rekening wordt gehouden met biologische en klimaatbeperkingen, de vraag naar voedsel en veevoer, het behoud van bos en biodiversiteit en geformuleerde beleidstrategieën voor landbouw, milieu en energie?

II. Hoe kunnen de economische prestaties van grootschalige productie- en handelssystemen van biomassa voor energie worden bepaald voor specifieke regio's?
III. Wat zijn de huidige initiatieven op het gebied van biomassacertificering voor energietoepassingen en, specifieker, in de ontwikkeling van principes, criteria, indicatoren en methoden om de effecten te bepalen van de productie van biomassa voor energietoepassingen en om tevens de duurzaamheid van die productie te waarborgen voor een breed scala aan regio's en biomassabronnen?
IV. Wat zijn de mogelijkheden en beperkingen voor een universele benadering om de duurzaamheid van de productie van biomassa en bio-energie te bepalen voor een breed scala aan regio's en biomassabronnen, met nadruk op de broeikasgasbalans?
V. Hoe kunnen de sociaal-economische en milieueffecten van een bio-energieketen, gerelateerd aan verschillende landgebruikscenario's, *ex ante* worden bepaald?

De onderzoeksvragen worden beantwoord in de hoofdstukken 2 tot en met 7 van dit proefschrift. Onderzoeksvraag I wordt geanalyseerd in hoofdstuk 2 en 3. Hoofdstukken 2 tot en met 4 geven een antwoord op onderzoeksvraag II. Onderzoeksvraag III wordt besproken in hoofdstuk 5. Hoofdstukken 5, 6 en 7 analyseren onderzoeksvraag IV. Hoofdstukken 6 en 7 geven een antwoord op onderzoeksvraag V. De belangrijkste bevindingen van de individuele hoofdstukken worden in dit samenvattende hoofdstuk besproken, waarna tot slot enkele algemene conclusies worden getrokken en aanbevelingen worden gegeven voor toekomstig onderzoek en voor verdere beleidsontwikkeling.

Hoofdstuk 2 geeft op regionaal niveau een inschatting van het technische potentieel en de kosten-aanbodcurves van bio-energie voor Midden- en Oost-Europese landen (CEEC): Bulgarije, Estland, Hongarije, Letland, Litouwen, Polen, Roemenië, Slowakije en de Tsjechische Republiek. De analyse wordt verricht op het zogenaamde NUTS-3[50] niveau (regio of districtsniveau). Vijf scenario's, geplaatst in een tijdspad tot 2030, zijn ontwikkeld om de invloed van verschillende sturingsfactoren op het potentieel en de kosten van biomassaproductie weer te geven. De scenario's V1 tot V5 kenschetsen de belangrijkste factoren die in het gebied invloed hebben op de ontwikkelingen van landbouw en landgebruik. De belangrijkste kenmerken van de scenario's zijn:

- *V1:* Er is een liberalisering van handelsverkeer en er bestaan geen handelsbarrières tussen de EU en de wereldmarkt voor landbouwproducten. De Europese Unie (EU) specialiseert zich in producten die op de wereldmarkt concurrerend zijn. De landbouwsector in de CEEC maakt gebruik van productiesystemen, die worden gekenmerkt door een hoge input en een geavanceerde technologie.
- *V2:* Het beleid is regionaal georiënteerd. Er bestaan handelsbelemmeringen tussen de West- en Oost-Europese markten. De landbouw in de CEEC ondervindt moeilijkheden om met de landbouw in West-Europese Landen (WEC) te concurreren. De landbouwsector in de CEEC maakt gebruik van de productiesystemen zoals die momenteel in gebruik zijn in de regio.

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[50] NUTS staat voor 'Nomenclature of Territorial Units for Statistics'. Dit zijn de statistische regio's van Europa en de Europese toetredingslanden (EUROSTAT 2002). NUTS-3 regio's zijn regio's die zich bevinden op het regio- of districtsniveau in een land (EUROSTAT 2002).

- *V3:* Er zijn geen interne handelsbelemmeringen in de EU. De handel tussen de EU en de wereldmarkt is gebaseerd op de huidige situatie (1997-1999). Het Gemeenschappelijke Landbouw Beleid (GLB) reguleert de landbouw in Europa. De CEEC passen de EU-wetgeving volledig toe en kunnen concurreren met de landbouw in de WEC. De landbouwsector in de CEEC maakt gebruik van ‘state-of-the-art’ productiesystemen, gekenmerkt door een hoge input.
- *V4:* Er zijn geen interne handelsbelemmeringen binnen Europa. Er bestaan handelsbarrières tussen de Europese markt en de wereldmarkt, aangezien Europa haar eigen markt sterk beschermt. De landbouwsector in de CEEC maakt gebruik van productiesystemen die worden gekenmerkt door een hoge input en geavanceerde technologie.
- *V5:* De EU (WEC en CEEC) geeft prioriteit aan duurzame ontwikkeling en natuurbehoud. Biodiversiteit, de bescherming van plattelandsgebieden en het behoud van de vitaliteit van bos en graslanden hebben een hoge prioriteit. Een bepaalde mate van bescherming van de markt is hiervoor nodig. De landbouwsector maakt gebruik van ecologische productiesystemen.

Het technische potentieel van bio-energiebronnen is onderzocht door middel van gedetailleerde bottom-up berekeningen. Het totale beschikbare bio-energiepotentieel, dat is berekend op regionaal of districtsniveau, is de som van de hoeveelheid biomassa, die afkomstig is van energiegewassen, hout van overtollig productiebos en van bos- en landbouwresiduen. Een voorwaarde in de bepaling van het potentieel is het voldoen aan de binnenlandse vraag naar voedsel en veevoer. Een bepaald areaal aan landbouwgrond is vereist om aan deze vraag te voldoen. De grootte van dit areaal hangt af van de vraag naar voedsel en veevoer, van de productiviteit van het landbouwsysteem en van allocatieprocedures die voor elk gewas – gebaseerd op de behoefte van het gewas - het meest geschikte areaal bepalen. Het huidige land, exclusief bosgebieden en beschermde gebieden, minus het vereiste land voor de productie van voedsel en veevoer en voor veeteelt, geeft de hoeveelheid land dat voor het verbouwen van energiegewassen kan worden gebruikt. Het technische potentieel van biomassa voor energie, afkomstig van deze energiegewassen, wordt berekend door het beschikbare land met de productiviteit van de energiegewassen te vermenigvuldigen. De kosten-aanbodcurves geven aan tegen welke kostenniveaus de biomassa voor energieproductie beschikbaar komt. De kostenniveaus zijn bepaald door een berekening van de kosten van biomassaproductie, uitgesplitst naar de scenario’s die in de analyse zijn onderzocht.

Een gebied van 36 tot 46 miljoen hectare – dat is 36% van het totaal beschikbare land voor landbouw - kan vrijkomen voor de productie van energiegewassen in de CEEC. De scenario's met een overheersend gebruik van de huidige landbouwsystemen (V2) of met een nadruk op het gebruik van ecologische productiesystemen (V5) tonen het laagste potentieel voor biomassaproductie voor energie, te weten 2 tot 5,7 EJ voor alle CEEC. Meer gunstige scenario’s laten als hoogste potentieel een waarde van 11,7 EJ zien. Hierbij is 85% afkomstig van energiegewassen, 12% van residuen en 3% van hout van overtollig productiebos. Het potentieel van bio-energie is in deze meer gunstige scenario's (V1, V3 en V4) groter dan het huidige primaire energieverbruik in de CEEC.

Het grootste deel van het potentieel (83 tot 94%, afhankelijk van het gekozen scenario) is afkomstig van energiegewassen. Hierbij wordt opgemerkt dat in deze scenario's aan de nationale vraag naar voedsel en veevoer wordt voldaan en dat bos- en natuurgebieden worden behouden.

De landen met de grootste landarealen, Polen en Roemenië, hebben het hoogste potentieel voor biomassaproductie voor energie. Behalve de beschikbaarheid van grote hoeveelheden land kunnen ook gunstige eco-fysiologische condities, zoals de aanwezigheid van vruchtbare gronden, kenmerkend zijn voor een gebied met een hoog biomassapotentieel. Het ecologische scenario (V5) laat een conflict zien tussen de uitbreiding van ecologische landbouw en grootschalige biomassaproductie voor energietoepassingen. De redenen zijn de lagere opbrengsten die met de ecologische landbouwproductiemethodes worden verkregen.

In de meeste CEEC landen kan het overgrote deel van het biomassapotentieel worden geproduceerd tegen kosten onder 2 €/GJ. Deze kosten liggen lager dan in de WEC landen en kunnen concurreren met de prijs voor fossiele brandstoffen. De meerjarige lignocellulose biomassagewassen zoals wilg, populier en miscanthus, hebben de laagste kosten. Zij worden gevolgd door suikerbiet en koolzaad. De kosten van biomassa, afkomstig van wilg, variëren van 1,0 tot 4,5 €/GJ in het scenario dat de huidige situatie van de landbouwsector in de CEEC weerspiegelt (V2) en van 1,6 tot 8,0 €/GJ in het scenario met de hoogste landbouwproductiviteit (V1). De belangrijkste reden voor de vermelde kostenverhoging is de veronderstelde toenames in land- en loonkosten. De input van meststof en landbouwchemicaliën is een andere belangrijke kostenpost. De hoogste kosten voor biomassaproductie voor energietoepassingen worden gevonden in scenario (V5), waarbij het gebruik van ecologische landbouwsystemen domineert. Hoge productiekosten worden tevens gevonden op gronden van geringe landkwaliteit.

Hoofdstuk 3 analyseert, voor de mogelijke verdere ontwikkeling van nationale en internationale markten, het potentieel en de economische haalbaarheid van grootschalige bio-energieproductie uit soja en switchgrass, verbouwd in een geselecteerde regio in Argentinië. Binnen de MERCOSUR regio laat Argentinië een veelbelovend potentieel zien voor de productie van biomassa voor energie. Op dit moment is soja het belangrijkste gewas voor export in Argentinië. Tegelijkertijd lijkt het verbouwen van switchgrass voor bio-energie een veelbelovende, maar nog weinig bekende optie. Deze redenen, plus het feit dat het bio-energie potentieel in Argentinië nog relatief weinig is bestudeerd, maken het land tot een interessante case.

Drie scenario's, met een tijdspad tot 2030, geven de invloeden weer van de belangrijkste sturingsfactoren op het potentieel en de kosten van deze bio-energiebronnen. Bovendien worden het potentieel en de kosten ook geëvalueerd voor de huidige situatie (CUR). Scenario A kenschetst een baseline voor de ontwikkeling van de economie. Scenario's B en C worden gekenmerkt door een sterkere economische groei. Scenario C is meer exportgericht dan scenario B, terwijl scenario B sterker gericht is op het ontwikkelen van de binnenlandse markt en daarnaast ook meer milieuvriendelijk georiënteerd is.

Het biomassapotentieel voor energie is bepaald op nationaal en provinciaal niveau. We hebben gebruik gemaakt van de bottom-up methodiek die eerder in hoofdstuk 2 van dit proefschrift is beschreven. In vergelijking met hoofdstuk 2 worden in deze studie meer specifieke nationale en regionale gegevens voor de berekeningen gebruikt. We hebben de selectie van een geschikte regio voor grootschalige bio-energieproductie in Argentinië gebaseerd op een set van criteria. Deze zijn:
i) Er moet voldoende land beschikbaar zijn voor bio-energieproductie in ieder van de scenario's;
ii) Er is een potentieel voor de productie van soja en switchgrass in de betreffende regio;
iii) Er is een beperkt risico voor concurrentie tussen land voor bio-energieproductie en land voor voedsel- of veevoerproductie;
iv) Er is een nabijheid van logistieke infrastructuur.

Bio-energieketens zijn vervolgens verder gedefinieerd om de economische prestatie van grootschalige biomassaproductie voor lokaal gebruik of voor export naar Nederland te kunnen analyseren. De kosten in onze analyses zijn bepaald voor iedere stap van de bio-energieketen.

Uit onze analyses in hoofdstuk 3 blijkt dat er op nationaal niveau $18*10^6$ ha (A2030) tot $33*10^6$ ha (CUR) land beschikbaar kan komen voor de teelt van soja voor bio-energieproductie. Voor de teelt van switchgrass voor bio-energie kan $10*10^6$ ha (A2030) tot $17*10^6$ ha (C2030) land beschikbaar komen. Switchgrass kan het hoogste potentieel van biomassa voor energietoepassingen bereiken van $243*10^6$ tds[51] (4,5 EJ) per jaar in het scenario (C2030). Dit scenario wordt gekenmerkt door een landbouwproductiesysteem dat gebruik maakt van hoge inputs en geavanceerdere technologie. Ter vergelijking: een biomassapotentieel van $99*10^6$ tds (1,9 EJ) per jaar kan worden bereikt in het scenario met een voortzetting van de huidige landbouwproductiemethodes (A2030). Sojaproductie kan, gebaseerd op de ruwe plantaardige olie-inhoud, een biomassapotentieel van $13{,}8*10^6$ tds per jaar (0,5 EJ) bereiken in CUR, vergeleken met een biomassapotentieel van $12{,}6*10^6$ tds per jaar (0,45 EJ) in C2030 en $7{,}1*10^6$ tds per jaar (0,25 EJ) in scenario A2030. De meeste bio-energieproductie kan worden behaald door gebruik te maken van een combinatie van geschikt (S) en middelmatig geschikt (MS) vrijkomend land. Wij concluderen dat het potentieel van switchgrass voor bio-energie over het algemeen genomen wezenlijk hoger is dan het potentieel van soja voor bio-energie. Mogelijke invloeden van klimaatverandering (droogte of meer regen) op de resultaten van het biomassapotentieel hebben wij in deze studie niet in overweging genomen.

Gebaseerd op de eerder beschreven criteriaset, is het meest geschikte gebied in Argentinië om energiegewassen te verbouwen de provincie ‘La Pampa’. In de provincie La Pampa, kan $65*10^4$ (A2030) tot $127*10^4$ ha (C2030) land beschikbaar komen voor de teelt van switchgrass voor bio-energie. Er kan $28*10^4$ (C2030) tot $42*10^4$ ha (B2030) land beschikbaar komen voor de teelt van soja voor bio-energie. Wanneer we ons in de analyse beperken tot het potentieel van geschikte (S) en marginaal geschikte (mS) gronden, kan

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[51] tds is een afkorting voor ton droge stof.

$17*10^4$ tot $30*10^4$ ha land beschikbaar komen voor sojaproductie voor bio-energie en kan $37*10^4$ tot $97*10^4$ ha land beschikbaar komen voor switchgrassproductie voor bio-energie. De productiekosten voor switchgrass in de provincie La Pampa zijn 33 US$/tds (22 €[52]/tds) op geschikte gronden in CUR tot 91 US$/tds (62 €/tds) op marginaal geschikte (mS) gronden in scenario B2030. De kosten voor sojaproductie variëren van 182 US$/tds (124 €/tds) op geschikte gronden (CUR) tot 501 US$/tds (341 €/tds) op marginaal geschikte gronden in scenario B2030. Het pachten van land en het gebruik van machines, brandstof, meststof en pesticiden (in het geval van sojaproductie) zijn de belangrijkste kostenposten voor de productie van energiegewassen.

In deze studie wordt verondersteld dat switchgrass wordt omgezet in pellets voor het opwekken van elektriciteit in Nederland of voor het lokaal opwekken van warmte in Argentinië. De productiekosten en vervoerskosten van pellets die in de provincie La Pampa worden geproduceerd, zijn 58 tot 143 US$/tds (40 tot 97 €/tds) voor lokaal gebruik en 150 tot 296 US$/tds (102 tot 201 €/tds) tot aan levering in de Europort van Rotterdam.

Elektriciteit van switchgrass pellets die uit Argentinië worden ingevoerd, kan in Nederland worden geproduceerd tegen een kostprijs van 0,06 tot 0,08 US$/kWh (0,041 tot 0,054 €/kWh). De huidige productiekosten in Nederland voor elektriciteit vanuit steenkool variëren van 0,05 tot 0,09 US$/kWh (Ouwens 2006); het laatstgenoemde getal met inbegrip van kosten voor CO_2-afvang en -opslag. De elektriciteitsproductiekosten voor het meestoken van pellets in de huidige situatie (CUR) en in scenario A2030 liggen dicht bij de productiekosten van elektriciteit uit steenkool als de kosten voor CO_2-afvang en -opslag bij steenkoolgebruik niet worden meegeteld.

De kosten voor warmte uit switchgrasspellets in Argentinië, waarbij aardgas wordt vervangen, variëren van 0,02 tot 0,04 US$/kWh (0,014 tot 0,027 €/kWh). Uitgaande van de huidige lage aardgasprijzen (gebaseerd op 2007-2008), kunnen switchgrasspellets niet concurreren met aardgas voor warmteopwekking in Argentinië. Wanneer de prijzen voor aardgas in de toekomst zouden toenemen, zoals aangenomen in enkele scenario's (B2030, C2030-mS) van deze studie, kunnen switchgrasspellets mogelijk wel gaan concurreren met aardgas voor warmteopwekking.

Er is aangenomen dat de soja, geproduceerd in de provincie La Pampa, wordt omgezet in biodiesel voor lokaal gebruik of voor export naar Nederland. Kijkend naar de diverse scenario's, kan biodiesel voor 0,3 tot 1,2 US$/liter (0,2-0,8 €/liter) voor lokaal gebruik en voor 0,5 tot 1,7 US$/liter (0,3 tot 1,2 €/liter) voor export naar Nederland worden geproduceerd. De huidige kosten voor biodiesel van soja (0,46 tot 0,54 US$/liter), dat geëxporteerd wordt naar Nederland, kunnen concurreren met fossiele brandstofkosten bij een olieprijs van 80 US$/olievat als er geproduceerd wordt op geschikte gronden en bij een olieprijs van 94 US$/olievat als er geproduceerd wordt op marginaal geschikte gronden. De huidige lokale productiekosten van biodiesel van soja (0,32 tot 0,39 US$/liter) zijn

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[52] Kostendata, verzameld in de periode 2007 tot begin 2008, zijn gebruikt als basis voor de huidige situatie (CUR). Het omzetten van de kostendata van € naar US$ in deze studie is gebaseerd op februari 2008. Deze wisselkoers (1€ = 1,47 US$) is ook gebruikt om resultaten te vergelijken tussen de CEEC en Argentinië.

concurrerend met fossiele brandstofkosten bij een olieprijs van 55 US$/olievat, als er geproduceerd wordt op geschikte gronden en bij een olieprijs van 67 US$/olievat, als er geproduceerd wordt op marginaal geschikte gronden. Dit betekent dat biodiesel economisch niet competitief is met fossiele brandstoffen bij een olieprijs als in begin 2009, toen de olieprijs daalde naar 40 US$/olievat in de maand januari (IEA 2009).

IEA geeft een projectie van de olieprijs van 100 US$/olievat voor de periode 2008-2015. De prijs stijgt naar 120 US$/olievat in 2030. In deze projecties zijn de fluctuaties van de olieprijs in 2007-2008 meegenomen. De IEA Outlook (2008) geeft aan dat “hoewel prijzen tijdelijk terug kunnen vallen door het uit balans zijn van de markt, het in toenemende mate duidelijk wordt dat het tijdperk van goedkope olie voorbij is”. Daarnaast wijst de Outlook erop dat “duidelijke prijsschommelingen op de korte termijn de regel blijven en dat tijdelijke sterke prijsstijgingen of –dalingen niet kunnen worden uitgesloten”. De IEA voorspelt een toenemende druk op de olieprijzen na 2015 naar het einde van de projectieperiode toe, vooral door vereiste investeringen in (extra) capaciteit om de toevoer te vergroten (OECD/IEA 2008). Stijgingen in de olieprijs op de korte tot middellange termijn zijn daarom waarschijnlijk.

Aangezien tegen 2010 grote hoeveelheden biodiesel nodig zijn om aan de Argentijnse Wet op Biobrandstoffen te voldoen, is het lokale gebruik van biodiesel gemaakt van soja een gunstige optie.

Belangrijke parameters voor de economische prestaties zijn kosten voor cultivering, voorbewerking, conversie en transport, evenals de kosten en prijzen voor fossiele brandstoffen en landbouwgoederen. Wanneer de markten zich verder gaan ontwikkelen, kan men verwachten dat de kosten voor bio-energie zullen afnemen door optimalisering van de logistieke keten, door verder onderzoek en ontwikkeling, en door technisch leren. De verbetering van de logistiek van het treinvervoer in Argentinië kan bestaande landbouwgebieden, die verder weg van de zeehavens liggen, economisch aantrekkelijker maken voor bio-energieproductie.

Het grote potentieel en de goede economische prestaties van de switchgrass bio-energieketen in de provincie La Pampa maken het interessant om switchgrassproductie in deze provincie verder te ontwikkelen, vooral op de meer marginale gronden. Tot nu toe is het lokale gebruik van switchgrasspellets ter vervanging van aardgas voor warmteopwekking economisch nog niet concurrerend. Het zou echter lonend kunnen zijn om (een deel van) de switchgrasspellets in La Pampa plaatselijk te gebruiken voor andere doeleinden. De switchgrasspellets zouden bijvoorbeeld gebruikt kunnen worden om de beschikbare energiebronnen in de regio te diversifiëren of om aan het 8% aandeel van hernieuwbare bronnen in de elektriciteitsopwekking bij te dragen, wat nationaal tot doel is gesteld voor 2016. Aangezien switchgrass een nieuw alternatief voor bio-energieproductie in Argentinië is, wordt demonstratie van dergelijke schema’s, wellicht geïntegreerd met meerjarige grassen voor veevoerproductie, aanbevolen.

Hoofdstuk 4 beoordeelt of de markt en handel voor biobrandstoffen voldoende rendabel kan zijn om een levering van biobrandstoffen vanuit de Midden- en Oost-Europese Landen (CEEC) naar de West-Europese markt te realiseren door de kostenprestaties van de geleverde energiedragers te bepalen. Een modulair spreadsheetmodel is gebruikt om een economische analyse van een grote verscheidenheid aan lange afstand bio-energieketens uit te voeren. De scenariokenmerken en het berekende biomassapotentieel op NUTS-2 regio[53] niveau van scenario V3 (zie hoofdstuk 2) zijn gebruikt voor deze studie.

Voor vijf NUTS-2 regio's in de CEEC landen, te weten regio's in Polen, Roemenië, Hongarije en de Tsjechische Republiek, bestaan goede vooruitzichten voor de productie van biomassa voor energie op zowel de korte als de lange termijn en zijn daarom voor deze studie geselecteerd. De geselecteerde bestemmingen in West Europa voor de biomassa of de hieruit geproduceerde brandstof zijn Rotterdam, Marseille en Duisburg. Er is verondersteld dat wilg, geproduceerd in de geselecteerde CEEC regio's, naar de geselecteerde bestemmingen wordt vervoerd in de vorm van pellets. De tweede optie kijkt naar het vervoer van wilg als pellets naar de geselecteerde bestemmingen voor grootschalige conversie naar ethanol ter plaatse. De derde optie gaat ervan uit dat wilgpellets lokaal in de CEEC regio's worden omgezet naar ethanol om vervolgens, als brandstof, vervoerd te worden naar de geselecteerde steden.

Pellets, die in de CEEC worden geproduceerd, kunnen tegen de kosten van 105 tot 220 €/tds op de geselecteerde bestemmingen worden geleverd. Vergeleken met de huidige kosten van pelletproductie van 74 tot 119 €/tds in Zweden en Oostenrijk, kunnen de productie en de export van pellets vanuit de CEEC voor een beperkt aantal regio's in de CEEC landen concurrerend zijn. Dit is toe te schrijven aan de hogere vervoerskosten.

Ethanol kan worden geproduceerd tegen kosten van 12 tot 21 €/GJ als conversie plaatsvindt in de geselecteerde bestemmingen in West-Europa, en tegen kosten van 15 tot 18 €/GJ als de ethanolconversie (kleinschaliger) plaatsvindt op de locatie waar de biomassa wordt geproduceerd. De berekende ethanolproductiekosten komen overeen met de kosten voor ethanolproductie op de korte (22 €/GJ) en op de lange termijn (11 €/GJ), zoals vermeld in Hamelinck *et al.* (2005a). Uitgaande van een geschatte bandbreedte van oliekosten van 13 tot 19 €/GJ, bij een aangenomen olieprijs van 100 tot 150 US$/olievat en een €/US koers van 1,35 kunnen de kosten voor ethanolproductie op zowel de kortere als langere termijn concurrerend zijn. Ethanol is waarschijnlijk niet langer competitief als de prijs voor olie 11 €/GJ (wat omgerekend ongeveer 85 US$/olievat is) of lager is, wat de situatie is in begin 2009. De verwachting is echter dat de olieprijs op de korte tot middellange termijn zal stijgen (zie ook hoofdstuk 3), wat de concurrentiepositie van ethanol ten opzichte van fossiele brandstoffen zal verbeteren.

Verdere verlagingen van de ethanolkosten kunnen worden gerealiseerd door een andere vergoeding (in deze studie 0,048 €/kWh) voor de overtollige elektriciteit, die naast ethanol tijdens het conversieproces wordt geproduceerd. Wanneer deze vergoeding zou stijgen tot

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[53] Een NUTS-2 regio is een samenvoeging van meerdere NUTS-3 regio's (zie ook hoofdstuk 2 van deze samenvatting) en is vaak het provinciale niveau van een land.

0,06 €/kWh, zouden de totale conversiekosten van een 400 MW centrale met 9% afnemen. Als de elektriciteitvergoeding zou afnemen tot 0,04 €/kWh, zouden de conversiekosten van een 400 MW centrale met 5% toenemen. De hoogte van de vergoeding is veelal beleidsafhankelijk en kan sterk variëren in de tijd en per land.

De kostenprestaties van de CEEC bio-energieketens tonen aan dat het belangrijk is om gunstige export- en bestemmingsregio's te selecteren voor het verlagen van de vervoerskosten. De regio's in Roemenië en Polen laten over het algemeen betere economische prestaties zien voor de handel van biomassa over lange afstanden dan de regio's in Hongarije en in de Tsjechische Republiek. Dit kan gedeeltelijk worden verklaard door de selectie van de bestemmingen en de geografische positie van de regio's die biomassa produceren. Die regio's in de CEEC met vervoeropties voor zeetransport zijn het meest geschikt voor het leveren van biobrandstoffen of grondstoffen aan internationale markten op lange afstand. Biobrandstoffen die geproduceerd zijn in CEEC regio's met minder gunstige vervoeropties, zullen hoofdzakelijk worden gebruikt door lokale markten.

Hoofdstuk 5 biedt een overzicht van de huidige initiatieven in biomassacertificatie (tot aan oktober 2007) en, meer specifiek, van de ontwikkeling van principes, criteria, indicatoren en methoden om duurzame biomassaproductie te waarborgen voor een scala van regio's en biomassabronnen.

Een aantal nationale overheden, zoals Nederland, Groot Brittannië, België en Duitsland en daarnaast de Europese Commissie heeft het initiatief genomen om een beleidskader te ontwikkelen om duurzame biomassaproductie voor energie te waarborgen. Ook hebben diverse NGO's zoals WNF, FBOMS en een samenwerking van Nederlandse NGO's, Position Papers gepubliceerd, waarin de belangrijkste zorgen en aandachtspunten over duurzame biomassaproductie tot uitdrukking worden gebracht. Andere NGO's (zoals Solidaridad) zijn pilotstudies gestart of spelen een actieve rol in forumdebatten over dit onderwerp.

De soort van initiatieven van bedrijven die actief zijn in de ontwikkeling van een biomassacertificatiesysteem (waaronder DaimlerChrysler of Shell), hangt af van de rol en het bedrijfsbelang in de bio-energieketen. Initiatieven vanuit internationale instellingen concentreren zich op een breed scala aan activiteiten, zoals het verstrekken van financiële en inhoudelijke ondersteuning aan ontwikkelingslanden of het oprichten van forums voor informatie uitwisseling over dit onderwerp.

Internationale instellingen zoals UNEP of het Global Bioenergy Partnership (GBEP) hebben specifieke projecten geformuleerd om beter inzicht te kunnen krijgen in de manier waarop een biomassacertificatiesysteem ontwikkeld kan worden. Internationale netwerken en Ronde Tafels, zoals de Ronde Tafel voor soja (RTRS), voor palmolie (RSPO) en voor biobrandstoffen (RSB), zijn gebaseerd op vrijwillige deelname en zouden eveneens in de ontwikkeling van een certificatiesysteem voor hun specifieke goederen moeten resulteren.

Tabel 1: Samenvattend overzicht van duurzaamheidprincipes die door diverse landen en stakeholdergroepen worden voorgesteld of in overweging worden genomen$^{1)}$, gebaseerd op de situatie in oktober 2007.

De principes hebben betrekking op:	Landen en de Europese Commissie$^{2)}$								NGOs$^{3)}$			$^{4)}$
	NL	BE	UK	BR	Can	GE	US	EC	SA	FB	N	E
Oorsprong van biomassa	●		●		●	●	●	●	●	●	●	●
Sociaal-economische kwesties $^{6)}$	●		●? $^{5)}$	●				●?	●	●	●	
Economische welvaart	●								●	●	●	
Arbeidsomstandigheden	●			●						●	●	
Mensenrechten	●			●						●	●	
Eigendomsrechten	●			●					●	●	●	
Welzijn	●									●	●	
Integriteit										●		
Milieukwesties $^{6)}$			●?					●?				
Broeikasgas- en/of energiebalans	●	●	●			●	●	●	●	●	●	●
Koolstof in de bodem	●							●			●	
Competitie rondom land	●								●	●	●	
Biodiversiteit	●					●			●	●	●	
Afval gebruik	●								●			
Gebruik agrochemicaliën	●									●		
Uitvoering van landbouw	●			●	●	●			●	●	●	
Duurzaam landgebruik	●			●		●	●		●	●	●	
Grond	●			●					●	●	●	
Water	●								●		●	
Luchtemissies	●				●				●			
GGO gebruik									●	●	●	

$^{1)}$ Niet alle initiatieven van NGO's, bedrijven en internationale instellingen worden getoond in deze lijst. Voor een volledig overzicht, zie hoofdstuk 5. $^{2)}$ NL = Nederland, BE = België, UK = Groot Brittannië, BR = Brazilië, Can = Canada, GE = Duitsland, US = Verenigde Staten (Californië), EC = de Europese Commissie. $^{3)}$ SA = Zuid-Afrikaanse NGO's, FB = Braziliaanse NGO's, N = Nederlandse NGO's. $^{4)}$ E = Bedrijf Electrabel. $^{5)}$? = Het meenemen van dit principe wordt in overweging genomen. $^{6)}$ Er is een bereidheid om sociaal-economische of milieuprincipes mee te nemen. Welke, is nog niet bepaald.

Er is slechts een beperkte hoeveelheid initiatieven om duurzaamheidprincipes concreet te vertalen naar operationele criteria en indicatoren en deze vervolgens te controleren en te verifiëren door een opgezet biomassacertificatiesysteem. In oktober 2007 waren er twee certificatiesystemen voor biomassa in werking, beiden gestart door energiebedrijven (GGL en Electrabel). De Britse, Belgische en Nederlandse overheden, evenals de RSPO, hebben eveneens initiatieven genomen om biomassacertificatiesystemen te ontwikkelen. De status van deze systemen varieert van het ontwikkelen tot het testen van duurzaamheidcriteria.

De ontwikkeling van biomassacertificatiesystemen wordt belemmerd door een aantal kwesties. Het overzicht van initiatieven, dat in hoofdstuk 5 wordt besproken, laat zien dat er verschillen zijn in de striktheid, de uitgebreidheid en het detailniveau van criteria door verschillen in belangen en prioriteiten. Een proliferatie van individuele normen en systemen kan een verlies van efficiency en geloofwaardigheid van duurzaamheidsverkenningen veroorzaken. Ook moeten nog veel onzekerheden over de haalbaarheid, de uitvoering en kosten van internationale biomassacertificatiesystemen worden opgelost. Dit geldt ook voor de naleving van internationale wetten en handelsovereenkomsten. Daarom is het lonend om in deze beginfase te overwegen welke wegen gevolgd kunnen worden om een betrouwbaar, efficiënt biomassacertificatiesysteem te ontwikkelen.

Er zijn diverse mogelijke benaderingen voor de ontwikkeling, de invoering en het beheer van een biomassacertificatiesysteem. Een belangrijk onderscheid is of het systeem vrijwillig of verplicht is en of het systeem nationaal of internationaal georiënteerd is. Alle benaderingen die zijn gepubliceerd, hebben hun eigen sterke punten en beperkingen. Voor al deze initiatieven geldt dat een aantal urgente acties nodig zijn om tot een verdere ontwikkeling en uitvoering te komen:

I. Een betere internationale coördinatie tussen initiatieven is vereist om coherentie en efficiëntie in de ontwikkeling van biomassacertificatiesystemen te verbeteren. Diverse internationale organisaties kunnen hiervoor het initiatief nemen zoals de Europese Commissie (voor de Europese regio), UNEP, FAO, UNCTAD of anderen. Dit zou een duidelijkere richting in de aanpak moeten bieden die op nationaal en lokaal niveau moet worden gekozen.

II. De bestaande WTO overeenkomsten, zoals het Akkoord over Technische Handelsbelemmeringen, het MFN-principe (Most Favoured Nation) of de ‘Code of Good Practice’, en de bijbehorende jurisprudentie geven al een aantal ideeën over de rol van de Wereldhandelsorganisatie met betrekking tot de ontwikkeling van een biomassacertificatiesysteem. Er bestaat over dit onderwerp echter nog geen precedent. Een onderhandelingsproces tussen WTO-leden om meer inzicht in en verdere overeenstemming over dit onderwerp te bereiken is vereist.

III. Certificatie is geen doel op zich, maar een middel. Het kan één van de beleidsmiddelen zijn om de duurzaamheid van biomassaproductie en -gebruik te waarborgen. Het opzetten van codes, gebaseerd op goede voorbeelden, en het integreren van duurzaamheidgaranties in mondiale bedrijfsmodellen zouden ook effectieve manieren kunnen zijn om dit te waarborgen. Een open visie voor (een combinatie met) alternatieve beleidsinstrumenten moet worden behouden om de best geschikte opties te vinden om duurzame biomassaproductie en handel te waarborgen.

IV. De ervaring om enkele criteria operationeel te maken is op dit moment beperkt. Het ontwerpen van specifieke criteria en indicatoren die voldoen aan de vereisten voor een regio, vereisen de ontwikkeling van nieuwe methodes en geïntegreerde benaderingen. Dit geldt tevens voor vragen over hoe ongewenste landgebruikveranderingen (te weten ‘leakage’) vermeden kunnen worden en hoe de invloed van de dynamiek van landgebruik meegenomen kan worden. Dit kan een aantal jaren vergen. Anderzijds is er een behoefte om de duurzaamheid van biomassa in een snelgroeiende markt al op de korte termijn veilig te stellen. Een geleidelijke ontwikkeling en uitbreiding van certificatiesystemen met leerpunten (door pilotstudies en onderzoek) in de tijd, gekoppeld aan de ontwikkeling van geavanceerde methoden, kan waardevolle inzichten bieden. Daarnaast kan het ook de haalbaarheid en betrouwbaarheid van biomassacertificatiesystemen verbeteren. Deze stapsgewijze benadering biedt mogelijkheden voor coherentie, toezicht en aanpassing van activiteiten.

Hoofdstuk 6 bespreekt in meer detail de broeikasgasbalans van bio-energiesystemen: de som van de emissies die door bio-energie systemen worden vermeden en gegenereerd. De broeikasgasbalans moet worden beschouwd als één van de belangrijke kwesties bij het opstellen van een certificatiesysteem. Er is een sterke toename van initiatieven om methodieken en tools te ontwikkelen voor het vaststellen van de broeikasgasbalans. De onderlinge verschillen tussen deze systemen tonen de moeilijkheid aan om tot een internationaal geaccepteerde methodiek en internationaal geaccepteerde default-waarden te komen. Verder is opvallend dat de kosteneffectiviteit van het reduceren van broeikasgasemissies met behulp van bio-energie in de diverse methodieken zelden wordt meegenomen, hoewel de economische haalbaarheid van bio-energieprojecten van belang is voor zowel investeerders als beleidsmakers.

Een scala aan methodische kwesties moet in overweging worden genomen als de broeikasgasbalans en kosteneffectiviteit van biomassa-energiesystemen moeten worden berekend. Bijvoorbeeld: de effecten van landgebruikveranderingen, het alloceren van emissies naar de hoofd- en bijproducten, veranderingen in de koolstofvoorraad van het gebied, de energie die in de upstream van die bio-energieketen wordt gebruikt en de efficiëntie van de energiesystemen. In hoofdstuk 6 is een gestandaardiseerde methodiek ontwikkeld om de broeikasgasbalans en kosteneffectiviteit van biomassa-energiesystemen te evalueren. Deze methodiek vormt de basis voor een gebruikersvriendelijke softwaretool om de broeikasgasbalansen en de kosteneffectiviteit van bio-energiesystemen te analyseren.

De belangrijkste kenmerken van deze tool zijn het zogenaamde flowchart ontwerp en het concept om met verschillende detailniveaus voor de invoergegevens en voor de berekeningen te werken. De in hoofdstuk 6 behandelde case studies, vijf in totaal, tonen aan dat de tool een breed scala aan biomassa-energiesystemen kan accommoderen. De flexibiliteit van de tool stelt gebruikers in verschillende regio’s in staat om deze methodiek te gebruiken waardoor de vergelijkbaarheid van en consistentie in de resultaten verbetert.

De case studies laten zien dat de belangrijke methodische kwesties voor het berekenen van de broeikasgasbalansen en kosteneffectiviteit van biomassa-energiesystemen in één enkele tool kunnen worden geaccommodeerd. Dit zijn de functionele eenheid, mitigatie parameters, de systeemgrens, het referentie energiesysteem, de directe veranderingen in landgebruik en de veranderingen in de koolstofvoorraad, de indirecte veranderingen in landgebruik, allocatieprocedures, tijdkwesties, kostenmetingen, de specifiekheid van locatie en het meenemen van onzekerheden.

Biomassa-energiesystemen omvatten een groot aantal biomassabronnen, technologieën die kunnen worden toegepast en energiedragers die kunnen worden geproduceerd. De software tool kan deze diversiteit accommoderen door de gebruiker de mogelijkheid te bieden om gebruik te maken van samengevoegde of gedetailleerde gegevens. De kwaliteit van de resultaten hangt natuurlijk af van de nauwkeurigheid van de gebruikte gegevens. De case studie ‘Brandstofproductie in Nederland van houtresiduen uit Canada' gaat ervan uit dat één eindproduct wordt opgeleverd, namelijk FT-diesel. Het alloceren van het energiegebruik, de emissies en kosten tussen de geproduceerde brandstof en elektriciteit tijdens het conversieproces zijn gebaseerd op substitutie en, als alternatief, op allocatie door energie-inhoud. Deze samenvatting toont de resultaten voor allocatie door energie-inhoud. De case studie illustreert, dat de totale broeikasgasemissies en energiekosten per eenheid GJ geleverde brandstof voor een gedetailleerd gegevensniveau respectievelijk 25 kg CO_2eq per GJ en 32 € per GJ zijn. Ter vergelijking: de resultaten voor totale broeikasgasemissies en energiekosten zijn respectievelijk 25 kg CO_2eq/GJ en 21 €/GJ wanneer samengevoegde gegevens worden gebruikt. Dit verschil (vooral in de kosten) kan voor investeerders, beleidsmakers en andere stakeholders significant zijn.

De case studie `Verbranden van reststromen van houtverwerking onder Finse/Zweedse omstandigheden' laat zien dat de selectie van het referentie-energiesysteem belangrijk is. Door te veranderen van een op dit moment in gebruik zijnde technologie (jaar 2000) naar een meer geavanceerde technologie (jaar 2020), nemen de broeikasgasemissies van het bio-energie systeem af van 15 naar 10 kg CO_2eq per GJ (som van geleverde warmte en elektriciteit) terwijl de energiekosten in beide gevallen min of meer hetzelfde zijn (7,6 versus 7,5 € per GJ).

Er is geen algemene procedure om broeikasgasemissies en kosten te alloceren naar de hoofd- en bijproducten van de bio-energieprojecten, die onder alle omstandigheden goed kan worden toegepast. Allocatie met behulp van de multifunctionele of substitutie benaderingen hebben de voorkeur, maar deze hebben ook hun beperkingen. De keuze voor allocatie gebaseerd op massa of energie-inhoud of op marktprijs van de verschillende producten, moet zorgvuldig worden gemaakt, omdat deze keuze een grote invloed op de resultaten kan hebben. Dit wordt geïllustreerd aan de hand van de case studie ‘Biodiesel van koolzaad in Groot Brittannië' waar een variatie van 35 tot 50 kg CO_2eq per GJ wordt getoond, afhankelijk van de geselecteerde procedure en de onderliggende veronderstellingen. Allocatie gebaseerd op energie-inhoud, zoals begin 2009 door de Europese Commissie is voorgesteld, is minder gevoelig voor de veranderlijkheid in inputparameters en onderliggende veronderstellingen dan allocatie gebaseerd op marktprijs.

Er is momenteel een discussie gaande over de vraag of, en op welke manier, veranderingen in indirect landgebruik moeten worden meegenomen in de methodiek voor het berekenen van de broeikasgasbalans. De case studie `Warmte van miscanthus in Groot Brittannië' laat zien dat de impact van veronderstellingen over landgebruikveranderingen groot kan zijn. Dit wordt geïllustreerd door de vermeden broeikasgasemissies in deze studie, die kunnen variëren van 13 tot 128 kg CO_2eq per GJ, afhankelijk van het veronderstelde referentie-landgebruiksysteem. De referentiesystemen die zijn inbegrepen, zijn: maaigrasland, wisselbouw op braakliggend land en land voor het verbouwen van koolzaad. De studie laat zien dat de prestaties van een biomassa-energiesysteem plaats- en tijdgerelateerd zijn.

Aangezien meer nauwkeurige inputgegevens ook meer nauwkeurige resultaten zullen opleveren, is het essentieel dat de gebruiker zeker is van de kwaliteit en de geschiktheid van de gebruikte gegevens. Ook kan worden geconcludeerd, dat er voorkeur moet worden gegeven aan plaatsspecifieke analyses met gebruik van gedetailleerde data. Nauwkeurige dataverzameling en ontwikkeling van consistente databestanden, in het bijzonder voor veelbelovende biomassaproductieregio’s voor energie, zijn nodig om de positieve en negatieve effecten van biomassaproductie en -handel te kunnen volgen.

Hoofdstuk 7 analyseert de haalbaarheid om *ex ante* een sociaal-economische en milieueffectanalyse in te zetten voor het beoordelen van grootschalige bio-energieproductie op een regionaal niveau, gebaseerd op een set van vastgestelde criteria en indicatoren. De analyse is uitgevoerd voor grootschalige bio-energieproductie van soja en switchgrass in de provincie La Pampa in Argentinië. De resultaten zijn berekend voor de huidige situatie (CUR) en voor de scenario's A, B en C voor het jaar 2030 (zie ook hoofdstuk 3). Switchgrass en soja worden verbouwd op geschikte (S) en marginaal geschikte (mS) gronden. De referentie landgebruiksystemen zijn akkerland (C), gedegradeerd grasland (D) en niet-gedegradeerd grasland (G). De beschikbaarheid van gegevens en methoden is voor elk geformuleerd duurzaamheidprincipe besproken en toegepast op de provincie La Pampa. In totaal zijn negen duurzaamheidprincipes in deze duurzaamheidbeoordeling gebruikt.

Een combinatie van kwantitatieve en kwalitatieve indicatoren is gebruikt om een indicatie van de sociaal-economische en milieuprestaties van bio-energieproductie in de provincie La Pampa in Argentinië te krijgen. We hebben kwalitatieve indicatoren gebruikt voor die principes waarvoor geschikte methoden of datasets om de prestaties te kwantificeren ontbreken. Dit zijn bijvoorbeeld principe 3, welke gaat over het niet in gevaar brengen van de voedsellevering en alternatieve lokale toepassingen van biomassa, en principe 9, welke de bijdrage tot sociaal welzijn behandelt.

Het gebruik van gestandaardiseerde methoden is gewenst, maar nog niet mogelijk voor alle principes. Er is geen geschikte methode beschikbaar om macro-economische sturingsfactoren te koppelen aan micro-economische effecten. De beschikbare methoden om de effecten van biomassaproductie op wateruitputting en op grondkwaliteit te beoordelen, vereisen een verdere uitwerking voor toepassing op een regionaal niveau voor een scala aan biomassabronnen.

Een norm of standaard moet worden bepaald voor elk van de toegepaste criteria om de verkregen resultaten in termen van absolute prestaties te kunnen interpreteren en waarderen. Deze standaard is beschikbaar voor biodiversiteit (de MSA[54] waarden) en voor de afname van broeikasgasemissies die moet worden bereikt (bijvoorbeeld tenminste 35% afname in broeikasgasemissies in vergelijking met het referentiesysteem). Momenteel ontbreekt een standaard voor andere principes. Daarom zijn de scores voor andere principes in onze beoordelingen gebaseerd op de relatieve en niet op de absolute prestaties van de bio-energieketens. Het type (standaardgegevens, lokale gegevens, expertise, kaarten) en het nauwkeurigheidsniveau van de beschikbare invoergegevens, variëren sterk tussen de onderzochte criteria.

De verandering van de koolstofvoorraad voor switchgrass varieert van 0,2 tot 1,2 ton C/ha per jaar en voor soja van -1,2 tot 0,0 ton C/ha per jaar, afhankelijk van het scenario. De afname in broeikasgasemissies varieert van 88 tot 133% voor de switchgrass bio-energieketen (waarbij steenkool of aardgas wordt vervangen) en van 16 tot 94% voor de soja bio-energieketen (waarbij fossiele brandstof wordt vervangen), zoals bepaald voor verschillende tijdsperioden. De MSA waarde, een indicator voor het effect van

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[54] MSA staat voor ‘Mean Species Abundance’ ofwel de gemiddelde aanwezigheid van soorten.

biomassaproductie op de biodiversiteit, varieert van +0,2 (bij omzetting van intensieve akkerlandproductie naar switchgrassproductie) tot -0,2 (bij omzetting van extensieve graslandproductie naar sojaproductie). De efficiëntie van watergebruik van biomassaproductie varieert van 0,4 tot 0,6 g_{ds}/kg water voor sojaproductie en van 1 tot 22 g_{ds}/kg water voor switchgrassproductie. Het jaarlijkse bodemverlies, in vergelijking met het referentie landgebruiksysteem, is 2 tot 10 ton/ha voor de soja bio-energieketen en 1 tot 2 ton/ha voor de switchgrass bio-energieketen.

De meeste milieuvoordelen kunnen worden bereikt wanneer switchgrass wordt geproduceerd op vrijgekomen akkerland. Als switchgrassproductie gedegradeerd grasland vervangt, wat de concurrentie met voedsel en veevoerproductie beperkt, dan levert het over het algemeen positieve duurzaamheidprestaties op, vooral voor scenario's (B-mS-D) en (C-mS-D). Switchgrassproductie, geproduceerd op niet-gedegradeerd grasland, kan resulteren in negatieve milieueffecten.

Sojaproductie voor bio-energie toont goede algemene duurzaamheidprestaties als vrijgekomen akkerland wordt gebruikt (A-S, C-S en CUR-S). De productie van soja op gedegradeerd grasland. De productie van soja voor bio-energie op zowel gedegradeerde als op niet-gedegradeerde graslanden resulteert verhoudingsgewijs in slechtere duurzaamheidprestaties.

Wanneer de niet-duurzame scenario's worden uitgesloten, ofwel scenario's (CUR-mS-D, A-mS-D, B-mS-D, C-mS-D) voor sojaproductie voor bio-energie en (B-S-G) voor de productie van beide energiegewassen, dan is de potentiële beschikbaarheid van S en mS land voor bio-energieproductie in de provincie La Pampa 0 tot $24*10^4$ ha (in plaats van 17 tot $30*10^4$ ha, zie hoofdstuk 3) voor sojaproductie en 17 tot $97*10^4$ ha voor switchgrassproductie (in plaats van 37 tot $97*10^4$ ha, zie hoofdstuk 3). De bovengrens voor switchgrassproductie voor energie blijft constant, omdat de scenario's met een hoog potentieel ook de scenario's met goede duurzaamheidprestaties zijn.

Aangezien sojaproductie voor biodiesel, zowel voor export als voor lokaal gebruik, rendabel is voor alle scenario's, blijft deze keten economisch haalbaar als de niet-duurzame scenario's worden uitgesloten. Grootschalige switchgrassproductie voor export blijft economisch haalbaar op korte en lange termijn, wanneer scenario (B-S-G) is uitgesloten. Het gebruik van switchgrasspellets voor lokale energieproductie is economisch niet haalbaar op de korte termijn (zie ook hoofdstuk 3).

De algemene prestaties van de bio-energieketens zijn over het algemeen genomen hoger voor switchgrass dan voor soja. Het is mogelijk om de milieueffecten (vooral het risico op veranderingen in direct landgebruik en biodiversiteit) van de bio-energieketen van soja te minimaliseren als het geproduceerde veevoer nadrukkelijk voor veeproductie in het gebied wordt gebruikt. Het surplusland (in de regio) kan vervolgens voor alternatieve doeleinden worden gebruikt zoals natuurherstel of biomassaproductie voor energietoepassingen.

De resultaten in de diverse scenario's tonen aan, dat de meeste sociaal-economische en milieuvoordelen kunnen worden bereikt wanneer een bio-energieproductieketen is gebaseerd op het meest efficiënte landbouwproductiesysteem dat nu kan worden toegepast. Daarbij wordt het landgebruiksysteem met de laagste economische en milieuprestaties in de regio vervangen. Hierbij is het uitgangspunt dat risico's op veranderingen in landgebruik worden vermeden.

Het is mogelijk om een grove indicatie te geven welke ketens en scenario's vanuit duurzaamheidoogpunt beter presteren dan anderen. Door het gebruik van scenario's kan een breed scala aan resultaten worden getoond in relatie tot gekozen landbouwbeheerssystemen, geschiktheid van land, referentie landgebruiksystemen, gekozen tijdsperiode, allocatieregels en de impact van indirecte landgebruikveranderingen. Deze benadering geeft inzicht in welke mate de onderliggende factoren de broeikasgasbalans en andere duurzaamheidkwesties beïnvloeden. Het referentie-landgebruiksysteem 'akkerland' in deze studie is bijvoorbeeld gebaseerd op sojaproductie. Een ander referentiegewas kan de resultaten aanzienlijk beïnvloeden.

Slotconclusies en aanbevelingen voor verder beleid en onderzoek

Het onderzoek, gepresenteerd in dit proefschrift, laat zien dat het mogelijk is om *ex ante* een selectie te maken van gebieden die in potentie goede vooruitzichten bieden voor biomassaproductie ten behoeve van energie op zowel de korte als langere termijn. Bij deze selectie wordt rekening gehouden met biologische en klimaatbeperkingen, de vraag naar voedsel en veevoer en het behoud van bossen en biodiversiteit. Dit gebeurt door in de studie verschillende (beleid-) scenario's te kiezen. Veelbelovende biomassaproductiegebieden kunnen worden geselecteerd aan de hand van een vooraf bepaalde set aan criteria, zoals in hoofdstuk 3 is aangetoond (Onderzoeksvraag I).

Het technische potentieel van bio-energiebronnen kan door middel van bottom-up berekeningen (zie hoofdstuk 2 en 3) worden bepaald. Deze analyses maken expliciet met welke verbeteringen in landbouwbeheer land voor biomassaproductie vrij kan komen, zonder indirecte landgebruikveranderingen te veroorzaken. De analyse voor de specifieke gebieden van de economische prestaties (Onderzoeksvraag II) van grootschalige productie- en handelssystemen van biomassa voor energie bouwt op deze benadering voort: de kosten worden berekend en hierbij wordt rekening gehouden met een ruimtelijke variatie in opbrengsten, landgebruik en prijzen, evenals in verdere logistieke activiteiten.

Dit proefschrift toont tevens aan dat internationale handelsstromen en prijzen van fossiele brandstoffen en landbouwgoederen een significante invloed kunnen hebben op het potentieel en de prestaties van bio-energieketens op een microniveau. Het koppelen van top-down aan bottom-up benaderingen wordt daarom aanbevolen. Daarnaast is een verdere analyse vereist naar de mogelijkheden en beperkingen om efficiëntieniveaus van landbouw- en veeproductiesystemen in de loop van de tijd te verbeteren.

In een groeiend aantal landen wordt een duurzame productie en gebruik van biomassabronnen tegenwoordig beschouwd als een vereiste voor het mogelijk maken van verdere uitbreiding van bio-energie. Nationale overheden, NGO's, bedrijven en internationale instellingen zijn recentelijk een breed scala aan initiatieven in biomassacertificatie begonnen. Dit omvat de ontwikkeling van principes, criteria, rekentools en methoden om duurzame biomassaproductie voor een breed scala aan regio's en biomassabronnen (Onderzoeksvraag III) te waarborgen. Concrete initiatieven om duurzaamheidprincipes te vertalen naar operationele criteria en indicatoren evenals om bio-energieprojecten te controleren en te verifiëren door een biomassacertificatiesysteem, zijn echter vrijwel afwezig.

De ontwikkeling van biomassacertificatiesystemen wordt belemmerd door een aantal kwesties (Onderzoeksvraag IV) als onzekerheden over de haalbaarheid, de uitvoering en de kosten voor internationale biomassacertificatiesystemen. Ook moet de naleving van internationale wetten en handelsovereenkomsten, zoals het Akkoord over Technische Handelsbelemmeringen, het MFN-principe (Most Favoured Nation) of de 'Code of Good Practice', worden verbeterd.

Voor benaderingen om de sociaal-economische en milieueffecten van bio-energieketens te analyseren en de gehele duurzaamheid van de ketens te evalueren, zijn de volgende punten van belang:

- De huidige sterke toename in bio-energieprojecten in verscheidene regio's in de wereld en de verschillende eisen om de duurzaamheid van biomassa-energieprojecten aan te tonen, vragen om een gestandaardiseerde benadering. Dit is nodig om een transparante analyse en een vergelijking van de resultaten te kunnen maken tussen verschillende landen, bio-energietechnologieën en gebruikte biomassabronnen. Daarom geven wij de voorkeur aan het gebruik van één standaardbenadering per criterium. Inspanningen om een gestandaardiseerde methode voor het berekenen van de broeikasgasbalans te kunnen realiseren gaan in de juiste richting, maar het doel is nog niet bereikt. De software tool, zoals beschreven in hoofdstuk 6, toont aan dat het mogelijk is om gebruikers uit verschillende gebieden dezelfde methodologie te laten gebruiken om de broeikasgasbalans en de kosteneffectiviteit van verschillende biomassa-energiesystemen te berekenen.

- Verschillende sociaal-economische en milieucriteria vereisen de ontwikkeling van nieuwe of betere methodes en prestatie-indicatoren. Meer inzicht is bijvoorbeeld nodig in de effecten van voedsel-, veevoer en landprijzen op directe en indirecte landgebruikveranderingen. Daarnaast is winderosie niet meegenomen in de universele vergelijking voor de berekening van het bodemverlies door water (USLE[55]), hoewel dit een robuuste methodologie is om het jaarlijkse grondverlies door watererosie te berekenen. Diverse indicatoren (zoals de totale bodemnutriëntenbalans, de balans van één karakteristieke bodemnutriënt of de hoeveelheid organische stof in de bodem) kunnen

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[55] De universele vergelijking voor de berekening van het bodemverlies door water is internationaal meer bekend als de USLE (Universal Soil Loss Equation) vergelijking.

worden gebruikt om het effect van biomassaproductie op de bodemkwaliteit te bepalen. Een (gestandaardiseerde) prestatie-indicator ontbreekt echter om dit effect te bepalen en te kwantificeren.

- Er is een gebrek aan normen (ofwel minimale of maximale waarden) per criterium, wat de beoordeling of een bio-energieketen wel of niet duurzaam is compliceert. Hoewel de efficiëntie van watergebruik door switchgrass en soja grofweg kan worden bepaald om de effecten van biomassaproductie op de beschikbare hoeveelheid water in een regio te beoordelen, is niet vastgesteld bij welk (ruimtelijk) niveau in de regio dit leidt tot een niet-duurzame afname van de beschikbare waterhoeveelheid. Tevens is geen norm beschikbaar om te beoordelen welke absolute afname of toename van jaarlijks grondverlies leidt tot niet-duurzame erosiesnelheden van de bodem.

- De nauwkeurigheid van de invoergegevens bepaalt de juistheid van de inschattingen over het potentieel en de prestaties van bio-energieketens op regionaal niveau voor de korte en de lange termijn. Betere landgebruiksgegevens en de ontwikkeling van transparante gegevensbestanden zijn nodig om het potentieel voor biomassaproductie en -handel nauwkeurig in kaart te kunnen brengen. Meer locatiespecifieke gegevens zijn bijvoorbeeld nodig om het effect van landbouwproductiesystemen op de koolstofvoorraad van de bodem te kunnen bepalen. Daarnaast is de kwaliteit van invoergegevens voor marginaal en gedegradeerde gronden over het algemeen beperkt. Regiospecifieke invoergegevens zijn o.a. nodig voor hydrologische analyses en voor het bepalen van effecten op de biodiversiteit. De beschikbaarheid van gegevens is vaak beperkter in ontwikkelingslanden. De ontwikkeling van voldoende geschikte gegevensbestanden voor deze landen, vooral voor de veelbelovende biomassaproductiegebieden, is dus zeer gewenst.

Ondanks de huidige beperkingen, kan worden geconcludeerd dat de sociaal-economische en milieueffecten van een bio-energieketen met betrekking tot verschillende landgebruikscenario's *ex ante* kan worden bepaald. Aldus kan worden nagegaan wat veelbelovende bio-energieketens voor de korte en langere termijn zijn (Onderzoeksvraag V). Hoofdstuk 7 toont aan dat het mogelijk is om met de huidige beschikbare criteria, indicatoren, normen en methoden een redelijke indicatie te geven welke bio-energieketens naar verwachting meer duurzaam zullen presteren dan andere. Een scenariobenadering, zoals toegepast in diverse hoofdstukken van dit proefschrift, biedt inzichten in de bandbreedte van resultaten voor het potentieel en de economische en duurzaamheidprestaties van bio-energieketens, wanneer onderliggende factoren worden veranderd. De gekozen bottom-up benadering maakt het mogelijk om scenario parameters te vertalen naar belangrijke variabelen die de effecten van de biomassa productiesystemen bepalen in de analyses. Dit geeft inzicht in het ontwikkelingspad dat zou kunnen worden gevolgd of vermeden om goede sociaal-economische en milieuprestaties voor bio-energieproductie te behalen.

De volgende factoren zijn hierbij van belang:

- Het is belangrijk om de verdere ontwikkeling te steunen van efficiëntere en productievere landbouw- en veeteeltbeheerssystemen die gebaseerd zijn op een optimaal gebruik van landbouwinputs, moderne gewassoorten en efficiënte technologieën.
- Biomassaproductie zou moeten worden toegewezen aan gebieden waar synergie kan worden bereikt in het potentieel, de sociaal-economische prestaties en milieuprestaties. Een goed voorbeeld hiervan, besproken in dit proefschrift, is de productie van meerjarige grassen op marginale gronden wat een gunstige invloed heeft op het tegengaan van erosie, het beschermen van de koolstofvoorraad in de bodem en het behoud van biodiversiteit. Nauwkeurige en specifieke Geografische Informatie Systemen en landgebruikgegevens zijn nodig om dit te bereiken.
- Het is van belang om een juiste selectie van een geschikt energiegewas (of een combinatie van gewassen) te maken door de agro-ecologische condities van een gebied af te stemmen op en, wanneer mogelijk, te optimaliseren voor de individuele vereisten van een gewas. De productie van meerjarige lignocellulose gewassen hebben over het algemeen de voorkeur wanneer hoge energieopbrengsten, lage biomassaproductiekosten en milieuvriendelijke productiemethodes met elkaar moeten worden gecombineerd. Dit geldt vooral wanneer marginale gronden kunnen worden gebruikt;
- Ruimtelijke ordening en het monitoren van landgebruikveranderingen op macroniveau zijn nodig, waarbij gebieden met een hoge biodiversiteitwaarde worden uitgesloten voor biomassaproductie. Gebieden met een lage biodiversiteitwaarde kunnen, aan de andere kant, worden toegewezen voor biomassaproductie aangezien dit kan bijdragen tot herstel;
- De logistiek zou geoptimaliseerd moeten worden door met elkaar gunstig verbonden export- en bestemmingregio's en geschikte vervoerwijzen te selecteren. Over het algemeen heeft zeetransport de voorkeur voor internationaal transport over lange afstanden, gevolgd door (in afnemende volgorde) kustvaart transport, binnenvaart, trein- en vrachtwagentransport. De kosten kunnen verder worden verlaagd als de installatie voor het voorbewerken of de conversie binnen of nabij de biomassa producerende regio wordt gevestigd, met inachtneming van de 'economies of scale' voor conversie-installaties.

Concluderend laat het onderzoek, zoals gepresenteerd in dit proefschrift, zien dat de haalbaarheid en duurzaamheid van grootschalige biomassaproductie (voor lokaal gebruik of handel) *ex ante* kan worden beoordeeld. Aangezien de prestaties van biomassaproductie- en leveringketens sterk in ruimte en tijd kunnen verschillen, blijkt het verankeren van de effectanalyse in een scenariobenadering een goede manier om dit probleem aan te pakken. Het gebruik van regionale analyses en de beschikbaarheid van voldoende specifieke gegevens (voor landgebruik, waterbeschikbaarheid, enz.) is onontbeerlijk om tot voldoende betrouwbare resultaten te kunnen komen. Daarnaast laat het gepresenteerde onderzoek zien dat de hierboven vermelde factoren elkaar (sterk) kunnen beïnvloeden. Bijvoorbeeld, de verbetering van één duurzaamheidprincipe (zoals het creëren van werkgelegenheid) kan een verslechtering van een ander principe betekenen (bijvoorbeeld de broeikasgasbalans), maar ook kan synergie worden bereikt. Daarom heeft dit proefschrift de titel: *Duurzaamheid van bio-energieketens: het resultaat zit in de details.*

Op basis van voorgaande conclusies, kunnen de volgende beleidsaanbevelingen worden gegeven:

- Het is nodig om beleid- en marktactiviteiten die zich richten op de (verdere) ontwikkeling van bio-energie, te baseren op gedegen potentieel- en impactanalyses. Hiervoor zijn voorbeelden gegeven in dit proefschrift.
- Gedegen regiospecifieke gegevens zijn vereist voor een betrouwbare regionale analyse van het potentieel, de kosten en de duurzaamheid van bio-energieketens. Dat dit op een redelijk detailniveau kan worden gedaan, is aangetoond in dit proefschrift.
- Het bereiken van internationale overeenstemming over geschikte benaderingen voor effectanalyses en de vereiste kwaliteit van gegevens is essentieel voor de geloofwaardigheid van certificatie en monitoring. Dit betreft in het bijzonder de harmonisatie van certificeringsystematieken en de daaraan gerelateerde ontwikkeling van indicatoren en analysetechnieken.
- Dit proefschrift laat zien dat het potentieel en de prestaties van bio-energieketens dynamisch zijn in de tijd. Monitoring van deze ketens in de tijd, gecombineerd met herhaalde evaluaties, wordt daarom aanbevolen.
- Demonstratieprojecten die voor een ‘leren door te doen’ benadering kiezen, kunnen de vereiste kennis verstrekken die nodig is voor de verdere ontwikkeling van bio-energieprojecten. De geleidelijke ontwikkeling van een biomassacertificatiesysteem, gekoppeld aan de ontwikkeling van geavanceerde benaderingen (bijvoorbeeld voor effecten op de bodemkwaliteit, voor landgebruiksveranderingen en voor de relatie met macro-economische sturingfactoren), kan de betrouwbaarheid van de beoordelingen stapsgewijs verbeteren.
- Duidelijke en coherente beleidsstrategieën zijn nodig om grootschalige duurzame biomassaproductie voor bio-energie in specifieke gebieden verder te ontwikkelen. Politiek moeten meerdere doelstellingen (bijvoorbeeld het creëren van werkgelegenheid, biodiversiteitherstel, de afname van broeikasgasemissies) in samenhang worden afgewogen voor stimulering van specifieke bio-energiesystemen. Alle relevante stakeholders in een regio zouden moeten worden betrokken bij het geven van prioriteiten aan specifieke effecten en doelstellingen van biomassaproductie voor energie;
- Integratie tussen verschillende beleidsvelden en het toevoegen van het thema bio-energie in het ruimtelijke ordenings-, landbouw- en (ruraal) ontwikkelingsbeleid zijn nodig om bovenstaande te kunnen realiseren.

Daarnaast worden de volgende onderzoeksaanbevelingen gegeven:

- Het is van belang om op scenario gebaseerde rekenmethodieken verder te ontwikkelen en testen, zodat stakeholders in staat worden gebracht om de sociaal-economische en milieueffecten van bio-energieprojecten op regionaal niveau te monitoren en zo nodig bij te sturen. Hiertoe is vooral een verbetering van de kwaliteit van landgebruikgegevens van belang.
- Een verdere ontwikkeling van methoden en procedures om (duurzaamheids) criteria af te kunnen wegen is nodig, bijvoorbeeld gebaseerd op standpunten van (geïnformeerde) stakeholders in een regionale setting.

- De koppeling van macro-economische sturingsfactoren met landgebruikveranderingen op een regionaal niveau moet verbeterd worden door bottom-up benaderingen te verbinden met top-down modelleringmethoden.
- Beter inzicht moet worden verkregen in hoe het landbouw (en veeteelt)-beheer verbeterd kan worden in samenhang met (macro-) economische sturingsfactoren, ruimtelijke-ordeningsbeleid en doelgerichte strategieën om tot een hogere efficiëntie en betere milieuprestaties te kunnen komen.
- Meer gedetailleerde gegevensbestanden zijn nodig van biomassaproductiesystemen en ketens voor verschillende settings (in het bijzonder in ontwikkelingslanden), voor marginale en gedegradeerde gronden en voor meerjarige gewassystemen. Daarnaast zijn forse inspanningen nodig om de haalbaarheid van dergelijke productiesystemen in de praktijk te bewijzen en te optimaliseren.
- Verder onderzoek naar de mogelijke impact van klimaatverandering op zowel de duurzaamheid als op het mondiale, regionale en lokale potentieel van bio-energieproductie is van belang.

Capítulo 8: Resumen y Conclusiones

Garantizar seguridad energética y acceso a la energía - especialmente en áreas rurales – y mitigar el cambio climático generado por los seres humanos son prioridades a resolver en las próximas décadas. Ellas tienen que ser resueltos sin comprometer otras necesidades como la seguridad en la comida, el agua y el mantenimiento de la biodiversidad (IPCC 2007a). La bio-energía es considerada como una de las opciones que pueden ser aplicadas para abastecer la creciente demanda de servicios eléctricos, y para mitigar el cambio climático generado por los seres humanos (IEA Bioenergy 2007; IPCC 2007a; OECD/IEA 2008a; OECD/IEA 2008b). Por estas razones, la bio-energía moderna es considerada una opción clave en la política energética de muchos países y se proyecta incrementar su uso considerablemente su uso en las próximas décadas (REN21 2008).

Un requisito importante para una provisión segura y a largo plazo de energía de biomasas, es la certeza de que recursos suficientes estén disponibles en forma permanente. Es posible considerar varias categorías de recursos de biomasa: residuos de agricultura y selvicultura, corrientes de desperdicios orgánicos, y más importante aún, la producción de diferentes cultivos dedicados a obtener la biomasa.[56] Las proyecciones indican que se espera que la mayoría del potencial de biomasa disponible, tanto a corto como a largo plazo provenga de los cultivos energéticos. Las regiones promisorias para la producción de energía de biomasa son la antigua Unión Soviética y los países de Europa del Este, el Caribe, América Latina y el África subsahariana. (Hoogwijk *et al.* 2005; Smeets *et al.* 2007; Dornburg *et al.* 2008b).

Es poco probable que biocombustibles, como el éster metílico de canola y el etanol de cultivos de almidón y azúcar en las zonas de clima moderado, realmente alcancen precios competitivos en las décadas próximas, a pesar de las continuas mejoras en la eficiencia de la producción y de las cosechas (IEA 2004). En algunos países, entre ellos el Brasil, los costos del etanol de caña de azúcar están cercanos o por debajo del costo de producción de la gasolina (Goldemberg 2007). La producción de metanol, ésteres dimetílicos (DME), hidrógeno, metanol vía Síntesis de Gas Natural (GNS), líquidos *fisher-tropsch*, y etanol producidos a partir de biomasa de lignocelulosa - los llamados biocombustibles de segunda generación - también pueden volverse competitivos a largo plazo mediante una mejora tecnológica continua, obtenida de la experiencia y una producción a gran escala (IEA Bioenergy 2007).

El potencial suministro de energía proveniente de biomasas depende, en gran medida, de la cantidad de área disponible para el crecimiento de cultivos energéticos, teniendo en cuenta que se debe cubrir globalmente la creciente demanda de alimentos, combinado con la protección de la biodiversidad, el manejo sustentable de los suelos, las reservas acuíferas y una variedad de otras condiciones de sustentabilidad.

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[56] En esta tesis, restringimos el análisis a los residuos de agricultura y selvicultura, manteniendo el foco principal sobre las tierras con producción dedicada a biomasas

Dado que la mayor parte de los futuros recursos de biomasas disponibles para la energía dependen de estas condiciones, no es posible presentar una cifra única para el potencial futuro de la producción de energía de biomasas (Dornburg *et al.* 2008).

Los aspectos mencionados sugieren que el incremento de la producción y la demanda de energía de biomasas serán simultáneos con un aumento en la preocupación por el rendimiento de la cadena de bio-energía, especialmente en lo relacionado con el impacto socio-económico y ambiental de estas cadenas.

La producción y uso sustentable de los recursos de biomasas se considera hoy día como un requisito clave de acceso a los mercados en un creciente número de países (Zarrilli 2006; Cramer *et al.* 2007). Los efectos ambientales y socio-económicos de la producción de energía de biomasas, considerados en la investigación de su sustentabilidad, son sus impactos en las emisiones de Gases de Efecto Invernadero (GEI), la competencia con la producción de alimentos, los impactos sobre la biodiversidad, el uso del agua, el balance de nutrientes del suelo y el impacto en el bienestar (local) y social. El desarrollo de principios, criterios e indicadores así como la creación de esquemas de certificación se reconocen como estrategias que pueden ayudar a asegurar la producción y comercio sustentable de energía de biomasas.

Entre los diferentes marcos de sustentabilidad y los enfoques de varios países y grupos financieros hay diferencias en la rigurosidad, extensión y nivel de detalle de los criterios sociales, económicos y ambientales propuestos. Un rango de asuntos a resolver existe, tales como la formulación precisa de los principios y criterios de sustentabilidad, y la selección de indicadores. La complejidad de estos procesos es grande debido al número de intereses financieros involucrados y el gran número y variedad de sistemas de producción de biomasas y escenarios a ser tomados en cuenta.

En este contexto, esta tesis se enfoca en comprender cómo la viabilidad y sustentabilidad de la producción a gran escala de bio-energía, el suministro y uso pueden ser determinados *ex ante* a nivel regional. Este es dirigido en el contexto de bioenergía para su uso local o comercio teniendo en cuenta las complejidades y variabilidad de factores subyacentes como la demanda alimentaria y el uso de la tierra.

Con este fin, se han formulado las siguientes **preguntas de investigación**:

I. ¿Cómo pueden ser seleccionadas las áreas *ex ante* que muestran buen potencial para la producción de energía de biomasas a corto y largo plazo, dentro de las regiones del mundo seleccionadas, considerando las limitaciones biológicas y climáticas, la demanda de comida y pienso, la necesidad de mantener bosques y la biodiversidad, las políticas directrices de la agricultura, el medio ambiente y la energía?
II. ¿Cómo se puede determinar el rendimiento económico de la producción de energía de biomasa a gran escala y los sistemas de comercio para regiones específicas?
III. ¿Cuáles son las iniciativas actuales en certificaciones de energía de biomasas, y más específicamente, en el desarrollo de principios, criterios, indicadores y metodologías para

determinar los impactos y para garantizar una producción sustentable de energía de biomasas para un amplio rango de regiones y fuentes de biomasa?

IV. ¿Cuáles son las posibilidades y limitaciones para llegar a un enfoque unificado que permitan definir la biomasa y producción de bio-energía sustentables para un amplio rango de regiones y fuentes de biomasa, con énfasis especial en la reducción de emisiones de GEI?

V. ¿Cómo se pueden evaluar *ex ante* los impactos ambientales y socioeconómicos de una cadena de bio-energía en relación a los diferentes escenarios de uso de la tierra?

Las preguntas de investigación están respondidas en los capítulos 2 a 7 de esta tesis. La pregunta de investigación I, está analizada en los capítulos 2 y 3. Los capítulos 2 a 4 responden la pregunta de investigación II. La pregunta de investigación III, esta desarrollada en el capítulo 5. Los capítulos 5 y 6 analizan la pregunta de investigación IV. Los capítulos 6 y 7 dan una respuesta a la pregunta de investigación V. Los principales hallazgos de cada capítulo se desarrollan aquí, seguidos de algunas conclusiones generales y recomendaciones para investigaciones futuras y desarrollo de políticas.

El capítulo 2 brinda una evaluación de los potenciales técnicos y de las curvas de costos-suministros de bio-energía a nivel regional en el centro y en los países del este de Europa (CEEC), incluyendo Bulgaria, Eslovaquia, Estonia, Hungría, Latvia, Lituania, Polonia, República Checa y Rumania. La evaluación se aplica a nivel de una región (distrito) llamada NUTS-3[57]. En este capitulo, se construyeron cinco escenarios en un marco temporal hasta 2030, para describir la influencia de diferentes factores en el potencial y los costos de la biomasa. Los escenarios V1 a V5 caracterizan los más importantes elementos de la región relacionados con la agricultura y el uso de la tierra: Las características principales de los escenarios son:

- *V1:* Hay una liberalización del comercio y no existen barreras a las transacciones entre la Unión Europea y el mercado mundial para los productos agrícolas. La Unión Europea (UE) se especializa en productos que son competitivos en el mercado mundial. El sector agrícola del CEEC utiliza insumos de alta calidad y sistemas de producción con tecnologías de avanzada.
- *V2:* Las políticas están orientadas regionalmente. Existen barreras entre los mercados de Europa del Oeste y Europa del Este. La agricultura en CEEC tiene dificultades para competir con la agricultura de los países de Europa del Este (WEC). El sector agrícola en la CEEC utiliza sistemas de producción aplicados en la actualidad.
- *V3:* No hay barreras para el comercio interior en la UE. El comercio entre la UE y los mercados mundiales se basa en la situación actual (1997-1999). La Política Común de Agricultura (CAP) regula la agricultura en la UE. La CEEC se ha adaptado completamente a la legislación de la Unión Europea y puede competir plenamente con la

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[57] NUTS es la abreviatura de '*Nomenclature of Territorial Units for Statistics*' (Nomenclatura de Unidades Territoriales para Estadísticas) y son las regiones para estadísticas de Europa y la *Accession Countries* (EUROSTAT 2002). Las regiones NUTS-3 son niveles distritales o regionales dentro de un país ((EUROSTAT 2002).

agricultura de los países de Europa Oriental (WEC). El sector agrícola de CEEC utiliza insumos de alto nivel y sistemas de producción de primera línea.

- *V4:* No hay barreras para el comercio interior dentro de Europa. Existen barreras entre el mercado europeo y los mercados mundiales, dado que Europa protege fuertemente su propio mercado. El sector agrícola del CEEC utiliza altos insumos y sistemas de producción con tecnologías de avanzada.
- *V5:* La UE (WEC y CEEC) da prioridad al desarrollo sustentable y a la conservación de la naturaleza. La biodiversidad, la protección de áreas rurales y el mantenimiento de la vitalidad de las áreas boscosas y los pastizales tienen una alta prioridad. Para esto se necesita asegurar un cierto nivel de protección de mercado. El sector agrícola utiliza sistemas ecológicos de producción.

El potencial técnico de los recursos bioenergéticos se investiga por medio de modelos de abajo hacia arriba (*bottom-up*) detallados. El total disponible del potencial bioenergético, calculado a nivel regional o distrital, es la suma de la biomasa de los cultivos energéticos, la madera excedente de la producción forestal y los residuos agrícolas y forestales. Un pre-requisito para la evaluación es que la demanda doméstica de comida y pienso sea satisfecha y para ello se considera que una determinada área de tierra dedicada a la agricultura, será necesaria para alcanzar esta demanda. El tamaño de esa área dependerá de la demanda de comida y pienso, de la productividad del sistema agrícola y de los procedimientos de asignación para la producción de comida y pienso, definiendo la porción de tierra más adecuada para cada cultivo sobre la base de sus requerimientos. La área actual, excluyendo las áreas forestales y las protegidas, menos las áreas necesarias para alimentos, pienso y producción ganadera dan como resultado las áreas excedentes que se pueden utilizar para la siembra de cultivos energéticos. El potencial técnico de la energía de biomasa derivada de estos cultivos se calcula multiplicando el área disponible por la productividad de los cultivos energéticos. Las curvas de costo-suministro indican a que niveles de costos, el potencial de la energía de biomasa se encuentra disponible. Los niveles de costos se estiman por medio de un cálculo de costo de producción de biomasa específico para los escenarios considerados en la evaluación.

Los resultados muestran que un área de 36 a 46 millones de hectáreas – el último corresponde al 36% del total de la tierra disponible para la agricultura – podría pasar a estar disponible para cultivos energéticos en la CEEC. Los escenarios dominados por el actual nivel de producción agrícola (V2) o con foco en sistemas ecológicos de producción (V5) muestran el menor potencial para la producción de bio-energía, de 2-5.7 EJ para toda la CEEC. Los escenarios más favorables muestran el potencial más alto: 11.7 EJ (85% de cultivos energéticos, 12% de residuos y 3% de madera de excedentes forestales). En los escenarios más favorables (V1, V3 y V4) los potenciales de la energía de biomasas son mayores que el uso actual de energía primaria en la CEEC. El volumen del potencial (83-94%, dependiendo del escenario escogido) proviene de cultivos energéticos. Nótese que en estos escenarios, las demandas nacionales de alimentos y pienso están cubiertas y las áreas forestales y la naturaleza son preservadas.

Los países con las áreas de tierras más grandes, Polonia y Rumania, tienen los potenciales más altos para la producción de energía de biomasas. Además de estas amplias áreas de tierras, las condiciones eco-fisiológicas favorables para la producción como los suelos fértiles, pueden caracterizar a una región con un alto potencial de biomasas. El escenario ecológico (V5) muestra un conflicto entre la extensión de la agricultura ecológica y la producción a gran escala de energía de biomasas. Las razones son los bajos rendimientos que se obtienen con los métodos de producción ecológica.

En la mayor parte de la CEEC, el volumen del potencial de biomasa puede ser producido con costos menores a 2 €/GJ, el cual es menor que en WEC y por lo tanto competitivo con los combustibles fósiles. Los cultivos de biomasas de lignocelulosa perenne como el sauce, el álamo y el miscantus tienen los costos de producción más bajos, seguidos por el azúcar de remolacha y la canola. Los costos de producción de biomasa de sauce en el escenario que refleja la situación actual de la producción agrícola (V2) están en el rango de 1.0 a 4.5 € /GJ y 1.6 a 8 € /GJ en el escenario con la mayor productividad agrícola (V1). El motivo principal del incremento de costos es el incremento que se ha asumido en el valor de la tierra y de la mano de obra. Otros componentes importantes de los costos son insumos tales como los fertilizantes y los agroquímicos. Los mayores costos de producción de bio-energía se encuentran en el escenario V5, donde prevalece la agricultura ecológica. Las tierras de calidad baja también muestran altos costos de producción.

El capítulo 3 analiza, para los mercados nacionales e internacionales en desarrollo, el potencial y la viabilidad de la producción de bio-energía a gran escala a partir de soja y *Panicum Virgatum* (switchgrass en ingles) cultivados en una región seleccionada de la Argentina; un país con un potencial promisorio para la producción de bio-energía en la región del MERCOSUR. La soja hoy en día es el principal cultivo de exportación en la Argentina. Al mismo tiempo, el cultivo de switchgrass para la producción de bio-energía, ampliamente desconocido como un cultivo energético en Argentina, parece promisorio. Esas razones, y el hecho de que el potencial bio-energético está relativamente poco estudiado, hacen de la Argentina un caso interesante.

Los tres escenarios, en un marco de tiempo hasta 2030, describen la influencia de las conductas más importantes en el potencial y costos de estos sistemas de bio-energía. Además el potencial y los costos también se evalúan para la situación actual (CUR). El escenario A refleja un contexto base para el desarrollo de la economía. Los escenarios B y C se caracterizan por un crecimiento económico más fuerte. Entre ambos, el escenario C está más orientado a la exportación, mientras que el escenario B se enfoca en proteger el medio ambiente y está orientado al desarrollo de los mercados internos.

El potencial de la biomasa para generar energía se evalúa a nivel nacional y provincial, utilizando la metodología de abajo hacia arriba aplicada en el capítulo 2 de esta tesis. Se usaron datos más específicos tanto a nivel nacional como provincial, en comparación a los usados en el capítulo 2.

La selección de un área apropiada para la producción de bio-energía a gran escala en la Argentina se basa en un conjunto de criterios definidos, siendo estos:

1. Suficiente tierra disponible para la producción de bio-energía bajo los escenarios supuestos;
2. Hay una potencial de producción de soja y switchgrass en la región definida;
3. Riesgo limitado de competencia entre tierras para la producción de bio-energía y aquellas utilizadas para la producción de alimentos y pienso.
4. Proximidad de la infraestructura logística.

Las cadenas de bio-energía han sido definidas para analizar el rendimiento económico de la producción de biomasa a gran escala, para uso local o para exportar a los Países Bajos. Los costos están definidos por eslabón en la cadena bioenergética.

A nivel nacional en Argentina, de $18*10^6$ ha (A2030) a $33*16^6$ ha (CUR) de tierra, podrían llegar a estar disponibles para la producción de bio-energía a partir de soja. Mientras que para la producción de bio-energía de switchgrass, la porción de tierra que estaría disponible sería de $10*10^6$ ha (A2030) a $17*10^6$ ha (C2030). El switchgrass puede alcanzar un máximo potencial de bio-energía de $243*10^6$ t_{ms} (4.5 EJ) por año, en el escenario de un sistema de producción de altos insumos y de aplicación de tecnología de avanzada (C2030), en comparación con $99*10^6$ t_{ms}[58] (1.9 EJ) por año en un escenario donde se mantengan los actuales métodos de producción (A2030). La producción de soja puede alcanzar, basada en su contenido de aceite vegetal crudo, potenciales de $13.8*10^6$ t_{ms} por año (0.5 EJ) en CUR y de $12.6*10^6$ t_{ms} anuales (0.45 EJ) en C2030 en comparación con $7.1*10^6$ t_{ms} por año (0.25 EJ) en A2030. La mayor parte de la producción de bio-energía proviene de una combinación de tierras excedentes adecuadas (S) y moderadamente adecuadas (MS). En general, es posible concluir que el potencial bioenergético del switchgrass es sustancialmente mayor que el de soja. En este estudio no se han tenido en cuenta los posibles impactos que el cambio climático (sequías o más lluvias) podrían tener sobre los resultados potenciales de biomasa.

Con base al conjunto de criterios definidos (mira la lista encima), la región más adecuada de la Argentina para ser destinada a cultivos energéticos es la provincia de La Pampa. En esta provincia, de $65*10^4$ (A2030) a $127*10^4$ ha (C2030) de área podrían estar disponibles para la producción de bio-energía de switchgrass. Para la producción de bio-energía a partir de soja, una superficie de $28*10^4$ (C2030) a $42*10^4$ ha (B2030) de área podría estar disponible. Si nos restringimos a las áreas apropiadas y moderadamente apropiadas (mS), una superficie de $17*10^4$ a $30*10^4$ ha de área podría estar disponible para la producción de bio-energía de soja y una área de $37*10^4$ hasta $97*10^4$ ha podría estar disponible para la producción de bio-energía de switchgrass.

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[58] ms = materia seca

Los costos de producción de switchgrass en la provincia de La Pampa son de 33U$/$t_{ms}$ (22 €[59]/ t_{ms}) en las áreas de tierra adecuada en (CUR) a 91 U$/ t_{ms} (62€/ t_{ms}) en las áreas moderadamente adecuadas (mS) en el escenario (B2030). Los costos de producción de soja varían desde 182 US$/ t_{ms} (124 €/ t_{ms}) en áreas de tierra adecuada en (CUR) a 501 US$/ t_{ms} (341 €/ t_{ms}) en áreas de tierra moderadamente adecuada en el escenario (B2030). El uso de la tierra, la maquinaría, el combustible, los fertilizantes y los agroquímicos (en el caso de de soja) son los componentes más importantes de los costos de producción de los cultivos energéticos.

Se asume que el switchgrass es convertido en pellets para la generación de energía en los Países Bajos o para el consumo interno en la Argentina. Los costos de producción y transporte de estos pellets producidos en la provincia de La Pampa son de 58-143 U$/ t_{ms} (40-97 €/ t_{ms}) para uso local y 150-296 U$/ t_{ms} (102-201€/ t_{ms}) hasta su envío a Europort de Rótterdam.

En los Países Bajos se puede producir electricidad a partir de pellets de switchgrass importado de la Argentina a un costo de 0.06 a 0.08 U$/kWh (0.041 a 0.054 €/kWh). El costo actual para producir electricidad a partir del carbón en los Países Bajos, varía de 0.05 a 0.09 U$/kWh (Ouwens 2006), éste último incluye el costo de la captura del dióxido de carbón y su almacenamiento geológico. El costo de la electricidad para la co-combustión de pellets en la situación actual (CUR) y en el escenario A2030 está cercano al costo de la electricidad producida a partir de carbón, cuando se excluyen los costos de captura y almacenamiento del dióxido de carbón.

Los costos de calefacción en la Argentina, en base al uso de pellets de switchgrass, en reemplazo del gas natural están en el orden de 0.02 a 0.04 U$/kWh (0.014-0.027 €/kWh). Considerando el bajo precio del gas natural actualmente (2007-2008), el pellets de switchgrass no puede competir con el gas para generar calor en la Argentina. En el caso de que el precio del gas natural aumente en el futuro, tal como se asume en algunos de los escenarios (B2030, C2030-mS) de este estudio, el pellets de switchgrass podrá volverse competitivo con el gas natural en la producción de calor.

En este estudio, también se asume que la soja producida en la provincia de La Pampa, se convierte a biodiesel para uso local o para exportación a los Países Bajos. En varios escenarios, el biodiesel puede ser producido a un costo de 0.3-1.2 U$/litro (0.2-0.8€/litro) para uso local y a 0.5-1.7 U$/litro (0.3-1.2 €/litro) para exportar a los Países Bajos. Los costos actuales para el biodiesel de soja (0.46-0.54 US$/litro), exportado a los Países Bajos pueden ser competitivos con los costos del combustible fósil considerando un costo del petróleo de 80 U$/barril (cuando se producen en la áreas adecuadas) y con un costo del petróleo de 94 US$/barril (cuando son producidos en áreas moderadamente adecuadas). Actualmente, los costos de la producción local de biodiesel de soja (0.32-0.39 US$/litro) son competitivos con el combustible fósil con un precio del petróleo de 55 US$/barril,

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[59] Los datos de costos recolectados desde 2007 hasta el principio de 2008 se utilizan como base para la situación corriente, La conversión de los datos de costos de € a U$ (o viceversa) corresponden a valores de febrero de 2008. La tasa de cambio (1 € = 1.47 U$) también se ha utilizado para compara resultados entre CEEC y la Argentina.

cuando se producen en áreas adecuadas y con un precio de 67 U$/barril cuando se produce en áreas moderadamente adecuadas. Esto quiere decir que el biodiesel no es competitivo con los combustibles fósiles, sobre la base de que el precio del combustible en el comienzo de 2009 descendió al nivel de 40 US$/barril en enero de 2009 (IEA 2009).

IEA brinda una proyección del precio del crudo de 100 US$/barril para el período 2008-2015, aumentando hasta 120 US$/barril en 2030. En esta proyección, se toman en cuenta las fluctuaciones en el precio del combustible en 2007-2008. La perspectiva de IEA (2008) indica que "mientras los desajustes del mercado puedan causar caídas temporales en los precios, se está haciendo cada vez más aparente que la era del combustible barato ha terminado" y que "los cambios pronunciados a corto plazo es probable que sean comunes y los picos de precios temporales o las caídas abruptas no se pueden descartar". IEA prevé una presión ascendente en el precio de los combustibles hacia el final del período del proyecto, más allá de 2015, principalmente debido a las inversiones requeridas en la capacidad (adicional) para aumentar la capacidad de abastecimiento (OECD/IEA 2008a). En consecuencia, los incrementos en el precio del combustible es muy probable que ya estén a corto o mediano plazo.

Como se necesitarán grandes volúmenes de biodiesel en la Argentina para el año 2010 a fin de cumplir con su Ley de Biocombustibles, el uso local de biodiesel de semillas de soja producido localmente aparece una opción favorable.

Los parámetros claves para evaluar el rendimiento económico son los costos de cultivo, costos de pre-procesamiento, del transporte y de conversión y los costos y precios del combustible fósil y otros productos agrícolas[60]. Si se desarrolla un mercado, se puede esperar que los costos de la bio-energía disminuyan por medio de la optimización de la logística, la investigación, el desarrollo, y el aprendizaje técnico. La mejora de la logística del transporte por ferrocarril en la Argentina puede hacer que las áreas agrícolas existentes, distantes de los puertos, sean económicamente atractivas para la producción de bio-energía.

El gran potencial y el buen rendimiento económico de la cadena bioenergética de switchgrass en la provincia de La Pampa, hace que sea interesante el futuro desarrollo de la producción de switchgrass en esa provincia, especialmente en las áreas moderadamente adecuadas. En la actualidad, el uso local de pellets de switchgrass no es económicamente competitivo para reemplazar al gas. Podría, sin embargo, valer la pena usar (una parte) del pellets de switchgrass localmente en La Pampa para usos alternativos. El pellets de switchgrass podría por ejemplo, ser utilizado para diversificar los recursos energéticos disponibles en la región, o para alcanzar el objetivo nacional del 8% de energía eléctrica renovable para el 2016. Dado que el switchgrass es una nueva alternativa para la producción bioenergética en la Argentina, el desarrollo de proyectos de demostración, posiblemente integrados con otras plantas perennes para la producción ganadera, es recomendable.

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[60] Como grano o soja comercializados a gran escala (*commodities* en ingles)

En el Capítulo 4 se evalúa si el mercado de biodiesel y el comercio pueden ser lo suficientemente rentables como para llevar a cabo un suministro de biocombustibles desde Europa central y los Países de Europa del Este (CEEC) hacia el mercado de Europa occidental, estimando el rendimiento y los costos de la energía (etanol, pellets) entregados. Un modelo de hoja de cálculo es utilizado para llevar a cabo el análisis económico de una variedad de cadenas de bio-energía de larga distancia. En este estudio se utilizaron las características del escenario y los resultados del potencial de biomasa calculados a nivel regional de un NUTS-2[61] del escenario V3 (ver el capítulo 2 en este resumen).

Cinco NUTS-2 regiones en los países de CEEC localizadas en Polonia, Rumania, Hungría y República Checa muestran proyecciones favorables para producir materia prima para energía de biomasas a corto y largo plazo; y han sido por lo tanto seleccionadas como regiones claves en este estudio. Los destinos seleccionados para la biomasa en Europa occidental son Rótterdam, Marsella y Duisburg. Se asume que los sauces producidos en las zonas de origen son transportados, convertidos en pellets, a los destinos seleccionados. La segunda opción analiza el transporte de sauces como pellets para convertirlos en etanol a gran escala en los destinos seleccionados. La tercera opción considera la conversión local de pellets de sauce a etanol en las áreas de origen y posteriormente su transporte a las ciudades seleccionadas.

El pellets, producido en la CEEC, se puede proveer a los destinos seleccionados a un costo de 105-220 €/t_{ms}. Comparado con el actual costo de producción de pellets de 74-119 €/ t_{ms} en Suecia y Austria, la producción y exportación de pellets desde la CEEC puede ser competitiva para un número limitado de regiones de origen debido a los costos más altos del transporte.

El etanol puede ser producido entre 12 y 21 €/GJ, si la conversión de la biomasa se realiza en los destinos seleccionados de Europa occidental o entre 15 y 18 €/GJ si la conversión de biomasa en etanol se realiza (a menor escala) donde ésta es producida. Los costos calculados para la producción de etanol coinciden con el indicado para la producción de etanol a corto plazo (22 €/GJ) y a largo plazo (11 €/GJ) (Hamelinck *et al.* 2005a). Sobre la base de un costo del combustible estimado en el rango de 13-19 €/GJ, asumiendo un precio de combustible de 100 a 150 U$/barril y una tasa de cambio €/U$ de 1.35, los costos de la producción de etanol pueden ser competitivos, tanto a corto como a largo plazo. El etanol podría no ser competitivo cuando el precio del combustible es de 11€/GJ (lo que es alrededor de 85 US$/barril) o menor, como sucedió a comienzos de 2009. Sin embargo, se espera que los precios del combustible se incrementen a corto y mediado plazo (ver también capítulo 3), lo que mejorará la competitividad del etanol.

Se pueden lograr mayores reducciones en los costos del etanol por medio del reembolso (en base a 0.048 €/kWh) de la electricidad excedente, la que es co-generada durante el proceso de conversión. En caso de que el reembolso de electricidad pudiese incrementarse hasta

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[61] Una región NUTS-2 es una combinación regiones de NUTS-3 (ver también el capítulo 2 de este sumario) y es con frecuencia el nivel provincial dentro de un país.

0.06 €/kWh, el costo total de reconversión de una planta de 400 MW decrecería un 9%. En el caso de que el reembolso de electricidad decreciese a 0.04 €/kWh, el costo de conversión de una planta de 400 MW se incrementaría en un 5%. El nivel de reembolso frecuentemente está vinculado con aspectos políticos y puede variar mucho en cada país y con el tiempo.

Los comportamientos del costo de las cadenas bioenergéticas de los CEEC muestran que es importante elegir regiones favorables para las exportaciones y áreas de destino para reducir los costos de transporte. Las regiones de Rumania y Polonia muestran en general un mejor resultado económico para el comercio de biomasas a larga distancia que las regiones de Hungría y la República Checa. Esto se explica en parte por la selección de los destinatarios y la ubicación geográfica de las zonas de producción. Esas regiones de la CEEC con opciones de transporte marítimo están mejor preparadas para distribuir biocombustibles o su materia prima a los mercados internacionales de larga distancia. Los biocombustibles provenientes de regiones de la CEEC, que no tienen conexión con opciones favorables de transporte, serán utilizados preferentemente en los mercados locales.

El capítulo 5 brinda una visión general respecto de las iniciativas actuales en la certificación de biomasas (hasta Octubre del 2007), y más específicamente en el desarrollo de principios, criterios, herramientas y metodologías que garanticen la producción sustentable de biomasas para un amplio espectro de regiones y recursos de biomasas.

Algunos gobiernos nacionales, como el de los Países Bajos, el Reino Unido, Bélgica y Alemania y la Comisión Europea, han tomado la iniciativa de desarrollar una política marco para garantizar el uso de la biomasa sustentable para la producción de energía. También algunas ONG's como WWF, FBOMS y una cooperativa de ONG's holandesas han publicado documentos donde toman posición y expresan preocupaciones importantes para la producción sustentable de biomasas. Otras ONG's han comenzado estudios piloto (como Solidaridad) o tienen un rol activo en los foros de debate sobre estas cuestiones.

Las iniciativas de las compañías, activas en el desarrollo de un sistema de certificación de biomasas (por ejemplo: DaimlerChrysler, Shell), dependen del rol e intereses que tengan en la cadena bioenergética. Las iniciativas de organismos internacionales se centran en un amplio rango de actividades tales como proveer apoyo financiero y científico para países en vías de desarrollo o establecer foros para intercambio de información. Organismos internacionales, como UNEP y la Asociación Global para la Bio-energía (GBEP - Global Bioenergy Partnership), han formulado proyectos específicos para llegar a comprender cómo desarrollar un sistema de certificación de biomasas. Las redes internacionales y los foros, como (RTRS) en el caso de la soja, (RSPO) para el aceite de palma y (RSB) para los biocombustibles, están basados en un enfoque voluntario y deberían también tener como resultado el desarrollo de un sistema de certificación para sus productos específicos.

Las iniciativas concretas de traducir los principios de sustentabilidad en criterios operacionales e indicadores, para observarlos y verificarlos a través de un sistema de certificación de biomasas establecido son más limitadas.

Tabla 1: Resumen de los principios para la sustentabilidad propuestos o considerados por varios países y grupos financieros, 1) según la situación de octubre del 2007.

Principios relacionados con:	Países y loa Comisión Europea 2)								ONG's 3)			E 4)
	NL	B	UK	BR	Ca	GE	US	EC	SA	FB	N	
Origen de la biomasa	●		●		●	●	●	●	●	●	●	●
Cuestiones socio-económicas 6)	●		●? 5)	●				●?	●	●	●	
Prosperidad económica	●								●	●	●	
Condiciones de trabajo	●			●						●	●	
Derechos Humanos	●			●						●	●	
Derecho de propiedad	●			●					●		●	
Bienestar	●									●	●	
Integridad										●		
Cuestiones ambientales 6)			●?					●?				
GEI, balance energético	●	●	●			●	●	●	●	●	●	●
Suelo carbonífero	●							●			●	
Competencia por la tierra	●								●	●	●	
Biodiversidad	●					●			●	●	●	
Desechos	●								●			
Uso de Agroquímicos	●									●		
Prácticas agrícolas	●			●	●	●			●	●	●	
Uso sustentable de la tierra	●			●		●	●		●	●	●	
Suelo	●			●					●	●	●	
Agua	●								●		●	
Emisión atmosférica	●				●				●			
Uso de OGM									●	●	●	

1) No se muestran todas las iniciativas de ONG's, empresas y Organismos Internacionales. Para un resumen completo vea el capítulo 5. 2) NL = Países Bajos, B = Bélgica, UK = Reino Unido BR = Brasil, Ca = Canadá, GE = Alemania, US = Estados Unidos (California), EC = Comisión Europea. 3) SA = ONG's Sudafricanas FB = ONG's Brasileras, N = ONGs Holandesas. 4) EL = Empresa Electrabel. 5) ? = La inclusión de este principio está siendo discutida. 6) Hay buena predisposición para incluir principios socio-económicos y medioambientales. Sin embargo, aún no ha sido definidos cuáles serán.

En octubre del 2007, había dos sistemas activos de certificación de biomasas, iniciados por compañías de energía eléctrica (GGL y Electrabel). El Reino Unido, Bélgica, el gobierno de Holanda y RSPO, también han comenzado iniciativas para desarrollar un sistema de certificación de biomasas. El estado de estos sistemas varía entre el desarrollo y la prueba y verificación de criterios de sustentabilidad.

El desarrollo de sistemas de certificación de biomasas se encuentra obstaculizado por innumerables aspectos. El resumen de las iniciativas que se presentó en el capítulo 5 demuestra que las diferencias se hacen más visibles en la precisión, la extensión y el nivel de detalle de los criterios debido a las diferencias de intereses y prioridades. La proliferación de estándares y sistemas individuales podría causar la pérdida de eficiencia y credibilidad. También deberán ser resueltas muchas incertidumbres sobre la viabilidad, la implementación y los costos de los sistemas de certificación internacional de biomasas y el cumplimiento con las leyes y acuerdos internacionales de comercio. Por consiguiente, vale la pena considerar en esta fase preliminar, qué caminos se pueden tomar para desarrollar un sistema de certificación de biomasas confiable y eficiente.

Hay varios enfoques posibles para el desarrollo, la implementación y el gobierno de un sistema de certificación de biomasas. La distinción principal está en ver si el sistema es voluntario u obligatorio y si tiene una orientación internacional o nacional. Todos los enfoques que fueron publicados tienen sus propias fortalezas y limitaciones. Sin embargo, en todas las iniciativas se pueden identificar algunas acciones urgentes para el futuro desarrollo de estos enfoques:

- Se requiere una mejor coordinación internacional entre las diferentes iniciativas para mejorar la coherencia y eficiencia en el desarrollo de los sistemas de certificación de biomasas. Varias organizaciones internacionales pueden tomar la delantera, como la Comisión Europea (para la región europea), UNEP, la FAO, UNCTAD u otras. Esto debería proveer una dirección más clara en el enfoque elegido a nivel nacional y local.
- Los acuerdos la Organización Mundial del Comercio (OMC) existentes, como Acuerdo de Barreras Técnicas al Comercio, los Principios de Nación más Favorecida, o el Código de Buenas Prácticas, y su jurisprudencia ya proveen ideas sobre el rol de la OMC con respecto al desarrollo de un sistema de certificación de biomasas. Sin embargo, no existen aún precedentes sobre este tema. Se necesita un proceso de negociación entre los miembros de la OMC para alcanzar mayores acuerdos sobre este tema.
- La certificación no es un objetivo en sí misma, sino un medio para alcanzar un fin. Puede ser una de las herramientas políticas para asegurar la sustentabilidad de la producción y el uso de biomasas. Instalar códigos de buenas prácticas e integrar salvaguardas de sustentabilidad en los modelos mundiales de negocios, también sería un camino efectivo para lograrlo. Se debería mantener una visión amplia sobre herramientas alternativas de políticas (o una combinación de ellas) para buscar las opciones más adecuadas a fin de asegurar la producción y el comercio sustentable de biomasas.
- Actualmente la experiencia es muy limitada como para crear varios criterios operativos. El diseño de criterios e indicadores específicos relacionados con los requerimientos de una región, así como interrogantes tales como ¿cómo incluir formas de evitar los efectos de evasión y la fuga, y la influencia de la dinámica del uso de la tierra?, requieren del desarrollo de nuevas metodologías y enfoques integrados. Esto podría llevar una cierta cantidad de años. Por otro lado, hay una necesidad de asegurar la sustentabilidad de las biomasas en un mercado en rápido crecimiento, ya a corto plazo. Un desarrollo gradual del sistema de certificación con aprendizajes (por medio de programas piloto e investigaciones) y la expansión en el tiempo, unido al desarrollo de metodologías avanzadas, podrá dar valiosas experiencias y mejorar aún más la viabilidad y confiabilidad de los sistemas de certificación de biomasas. Este enfoque gradual otorga posibilidades para la coherencia, el monitoreo y el ajuste de las actividades.

El Capítulo 6 analiza en más detalle el balance de gases de efecto invernadero (GEI) de los sistemas bioenergéticos, considerado como una de aspectos importantes de un sistema de certificación. Los desarrollos actuales muestran un fuerte crecimiento de las iniciativas para desarrollar metodologías y herramientas para considerar GEI. Las diferencias entre ellas muestran las dificultades para lograr una metodología aceptada internacionalmente así como también en los valores mínimos para calcular los balances de GEI. A pesar de que la viabilidad económica de los proyectos de bio-energía es importante, tanto para los inversores como para quienes crean las políticas de mercado, la rentabilidad de la bio-energía para mitigar las emisiones GEI es raramente considerada.

Se debe tomar en cuenta una variedad de cuestiones metodológicas cuando se calcula el balance de GEI y la rentabilidad de los sistemas de energía de biomasas, tales como los efectos de fuga, la asignación de las emisiones a los productos principales y los emergentes, la dinámica de almacenamiento de carbono, los insumos energéticos ascendentes y la eficiencia de los sistemas de energía. En el capítulo 6, se desarrolla una metodología unificada para evaluar el balance de GEI y la rentabilidad de los sistemas de biomasas.
Esta metodología sirve como base para el marco de un software que permita analizar el balance de GEI y la rentabilidad de la mitigación de GEI.

Las características principales de la herramienta son el diseño de diagramas de flujo y el concepto de trabajar con diferentes niveles de cálculo y de ingreso de datos. Los casos de estudio que hemos realizado, cinco en total, muestran que la herramienta es capaz de considerar un amplio rango de sistemas de energía de biomasas. Su flexibilidad les permite a los usuarios de diferentes regiones utilizar una metodología que incremente la posibilidad de comparaciones y consistencia de los resultados.

Los casos de estudio tratados con esta herramienta demuestran que los aspectos metodológicos centrales para calcular el balance de GEI y la rentabilidad de los sistemas de energía de biomasas, pueden ser incluidas en una sola herramienta. Éstas son: las unidades funcionales, los parámetros de mitigación, los límites del sistema, los sistemas de energía utilizados como referencia, los cambios por el uso directo de la tierra y el carbón, los cambios por el uso indirecto de la tierra, los procedimientos de asignación, las cuestiones de tiempo, la medición de los costos, la especificidad del lugar, y la incertidumbre.

Los sistemas de energía de biomasas cubren un amplio rango de las opciones de demanda y suministro. El software es capaz de incluir esta diversidad permitiéndole al usuario utilizar información conjunta o desagregada. La calidad de los resultados depende por supuesto, de la precisión de los datos utilizados. El caso de estudio sobre “Producción de combustible en los Países Bajos a partir de residuos de madera del Canadá”, asume que se genera un producto: el FT-diesel. La electricidad se genera como un subproducto. La asignación de los insumos de energía, las emisiones y los costos entre la generación de combustibles y la electricidad en el proceso de conversión se basa en la substitución y alternativamente, en el contenido energético. En este resumen, se muestran los resultados de la asignación basada en el contenido de energía. Los resultados del caso de estudio muestran que el total de las emisiones de GEI y el costo de la energía por GJ entregado (GJ_{del}) desde un nivel detallado de datos son, respectivamente, 25 kg CO_2 eq./ GJ_{del} y 32 €/GJ_{del}. En comparación, el total de las emisiones de GEI y el costo energético por GJ entregados son respectivamente 25 kg CO_2 eq./GJ_{del} y 21 €/GJ_{del} cuando se utilizan datos conjuntos. Esta diferencia (especialmente en los costos) puede ser significativa para los inversores, los creadores de políticas y otros grupos financieros.

El caso de estudio “Combustión de residuos forestales de procesamiento bajo condiciones Sueco/Finlandesas”, demuestra que la elección del sistema energético de referencia es importante, ilustrando que el cambio entre una tecnología actual (2000) hacia una más avanzada (2020) disminuye las emisiones del sistema bioenergético de 15 a 10 kg CO_2 eq./GJ_{del} (suma de la energía de calor y electricidad) mientras que los costos son más o menos equivalentes (7.6 versus 7.5 €/GJ_{del}).

No existe un procedimiento general para asignar las emisiones de GEI y los costos al producto principal y a los derivados de los proyectos de biomasa que puedan ser aceptados bajo toda circunstancia. Se prefiere la asignación utilizando un enfoque multifuncional o de substracción, pero estos tienen sus limitaciones. La elección de asignar, basados en la masa, el contenido energético o el precio de mercado de los diferentes productos debería tomarse con cuidado dado que puede tener una gran influencia sobre los resultados. Esto se visualiza en el caso de estudio sobre ‘Biodiesel de canola en el Reino Unido’, el cual muestra una variación de 35 a 50 kg CO_2 eq./GJ_{del} dependiendo del procedimiento seleccionado y las presunciones subyacentes. La asignación basada en el contenido energético, que propone actualmente (comienzo de 2009) la Comisión Europea, es menos sensible a la variabilidad de los parámetros de materia prima y a las presunciones subyacentes que las asignaciones basadas en el precio de mercado.

La discusión sobre si incluir, y cómo hacerlo, los cambios que genera el uso indirecto de la tierra en la metodología para calcular el balance de GEI se encuentra actualmente en proceso. El caso de estudio ‘Calor a partir de switchgrass en el Reino Unido’, muestra que el impacto de las presunciones de cambios en el uso de la tierra pueden ser grandes, ilustrado también al evitar las emisiones de GEI que varían de 13 a 128 kg CO_2 eq./GJ_{del} dependiendo del sistema de referencia de uso de la tierra que se asuma. Las referencias que se incluyen son: cortar el pasto de las praderas, la rotación preventiva de la tierra, y la producción de los cultivos de canola. Este caso de estudio señala que el rendimiento de un sistema de energía de biomasas es específico en su lugar y su momento.

Dado que cuanto más exactos sean los datos de ingreso, más certeros serán los resultados, es esencial que el usuario pueda confiar en la calidad y adaptabilidad de los datos utilizados. También puede concluirse que se prefieren los análisis de lugares específicos utilizando datos desagregados. Se necesita una recolección de datos más amplia y el desarrollo de bases de datos consistentes con un enfoque en las promisorias regiones de producción de energía de biomasas para poder monitorear los impactos positivos y negativos de la producción y comercio de biomasas.

El Capítulo 7 analiza la viabilidad de utilizar el análisis socio-económico y de impacto ambiental *ex ante* para la producción a gran escala a nivel regional, basados en un grupo de criterios e indicadores ya definidos. El análisis se ha realizado para una producción de soja y switchgrass a gran escala en la provincia de La Pampa (Argentina). Los resultados se calculan para la situación actual (CUR) y para los escenarios A, B y C para el año 2030 (ver capítulo 3). El switchgrass y la soja son producidas en áreas de tierras apropiadas (S) y moderadamente apropiadas (mS). Los sistemas de referencia de uso de las tierras son, tierras de cultivo (C), praderas degradadas (D) y praderas no degradadas (G). La disponibilidad de los datos y las metodologías se trata para cada uno de los principios de sustentabilidad formulados y aplicados a la provincia de La Pampa. En esta evaluación de la sustentabilidad se utilizaron en total nueve principios de sustentabilidad.

Se ha utilizado una combinación de indicadores cuantitativos y cualitativos para obtener una indicación del comportamiento socio-económico y ambiental de la producción bioenergética en la provincia de La Pampa, en la Argentina. Los indicadores cualitativos se utilizaron para el principio 3, estableciendo el hecho de no poner en peligro el suministro de alimentos y otras aplicaciones locales alternativas para la biomasa, y para el principio 9 sobre la contribución al bienestar social que carece de una metodología apropiada o grupo de datos para cuantificar los resultados.

Es deseable el uso de metodologías estandarizadas, pero aún esto no es posible para todos los principios. Por ejemplo, no hay disponible una metodología apropiada para reunir los indicadores del impacto macro y micro económico. Las metodologías disponibles para evaluar los impactos de la producción de biomasas en el agotamiento del agua y sobre la calidad del suelo requieren mayor elaboración para ser aplicables a nivel regional para diferentes fuentes de biomasa.

Se debe establecer una norma o estándar para los criterios usados a fin de poder interpretar y cuantificar los resultados obtenidos en términos de resultados absolutos. Estos estándares están disponible para la biodiversidad (valores de MSA) y para la reducción de emisiones de GEI que deberían alcanzarse (por ejemplo: un mínimo de 35% de reducción de emisiones de GEI en comparación con el caso de referencia), pero en la actualidad están faltando para otros principios. En nuestras evaluaciones por lo tanto los marcadores para los otros principios se basan en el desempeño relativo y no absoluto para las cadenas bioenergéticas. La clase (datos mínimos, datos locales, habilidad, mapas) y el nivel de exactitud de los datos de entrada disponibles varían fuertemente entre los criterios investigados.

El cambio de almacenamiento de carbono para el switchgrass está en el rango de 0.2 a 1.2 t C/ha por año y para la soja varía de -1.2 a 0.0 t C/ha por año, dependiendo del escenario. La reducción de la emisión de GEI fluctúa en un rango de 88-133% para la cadena bioenergética de switchgrass (reemplazando al gas natural o al carbón) y de 16-94% para la cadena bioenergética de soja (reemplazando a los combustibles fósiles) para varios periodos de tiempo. El valor MSA, un indicador para el impacto de la producción de biomasa sobre la biodiversidad, oscila de +0.2 (conversión de la producción intensiva de tierras de cultivo a la producción de switchgrass) a -0.2 (conversión de pastizales extensos a la producción de soja). El uso eficiente del agua (UEA) en la producción de biomasas alcanza un rango de 0.4 a 0.6 g_{ms}/kg de agua para la producción de soja y de 1 a 22 g_{ms}/kg para la producción de switchgrass. La pérdida anual de suelo en comparación con el sistema de referencia de uso de la tierra es de 2 a 10 ton/ha para la cadena de bio-energía de soja y de 1 a 2 ton/ha para la cadena de bio-energía de switchgrass.

La mayoría de los beneficios ambientales pueden ser alcanzados cuando el switchgrass se produce en terrenos de cultivo abandonados. La producción de switchgrass en reemplazo de praderas degradadas, limitando la competencia con la producción de alimentos y pienso, también muestra un buen desempeño general de la sustentabilidad, especialmente para los escenarios (B-mS-D) y (C-mS-D). La producción de switchgrass en praderas no degradados podría resultar en impactos ambientales negativos.

La producción de soja para bio-energía muestra un buen rendimiento general de la sustentabilidad si se produce en terrenos de cultivos abandonados (A-S, C-S, y CUR-S). La producción de soja en terrenos degradados origina un menor rendimiento en sustentabilidad. La producción de soja en praderas degradadas y no degradadas resulta en un desempeño de sustentabilidad relativamente menor.

Excluyendo los escenarios no sustentables, siendo (CUR-mS-D, A-mS-D, B-mS-D, C-mS-D) para la producción de soja y (B-S-G) para la producción de ambos cultivos, la disponibilidad potencial de tierras para la producción de cultivos bioenergéticos en la provincia de La Pampa, tierras en S y mS oscilan desde las 0 a $24*10^4$ ha (en lugar de 17 a $30*10^4$ ha, ver capítulo 3) para la soja y de 17 a $97*10^4$ ha para el switchgrass (en lugar de 37 a $97*10^4$ ha, ver capítulo 3). El límite superior para la producción de switchgrass dedicado a la energía se mantiene constante ya que los escenarios con un alto potencial también son escenarios con buenos resultados en sustentabilidad.

Como la producción de soja para biodiesel para exportación y para consumo local es rentable para todos los escenarios, esta cadena se mantiene viable económicamente cuando se excluyen los escenarios no sustentables. La producción a gran escala de switchgrass se mantiene viable económicamente para la exportación a corto y largo plazo cuando se excluye el escenario (B-S-G). El uso de pellets de switchgrass para la producción local de energía a corto plazo no es económicamente viable (ver capítulo 3).

El desempeño general de las cadenas bioenergéticas es en general superior para el switchgrass que para la soja. Es posible minimizar significativamente el impacto ambiental (especialmente el riesgo de fuga en el uso de la tierra y cambios en la biodiversidad) en la cadena bioenergética de soja cuando el pienso generado es utilizado específicamente para la producción ganadera de la región. La tierra excedente entonces puede ser utilizada para propósitos alternativos como regeneración natural o producción de energía de biomasa.

Los resultados en los diversos escenarios muestran que la mayoría de los beneficios socio-económicos y ambientales pueden ser alcanzados cuando la cadena de producción de bio-energía apunta a usar el sistema de producción agrícola más avanzado disponible, en términos técnicos y ambientales, reemplazando los sistemas de uso de la tierra de esta región, con el desempeño económicos y ambiental más bajo, mientras se previene la fuga.

Es posible brindar someras indicaciones en cuanto a qué cadenas y escenarios se espera que rindan en forma más sostenible que otras. El uso de escenarios permite mostrar la amplia gama de resultados que se pueden obtener debido a la variación en los sistemas de manejo agrícola, adecuación de la tierra, sistemas de referencia de uso de la tierra, duración de los períodos de tiempo investigados, procedimientos de asignación y el impacto del cambio en el uso indirecto de la tierra. El enfoque genera una comprensión de hasta qué punto los factores subyacentes influencian el balance de GEI y otras cuestiones de sustentabilidad. Nótese por ejemplo que el sistema de uso de la tierra de referencia 'dedicada a cultivos', en este estudio, se basa en la producción de soja. La elección de un cultivo alternativo puede cambiar los resultados significativamente.

Conclusiones finales y recomendaciones para el desarrollo de políticas e investigación

La investigación presentada en esta tesis demuestra que es posible hacer selecciones *ex ante* de áreas promisorias para la producción de energía de biomasas a corto y largo plazo, tomando en cuenta las condiciones biológicas y climáticas, la demanda de alimentos y pienso, la necesidad de mantener la biodiversidad y la conservación forestal, para diferentes escenarios (políticas). Las regiones promisorias pueden ser seleccionadas por medio de un grupo predefinido de criterios como se demuestra en el capítulo 3 (Pregunta de investigación I). El potencial técnico de los recursos de biomasas puede ser investigado por medio de modelos de abajo hacia arriba (ver capítulos 2 y 3), que explicitan bajo qué niveles de mejoras en el manejo agrícola, la tierra se puede liberar para la producción de biomasas sin causar cambios por el uso indirecto de la tierra. El análisis del rendimiento económico (Pregunta de investigación II), los sistemas de producción y el comercio de energía de biomasas a gran escala para las áreas seleccionadas se construye en base a este enfoque: los costos se calculan considerando las variaciones espaciales en el rendimiento, el uso de la tierra, los precios y las subsecuentes operaciones de logística.

Esta tesis muestra simultáneamente que los modelos de comercio internacional, los precios de combustibles fósiles y los productos agrícolas pueden tener un importante impacto en el potencial y el rendimiento de las cadenas bioenergéticas a nivel micro. Por lo tanto es recomendable asociar los enfoques abajo hacia arriba (bottom-up) y de arriba hacia abajo (top-down). Además las posibilidades y limitaciones para mejorar los niveles de eficiencia de los sistemas de producción agrícola y ganadera, merecen mejores análisis.

En un creciente número de países, la producción sustentable de recursos de biomasa es hoy en día, considerada como un requerimiento clave para su mayor despliegue. Gobiernos nacionales, ONG's, compañías y organismos internacionales han iniciado recientemente un amplio rango de iniciativas en certificación de biomasas. Estos incluyen el desarrollo de principios, criterios, herramientas y metodologías que garanticen la producción sustentable de biomasas para un amplio espectro de regiones y recursos de biomasa (Pregunta de investigación III). Sin embargo, por el momento, faltan iniciativas concretas de convertir los principios de sustentabilidad en criterios e indicadores operativos y para controlar y verificar los proyectos de bio-energía por medio de un sistema establecido de certificación de biomasas.

El desarrollo de sistemas de certificación de biomasas se encuentra obstaculizado por innumerables aspectos (Pregunta de investigación V). Se debe resolver la incertidumbre respecto de la viabilidad, implementación y costos de sistemas internacionales de certificación de biomasas, y la adecuación con las leyes y acuerdos internacionales sobre el comercio, como el Acuerdo de Barreras Técnicas al Comercio, el Código de Buenas Prácticas, y el Principio de Nación Más Favorecida.

Los siguientes puntos son importantes para que los enfoques analicen los impactos ambientales y socio-económicos y para evaluar la sustentabilidad general de las cadenas bioenergéticas:

- El fuerte crecimiento actual en los proyectos de bio-energía en un amplio espectro de regiones en el mundo y los variados requerimientos para demostrar la sustentabilidad de los proyectos de energía de biomasas, necesitan un acercamiento unificado que habilite un análisis transparente y permita una comparación de los resultados para los distintos países, tecnologías de bio-energía y fuentes de biomasa utilizadas. Por lo tanto, es preferible usar un enfoque estándar para cada criterio, por sobre distintos enfoques, los cuales generalmente obtienen diferentes resultados. La elaboración de una metodología unificada para calcular los balances de GEI se encuentra avanzando en la dirección correcta, pero no ha finalizado aún. La herramienta de software descripta en el capítulo 6 nuestra que es posible permitirle a los usuarios de diferentes regiones usar la misma metodología para calcular el balance de GEI y la rentabilidad de los diferentes sistemas de energía de biomasas.

- Varios criterios socio-económicos y ambientales requieren el desarrollo de nuevos y mejorados enfoques e indicadores de rendimiento. Se requiere, por ejemplo, una mejor comprensión de la influencia de precios de los alimentos, del pienso, y de las tierras en los cambios por uso directo e indirecto de las tierras. Además, aunque la Ecuación Universal de Pérdida de Suelos (USLE) es una metodología sólida para calcular la pérdida anual de suelos por erosión del agua, esto no incluye la erosión del viento. Varios indicadores (por ejemplo: el balance total de nutrientes del suelo, el balance de un nutriente clave del suelo, cantidad de materia orgánica del suelo) pueden ser utilizados para evaluar el impacto de la producción de biomasas en la calidad del suelo. Sin embargo, hasta este momento falta un indicador (estandarizado) de rendimientos para definir y cuantificar este impacto.

- Faltan estándares (o umbrales) para cada criterio, lo cual complica la evaluación de si una cadena de bio-energía es o no sustentable. Aunque la Eficiencia del Uso del Agua para el switchgrass y la soja puede ser estimada aproximadamente para evaluar el impacto de la producción de biomasas sobre de la cantidad de agua en una región, no está definido a qué nivel (espacial) de la región resultaría en un (insostenible) agotamiento del agua. Además, no existen estándares disponibles para evaluar qué disminución o crecimiento absoluto en la pérdida anual de los suelos resulta en tasas de erosión del suelo insostenibles.

- La precisión de los datos de origen determina el nivel de exactitud en las predicciones del potencial y rendimiento de las cadenas de biomasa a corto y a largo plazo a nivel regional. Se necesitan mejores datos sobre el uso de la tierra y sobre el desarrollo de bases de datos transparentes para lograr un mapa precisa del potencial de la producción y comercio de biomasa. Se necesitan datos más específicos de los lugares para mostrar el impacto del manejo de sistemas agrícolas en los valores de referencia de carbono en el suelo. Además, los datos sobre la calidad de las tierras marginales y degradadas generalmente son limitados. Se necesitan datos regionalizados, entre otros, para los análisis hidrológicos y para las evaluaciones de impacto en la biodiversidad. Los datos disponibles a menudo son limitados en los países en vías de desarrollo y el desarrollo de conjuntos de datos adecuados y suficientes de estos países, con un enfoque en las regiones de producción de biomasa promisorias, son altamente deseados.

A pesar de las limitaciones actuales, los impactos socio-económicos y de medio ambiente de la cadena de bio-energía en relación con los diferentes escenarios de usos de la tierra pueden ser evaluados *ex ante* para cadenas de bio-energía promisorias y decisivas, a corto y a largo plazo (Pregunta de investigación V). El Capítulo 7 muestra que es posible generar una indicación razonable de qué cadenas bioenergéticas se espera que rindan en formas más sustentables que otras teniendo en cuenta los criterios, indicadores, estándares y metodologías disponibles en la actualidad. Un enfoque de escenarios, como se aplica en varios capítulos de esta tesis, provee comprensión del rango de resultados que pueden ser alcanzados en el desempeño potencial económico y de sustentabilidad de las cadenas de bio-energía, si los factores subyacentes son modificados. El enfoque de abajo hacia arriba elegido, permite convertir los parámetros de escenario en los cambios de las variables clave, que determinan los impactos de los análisis de sistemas de producción de biomasa. Esto evidencia claramente los caminos de desarrollo de bio-energía que deberían tomarse o evitarse para obtener rendimientos socio-económicos y medioambientales sensatos.

Los siguientes son factores importantes:

- Apoyar el desarrollo de sistemas de gerenciamiento agrícola y ganadero más eficientes y productivos, basados en un uso óptimo de los insumos agrícolas, variedades modernas de cultivos, y tecnologías eficientes;
- La asignación de la producción de biomasas en áreas donde las sinergias en el potencial y el rendimiento socio-económico y ambiental puedan ser obtenidas. Un ejemplo clave analizado en esta tesis es la producción de plantas perennes en las tierras más marginales, con beneficios en la reducción de la erosión del suelo, protegiendo el contenido carbonífero del suelo y manteniendo la biodiversidad. Para alcanzar esto, se necesitan sistemas de información geográfica y del uso de la tierra mas específicos y precisos;
- La elección del cultivo energético (o combinación de cultivos) adecuado para hacer coincidir y optimizar las condiciones agro-ecológicas de una región con los requerimientos de un cultivo particular. Generalmente, se prefiere la producción de cultivos de lignocelulosa perenne, cuando se buscan combinar altos resultados energéticos, bajos costos de producción de biomasa y métodos de producción benignos para el medio ambiente. Esto es así en especialmente relevante cuando se utilizan tierras marginales;

- La planificación del uso de tierra y el control sobre los cambios que produce el uso de la tierra a nivel macro, excluyendo las áreas con alto valor de biodiversidad para la producción de biomasas. Por otra parte, áreas con bajo valor de biodiversidad pueden ser asignadas a la producción de biomasas ya que contribuyen a su rehabilitación;
- La optimización de la logística por medio de la elección de conexiones favorables para regiones de exportación y áreas de destino y modos de transporte. Generalmente se prefiere la vía marítima para el transporte de larga distancia internacional, seguido, en orden decreciente, por envíos marítimos cortos, por ríos navegables, ferrocarril y transporte automotor. Los costos se reducen más cuando las plantas de pre-procesamiento o de conversión están ubicadas dentro o cerca de la región productora de biomasa y cuando se utilizan economías de escala para la conversión (final) para transportadores de energía.

En conclusión, el trabajo combinado que se presenta en esta tesis, demuestra que la viabilidad y sustentabilidad de la producción de biomasa a gran escala (para uso local o comercio) puede ser evaluada *ex ante*. Como el rendimiento de la producción de biomasa y de las cadenas de suministros puede tener fuertes variaciones en tiempo y espacio, la inclusión de análisis de impacto en las metodologías basados en escenarios es una forma clave de abordarlo. El uso de análisis regionales y la disponibilidad de datos lo suficientemente desagregados (sobre uso de la tierra, disponibilidad de agua, etc.) es indispensable para alcanzar resultados suficientemente confiables. Además, el trabajo presentado demuestra que los factores mencionados arriba, están relacionados entre si. Por ejemplo, la mejora de un principio de sustentabilidad (generación de empleo) puede significar el deterioro de otro (por ejemplo: el balance de emisiones de GEI), pero también se puede alcanzar la sinergia. En consecuencia, en cuanto a la *Sustentabilidad de las cadenas de bio-energía: el resultado está en los detalles.*

Se formulan las siguientes recomendaciones de políticas sobre la base de las conclusiones alcanzadas:

- Se necesitan análisis con bases sólidos sobre el potencial, el rendimiento económico y de sustentabilidad, de los cuales se muestran ejemplos en esta tesis, para guiar políticas y actividades de mercado que apunten al (mayor) desarrollo de los potenciales de producción de biomasas.
- Se requieren datos regionales sólidos y específicos para lograr análisis regionales confiables del potencial, los costos y la sustentabilidad de las cadenas bioenergéticas. Se ha demostrado en esta tesis que estas se pueden confeccionar con un razonable nivel de detalle.
- Alcanzar acuerdos internacionales acerca de los enfoques adecuados para el análisis de los impactos y la calidad de los datos requeridos es crucial para una certificación internacionalmente creíble y los esfuerzos de control. La armonización de los esfuerzos en pos de la certificación y el desarrollo de indicadores relacionados y las herramientas de análisis es altamente deseable.

- La tesis muestra que el potencial y el rendimiento de una cadena de bio-energía son dinámico a través del tiempo. Por eso se recomienda el monitoreo de las cadenas, combinado con reiteradas evaluaciones.
- Los proyectos de demostración que aplican un enfoque de aprender-mientras-se-hace pueden proveer el conocimiento necesario para futuros desarrollos en producción de bio-energía. El desarrollo gradual de un sistema de certificación de biomasa vinculado con el desarrollo de enfoques de avanzada (por ejemplo: evaluar sobre impactos en la cantidad de suelo, para los cambios en el uso de la tierra, y la relación con las conductas de la macro-economía) podrán ir mejorando paulatinamente la viabilidad y confiabilidad de las evaluaciones.
- Se deberán formular estrategias de políticas claras y coherentes para desarrollar más la producción sustentable a gran escala de biomasas para bio-energía en regiones específicas. Las políticas deberán considerar que objetivos múltiples (por ejemplo: generación de empleo, rehabilitación de la biodiversidad, reducción de las emisiones de GEI) pueden ser alcanzados cuando se implementan sistemas de bio-energía. El proceso para priorizar los impactos y objetivos de la producción de biomasa para energía debería involucrar a todos los grupos financieros de la región.
- Para hacer esto, se necesitan interrelaciones entre los diferentes foros de políticas y la incorporación de la bio-energía en el uso de la tierra, y las políticas de desarrollo agrícola (rurales).

Finalmente, se brindan las siguientes recomendaciones para futuras investigaciones:

- Más desarrollo y prueba de herramientas basadas en escenarios para evaluar fielmente los impactos socio-económicos y medio-ambientales de manera tal que los grupos financieros sean capaces de monitorear y conducir el rendimiento de los proyectos de bio-energía, combinados con mejoras en la calidad de los datos sobre el uso de la tierra;
- El desarrollo de enfoques para sopesar criterios individuales (sustentabilidad), por ejemplo, basados en las perspectivas (informadas) de grupos financieros ubicados regionalmente;
- El mejoramiento de las relaciones entre las conductas macro-económicas en los cambios que produce el uso de la tierra a nivel regional, vinculándolo con los enfoques abajo hacia arriba y los modelos de arriba hacia abajo;
- Mejores elementos para comprender cómo el gerenciamiento agrícola (y ganadero) puede mejorar con el tiempo en relación con las directivas macro-económicas, las políticas de uso de la tierra y las estrategias dirigidas a incrementar la eficiencia y el rendimiento ambiental;
- Grupos de datos más detallados para la producción de biomasas y los sistemas de suministros para los distintos lugares, en particular en los países en vías de desarrollo, para tierras degradadas y marginales, y para sistemas de cultivos perennes. Además, se necesitan esfuerzos sustanciales para demostrar en la práctica la viabilidad de estos sistemas de producción, y optimizarlos con el tiempo;
- Investigaciones sobre el impacto que el cambio climático podría tener en el potencial, global, regional y local y la sustentabilidad de la producción de energía de biomasa.

Abbreviations

ARG	Argentina
BA	Buenos Aires
BB	Bahía Blanca
C	Cropland (reference land-use system)
CAP	Common Agricultural Policy
CDM	Clean Development Mechanism
CEEC	Central and Eastern European Countries
CGP	Central Gathering Point
CUR	Current situation
D	Degraded grassland (reference land-use system)
DOM	Dead Organic Matter
EC	European Commission
EF	Emission Factor
EJ	Exa Joule (10^{18} Joule)
EU	European Union
FCE	Feed Conversion Efficiency
FT	Fisher Tropsch
G	Non-degraded grassland (reference land-use system)
GDP	Gross Domestic Product
GHG	Green House Gas
GJ_{del}	Gigajoule (10^9 Joule) delivered
GMO	Genetically Modified Organisms
GWth	Gigawatt thermal
HCV area	High Conservation Value area
HHV	Higher Heating Value
HI system	High input production system
HI+ system	High input and advanced technological production system
HWP	Harvested Wood Products
ILUC	Indirect Land-use Change
IWW	Inland water way
JI	Joint Implementation
LCA	Life Cycle Analysis
LUC	Land-use Change
mS land	Marginally suitable land
MS land	Moderately Suitable land
MSA	Multiple Species Abundance

NGO	Non-Governmental Organization
NL	The Netherlands
NS land	Not Suitable land
NUTS	Nomenclature of Territorial Units for Statistics
PPI	Price Producer Index
RED	Renewable Energy Directive
R'dam	Rotterdam
RES	Renewable Energy Sources
ROS	Rosario (located in Argentina)
S land	Suitable land
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSS	Short sea shipping
tdm	Tonne dry matter
USLE equation	Universal Soil Loss equation
VS land	Very Suitable land
WEC	Western European Countries
WTO	World Trade Organization
WUE	Water Use Efficiency

Core Glossary

A scenario	This scenario reflects the baseline scenario for the development of the economy for the case study in Argentina.
B scenario	This scenario, used for the case study in Argentina, is characterized by a stronger economic growth than scenario A. Scenario B is oriented on developing domestic markets and has an environmental friendly orientation.
Bioenergy	This is energy that is derived from biological sources (e.g. plants or animals) and which has not undergone any geological process. Sources of bioenergy may be solid, liquid or gaseous.
Biofuel	Liquid or gaseous fuel for transport produced from biomass.
Bioliquid	Liquid fuel for energy purposes, including electricity and heating and cooling, produced from biomass.
Biomass	The biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.
By-products	Products that are produced along with the main product and having smaller financial revenues than the main product
Co-products	Products that are produced along with the main product and having similar financial revenues as the main product.
Criteria	Criteria describe the requirements that have to be fulfilled to meet the requirements of the sustainability principle.
C scenario	This scenario, used for the case study in Argentina, is characterized by a stronger economic growth than scenario A. Scenario C is more export oriented than scenario B.
NUTS	These are the statistical regions of Europe and the Accession countries. NUTS-3 regions are regional or district levels within a country.
Principle	A principle defines the aim of certification and describes the requirements to be fulfilled for certification. A principle is combined with a set of criteria.
Scenario	In this study defined as an imagined possible future situation placed in a defined time set.
Total removals	The volume of all trees, living or dead that are felled and removed from the forest, other wooded land or other felling sites.

V1 scenario	This scenario is used for the case study in the CEEC. There is a liberalization of trade and no market barriers exist between the EU and the world market for agricultural products. The EU specializes in products which are competitive on the world market. The agricultural sector in the CEEC makes use of high input and advanced technology production systems.
V2 scenario	This scenario is used for the case study in the CEEC. Policies are regionally oriented. Trade barriers exist between the Western and Eastern European markets. The agriculture in CEEC has difficulties to compete with agriculture in WEC. The agricultural sector in the CEEC makes use of production systems as currently applied.
V3 scenario	This scenario is used for the case study in the CEEC. There are no internal trade barriers in the EU. Trade between the EU and the world market is based on the current situation (1997-1999). The CAP regulates agriculture in the EU. The CEEC have completely adapted EU legislation and can compete fully with WEC agriculture. The agricultural sector in the CEEC makes use of high input, state-of-the-art production systems.
V4 scenario	This scenario is used for the case study in the CEEC. There are no internal trade barriers within the EU. Market barriers exist between the European market and the world market, as Europe protects its own market strongly. The agricultural sector in the CEEC makes use of high input and advanced technology production systems.
V5 scenario	This scenario is used for the case study in the CEEC. The EU (WEC and CEEC) has a priority for sustainable development and nature conservation. Biodiversity, protection of rural areas and maintenance of the vitality of forest and grassland areas has a high priority. A certain level of market protection is needed for this. The agricultural sector makes use of ecological production systems.

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Curriculum Vitae

Jinke van Dam was born on the 13th of June 1976 in Leiderdorp, the Netherlands. From 1994 to 1999, she studied for three years physical geography and graduated in environmental sciences at Utrecht University, the Netherlands. During this time, she was President of the study association for physical geography Drift 66. She wrote her Msc thesis on ‘the role of land quality behind the process of migration to the Sierra Madre’ after a six months field work in Luzon in the Philippines.

After graduating, Jinke worked at DHV consultancy and had assignments at the Dutch Habitat Platform, the international department of the Association of Dutch Municipalities (VNG) and at the Faculty of Agriculture & Soil Science of the University of Sydney. She joined the department of Science, Technology and Society (STS) of Utrecht University as a junior researcher in February 2003.

From mid 2004 until summer 2006, she stayed for almost 2 years in Vietnam. Jinke worked in Hue as Junior Professional Officer (JPO) at the NGO Tropenbos Vietnam Program to assist the local team in the management, monitoring and coordination of projects and activities. Back in the Netherlands, she worked for six months at the STS department of Utrecht University to make an overview of ongoing certification activities in the field of biomass and bioenergy certification.

From January 2007 until March 2008, Jinke worked and lived in Buenos Aires, Argentina. During 2007, she worked as an Interim Executive Secretary for the Roundtable on Responsible Soy (RTRS). From summer 2007 onwards, she started her research in Argentina on the potential, economic and environmental feasibility of large-scale bioenergy production from soybeans and switchgrass in Argentina. Since August 2008, Jinke has been appointed as researcher at the department of Science, Technology and Society, which is part of the Copernnicus Institute for Sustainable Development and Innovation of Utrecht University". Her key research area is sustainable biomass and bioenergy production, trade and use.