Bioenergy Alongside Other Land Use: Sustainability Assessment of Alternative Bioenergy Development Scenarios

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Abstract

The development of bioenergy offers major possibilities for the reduction of greenhouse gas emissions and fossil fuel dependency, but negative impacts can also occur—e.g., the outcome for food production and biodiversity can be negative. This is a dilemma for policy: how to promote bioenergy developments that can substantially reduce greenhouse gas (GHG) emissions and fossil fuel use without jeopardizing other policy objectives. One major activity within IEA Bioenergy Task 30 and its successor Task 43 concerns strategies to integrate expanding bioenergy systems with the existing land use, in order to reduce land use competition and displacement risks, and with the aim of improving land use productivity and reducing negative environmental impacts of the existing land use.

This paper presents the outcome of an activity within this topic area: an evaluation tool that is being developed for comparing alternative ways of producing biofuel feedstocks—here applied on selected approaches that combine fuel production with other objectives. The tool, described as a generalized integrative assessment tool, has been used to evaluate several alternative bioenergy development options: (i) an alternative sugarcane expansion scenario for the Cerrado areas in Brazil, (ii) the use of crop or industrial residues for biogas production in the Netherlands, and (iii) an accelerated agricultural growth scenario generating additional food and biofuel feedstocks while conserving biodiversity areas in Ukraine.

The results suggest that the tool can be useful for presenting and evaluating multidimensional effects of bioenergy expansion—by listing, analyzing and depicting all dimensions in a clear and comprehensive way. The evaluations of the three cases show that if biofuel feedstock production systems are developed in ways that do not lead to displacement of the prevailing land use, impacts on local food production capacity and biodiversity can be avoided, or at least significantly reduced, compared to a scenario of bioenergy expansion crowding out other land uses. Integrated bioenergy food systems can offer opportunities for both economic and social development.

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Introduction

A large potential for producing biomass for energy exists in many agricultural areas of the world, but there is also a risk that the realization of this potential will cause adverse environmental and socio-economic impacts. Countries that have large theoretical bioenergy potential need to develop strategies for exploiting this potential so as to generate positive outcomes—e.g., job creation and greenhouse gas (GHG) savings while keeping possible negative impacts at an acceptable level. There are concerns that expanding bioenergy feedstock production claims land and inputs presently used for food production, where the existing land users do not benefit and it has been stated as a requirement that biomass production for international bioenergy markets carefully considers the interests of the local population in the exporting countries (Cramer Commission 2007).

Countries seeking ways to link biomass production for energy with local development also need to avoid far-reaching degradation of forests and other valuable natural ecosystems—critical ecosystem functions should be maintained at least to a certain minimum extent. Furthermore, CO_2 emissions arising from the conversion of forests and other carbon-

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Table 1. *Selected standard initiatives for certification of biofuels and sugarcane.*

Initiative	Aim	Country	Type	Stage	Scope
Roundtable on sustainable biofuels: Global principles and criteria for sustainable biofuels production—RSB	Certification	Based in Switzerland but multi-stakeholder process	Voluntary—institutional	Public consultation of documents	Crop production and biofuel processing
Regulation for assessment of conformity for fuel ethanol—INMETRO	Certification	Brazil	Voluntary—govern-mental	Public consultation of documents	Crop production and biofuel processing
Better sugarcane initiative—BSI	Certification	Based in UK but multi-stakeholder process	Voluntary—institutional	Public consultation of documents	Crop production and sugar processing
Renewable transport fuel obligation—RTFO	Reporting	UK	Compulsory —govern-mental	Implementation	Plantation; exclude pro-cessing and transportation
Verified sustainable ethanol initiative—SEKAB	Verification	Sweden, Brazil	Voluntary—private (business to business)	Implementation	Crop production, biofuel processing and distribution

Source: Huertas Bernal et al. (2010).

rich ecosystems to bioenergy plantations can dramatically reduce the climate change mitigation benefit of the bioenergy establishment (IEA Bioenergy 2011).

While there are many examples showing that bioenergy systems can operate alongside local (food) production and land use, there are diverging views about the level of "disturbance" of present-day bioenergy production. The link between bioenergy and associated land use change (LUC)—and how LUC effects can impact the environmental profile of bioenergy, including the achievable level of GHG emissions reduction—has been subject to intensive debate in recent years. In particular, the quantification and linking of indirect land use change (iLUC) effects to specific bioenergy projects has been controversial. The lack of scientific consensus, including commonly agreed methodology and solid empirical data on critical aspects, hampers progress and constructive debate. Bioenergy debates have instead many times shown a tendency to remain incomplete and unbalanced because the lack of firm evidence leaves room for speculative assumptions supporting various agendas. Further, the present debates to a large extent focus on bioenergy systems that are based on conventional food/feed crops and thus may fail to address—and consequently will not prepare society for handling—issues possibly arising as new types of plants and production systems develop to provide biomass for energy.

In IEA Bioenergy, much emphasis is put on facilitating informed and balanced decision-making by providing scientific data and analysis. The main objective of Task 43 (Biomass feedstocks for energy markets) is to promote sound bioenergy development driven by well-informed decisions in business, government and elsewhere. This is to be achieved by providing timely and topical analyses, syntheses and conclusions on biomass feedstock, biomass markets and the socioeconomic and environmental consequences of feedstock production (for information about Task 43, see IEA Bioenergy 2012).

Developing sound bioenergy options requires balanced and solid empirical data on bioenergy production systems and their impacts on local land use, including data on the impact of changing land use systems on prosperity, legal status and well-being of local inhabitants. In addition, procedures are required that can make use of these data in an evaluation process to guide actors facing the challenge of making decisions based on a wide set of considerations.

At present, different approaches are available to define criteria for controlling whether bioenergy production chains are environmentally and socially acceptable, apart from being technically feasible and economically sound. Overviews providing assessments of criteria and indicators include van Dam et al. (2010), Lattimore et al. (2009) and FAO (2010). Huertas Bernal et al. (2010) assess how certification initiatives are perceived by actors in the bioenergy sector, with focus on the Brazilian ethanol system. Initiatives for sustainability certification of biofuels are commonly focused on a limited set of sustainability aspects—mostly social and environmental conditions—while quality aspects (e.g., physical characteristics) are little considered (Table 1).

The relevance of criteria that can be applied in an evaluation procedure is emphasized by the current situation, where alternative studies use different methods, apply alternative approaches and comply with mutually excluding systems boundaries, making it very difficult to compare their outcomes (see, for example, Liska and Cassman 2008, Menichetti and Otto 2009).

The issue of systems boundaries for bioenergy systems analyses is currently being discussed in several international fora, but data availability and quality, and the shaping of evaluation procedures, are equally important. This holds especial-

Table 2. *Grading of standards for the selected criteria (Msimuko et al. 2007). Grade 0 is given if a criterion is not included. Grade 2 represents full inclusion.*

	Criteria							
Standard	GHG emissions	Environment	Biodiversity	Social well-being	Competition with food	Economic prosperity	Traceability & crop management	*Criteria pooled*
SQF 2000	0	1	0	1	1	0	1	*4*
EUREPGAP	2	2	2	1	0	0	2	*9*
ISO 14001	1	1	0	1	0	0	1	*4*
FSC	1	1	2	2	1	1	2	*10*
Eugene	1	1	0	0	0	0	0	*2*
Cerflor	0	1	1	2	0	2	2	*8*
EU regulation 2092/91	1	2	2	1	0	0	2	*8*
IFOAM	1	2	2	2	0	2	2	*11*
ILO	0	1	1	1	0	0	0	*3*
EMAS	2	2	2	1	0	0	0	*7*
ETI	0	0	0	1	0	0	0	*1*
Green Gold Label	0	1	1	1	0	0	1	*4*
RSPO	0	1	1	1	1	1	1	*6*
RTRS	1	1	1	1	0	1	0	*5*
Standards pooled	*11*	*23*	*19*	*21*	*4*	*9*	*19*	

ly for non-technical aspects of bioenergy production, including economic, social and legal impacts. This is clearly shown in the table below, which compares criteria and certification schemes with the sustainability criteria defined by the Cramer Commission. As can be seen in Table 2, most schemes lack criteria to address potential competition of bioenergy production with food. Coverage is also weak for prosperity, while well-being generally is treated in a rather general way.

Bioenergy strategy development requires careful consideration of both technical (e.g., GHG balances, land requirements, effects on water quality) and non-technical (positive and negative) aspects, such as those arising from the increased competition for land, water and other natural resources. The development of strategies will in several places also need to tackle the fact that there is limited scientific information available. It is thus important to develop evaluation procedures that can cover both technical and non-technical issues, can address local and larger-scale effects and can make proper use of both scientific and non-scientific information. The basic objective should be, as was stated above, to support balanced and well-informed decision-making.

This paper presents an evaluation procedure (or tool) that is intended to serve this purpose. We present an integrated procedure that combines technical and non-technical, scientific and non-scientific information, and provides a clear qualitative or semi-quantitative outcome. As an illustration of how the procedure can be used, it is applied to three different cases: (i) expanding sugarcane ethanol production in Brazil, (ii) biogas production from crop residues in the Netherlands, and (iii) accelerated agricultural development for food and bioenergy in Ukraine. The purpose is not primarily to evaluate three bioenergy options and conclude whether they are sustainable. Rather, the presentation and application of the evaluation procedure is intended to contribute to the ongoing process of improving decision support systems developed to support actors in the bioenergy area, including policy advisors and policymakers seeking ways to guide the bioenergy development.

Materials and Methods

We applied a three-step approach to evaluate bioenergy options. In the first step, options for bioenergy development are identified. An inventory is made of alternative development routes, considering different sustainability aspects of relevance in the specific situation. Following this inventory, two different development scenarios (or storylines) are defined. The main aim of developing these scenarios is to describe alternatives for bioenergy development, and to identify what approaches may be selected. Both scenarios are broadly elaborated: We define processes of biomass production in terms of (changes in) land use, and the character of crop cultivation and management, and we assess consequences for natural resources including land and water availability, local land use and market conditions, and social and economic consequences.

In the second step, literature is collected to support an evaluation of the sustainability aspects of each development scenario. This inventory includes formal and informal sources, and covers a range of disciplines. Both quantitative and qualitative data are considered. The collected information is assessed and summarized to allow analysis of the pros and cons of each development route.

Finally, in the third step, the different development scenarios are evaluated and presented. This is done based on assessing their performance in relation to six dimensions of sustainability. Following different instruments that were designed to evaluate sustainability of biofuel production chains, scores are determined for each scenario with respect to: (i) reduction of GHG emissions, (ii) biodiversity effects, (iii) competition for natural resources, (iv) effects on local food and land prices, (v) consequences for local prosperity and economic development, and (v) effects on well-being.

The method presented here is basically a *generalized integrative assessment* tool. It has a number of distinctive features. First, (i) it integrates data, including both formal and informal information from many disciplines, to provide a semi-quantified assessment. Further, (ii) scores are normalized and presented on a gradual scale. The tool is (iii) scale neutral, which means it can be applied at any scale level. It can, finally, be applied using (iv) scenarios providing a comparative evaluation of alternatives in technology, policy or economic decision-making.

We defined seven classes of performance rating, ranging from less than 0.1 to over 0.9. The outcomes are further generalized into sustainability labels, where high scores (excellent performance) are being depicted by A labels, and low scores (very poor performance) by G labels. Scoring and labeling of performance classes are presented in Table 3. Scoring is done in a quantitative way, but when sufficient (quantitative) data are lacking, an expert assessment is done on the basis of collective data. It is stressed here that the scoring of individual indicators is done according to the character and amount of information that is available. Some indicators (e.g., GHG emission reduction) can be fully quantified. Others (e.g., impact on food and land prices) are combined estimates of a number of effects. They may or may not be quantified according to the type of data that are available. Still other indicators may be so complicated that quantification of the effects in practice rarely is done. This applies to the impact on biodiversity, which consists of a number of effects that usually are not quantified, and to the effect on well-being. These indicators, at best, consist of a number of quantifiable effects and a number of non-quantifiable effects.

Table 3. *Scoring and labeling of bioenergy production chain performance.*

Performance	Score	Label
Excellent	Higher than 0.9	A
Very good	From 0.7 up to 0.9	B
Good	From 0.5 up to 0.7	C
Average	From 0.3 up to 0.5	D
Modest	From 0.1 up to 0.3	E
Poor	Lower than 0.1	F
Very poor	0	G

An example of the scoring is given in Figure 1. Scores are depicted on the axis between the crossing point and Indicator 1. Examples of label values are given left of this axis. Scenario 1 in this figure has been allocated scores 0.5, 0.9, 0.7, 0.6, 0.4 and 0.2. Under the given rating, this scenario is rated with labels C, A, B, C, D and E, for indicators 1 to 6, respectively.

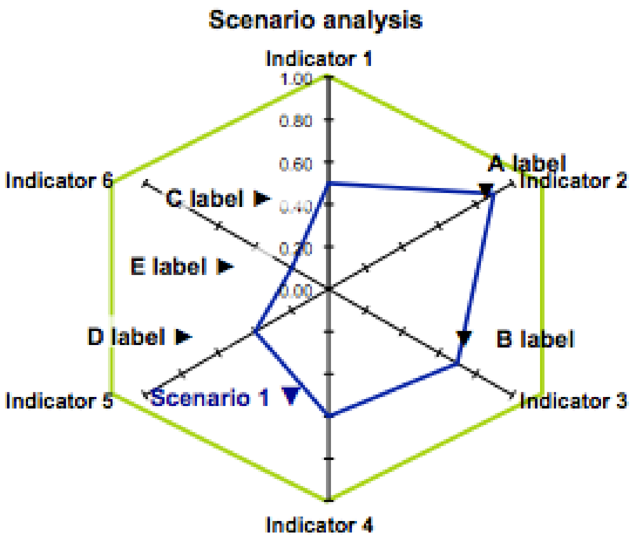


Figure 1. *Illustrative example of scoring of a scenario and awarded labels for each indicator. Information on labels is provided in Table 3 and in the text.*

The outcome of the scoring depends on how the bioenergy system is shaped in a given scenario. This reflects issues of land use and crop cultivation: requirement for agricultural land, biodiversity effects (e.g., via land displacement that could lead to clearing of valuable forest areas), the way inputs (such as water) are applied and utilized, and amounts of chemical and other external inputs that are used, as well as the way this affects local land, soil and water resources.

It also evaluates other issues of bioenergy chain organization: biomass transport (means of transport, distance), utilization of crop residues or other wastes, and crop conversion technology (e.g., energy input requirement per unit of bioenergy, efficiency of energy utilization, emissions caused, etc.). The evaluation, finally, assesses how the bioenergy system (crop cultivation, transport or conversion) affects natural resources and local communities. Thus, it refers to issues related to biophysical as well as environmental and economic aspects, and social quality of life. Aspects considered include influence on local food and/or land prices, job creation, incomes and services provided, and also more general aspects of regional development and social coherence.

For reasons of conciseness, this paper does not treat the impacts in great detail or at great length. Instead, we present generalized results. Spider-web figures are used to depict scenario performance along each of the six sustainability dimensions included. For a case study, two (three) figures are presented to facilitate a comparison of alternative scenarios along the different sustainability dimensions. The figures represent one way of demonstrating the outcomes of the scenarios.

Results

Case 1: Sugarcane expansion in Brazil

The Cerrado is a tropical savannah ecoregion in Brazil that covers a surface of about 2 million square km. It has the richest flora among the world's savannahs (>7,000 species), a high level of endemism and equally high species richness of birds, fish, reptiles and amphibians. During the past 35 years, more than half of the natural vegetation area in the Cerrado has been replaced by agriculture lands (Brannstrom et al. 2008). Two-thirds of the Cerrado area can support crop cultivation, cattle ranching or forestry production. Soils are mostly highly weathered and characterized by high acidity and low availability of essential nutrients (Scheid Lopes 1996). Other crop production limitations include low water-holding capacity. Agricultural conditions are further determined by annual rainfall that ranges from 900 to 2000 mm, a five-to-six-month dry season (April to September) and frequent dry spells during the rainy season (Scheid Lopes 1996).

The establishment of sugarcane plantations is commonly not associated with direct deforestation in this area, but rather with conversion of pastures/grasslands and croplands cultivated with other crops (Sparovek et al. 2008). According to Macedo (2008), sugarcane expansion is almost exclusively taking place on pasture and cropland areas. Only a small percentage is leading to the replacement of natural vegetation. Deforestation and other LUC leading to loss of soil carbon stocks is a major contributor to Brazil's GHG emissions, which are among the largest in the world. But sugarcane expansion is not among the major direct drivers behind this LUC. Sugarcane's role—if any—is mostly indirect: When sugarcane is planted on agriculture land, the displaced actors may re-establish their businesses in a previously forested area and thereby cause deforestation (Lapola et al. 2010). Deforestation and other LUC can also arise because of the macroeconomic effects: The lost meat and dairy production leads to lower supply in relation to the given demand, which drives up prices and thereby stimulates increased animal production and expansion of pastures into forests and other natural ecosystems. Part of the increased animal production will likely be accomplished through intensification, and the displaced actors may turn to activities other than those connected to cattle ranching or other land use (see, e.g., Lapola et al. 2010).

Among the land types that more commonly are claimed for sugarcane plantations, highest carbon stocks are found under natural and well-managed cultivated grassland, soya beans and Cerrado vegetation. When sugarcane plantations are harvested manually using pre-harvest burning of the fields, substantial C losses may take place. If sugarcane plantations are mechanically harvested, part of the harvesting residues can be left in the field, contributing to soil carbon. As can be seen in Table 4, soil C content can vary significantly—higher estimates of soil C than those given in the table have been reported for Cerrado savannah vegetation and soya bean, but these often include deeper soil layers. Above-ground carbon stocks are highest in typical Cerrado savannah vegetation, and in unburned cane fields (data not shown).

Table 4. *Soil carbon stocks in Cerrado and Amazon tropical forests (tonnes carbon/ha).*

Land cover	do Amaral et al. (2008) 1)	Other sources
Natural grassland	56	44 2) a)
Cultivated grassland	52	66 3) b)
Soya bean	53	70-100 4, 5) c)
Cerrado, typical savannah vegetation	46	136 6) b), 100 3) c), 44 2) a)
Cane—crop burned before harvesting	35	-
Cane—not burned	44	-
Tropical forests	-	120 c), 47 2) a)

Sources: a) Macedo (2008), plus Fargione et al. (2008), b) Lilienfield et al. (2003), c) Bustamante et al. (2007).

Notes: 1) 0-20 cm soil depth, 2) soil depth not indicated, 3) 0-30 cm soil depth, 4) 0-100 cm soil depth, 5) highest figure referring to soya bean-millet-maize and lowest to continuous soya bean cultivation, 6) 0-120 cm soil depth.

Thus, unless Cerrado savannah or grasslands with high C content are converted, changes in soil C stocks following *conversion to sugarcane* remain limited if the cane is mechanically harvested. Because the average aboveground carbon stocks of cane crops (both burned and unburned) are relatively high, the net impact tends to be positive for unburned cane or slightly negative for burned cane crops (with the exception of forest/savannah conversion, see do Amaral et al. (2008) for details).

Expansion of cane cultivation is expected in the South-Central Cerrado, where it may displace grassland or other crops. As described above, this may lead to a search for new land elsewhere. Alternatively, Cerrado grassland productivity may be increased to compensate for land losses. Following Goldemberg et al. (2008), we evaluate the impact of both scenarios, using criteria originally listed by the Cramer Commission.

For the first scenario, we assume an expansion of cane cultivation of 1 million ha. New cane land is obtained by converting managed/natural Cerrado grassland (80%) and arable land (20%, mainly maize). This causes a loss of soil carbon stocks on the former grassland area and may lead to iLUC as cattle production is displaced. In the second scenario, conversion of the Cerrado grassland area is assumed to coincide with substantial productivity increases on the remainder (non-converted) Cerrado grassland area that is managed for grazing. This productivity increase is assumed to fully compensate for the production losses associated with the displacement of cattle production with sugarcane plantations: Food prices do not increase and no iLUC takes place. Both scenarios are explained in more detail below.

Scenario 1: Cane area expansion and displacement

In the first scenario (expansion), 1 million hectare (ha) of extra cane will be cultivated in the Cerrado area. Input and yield levels are similar to current levels, crop and farming systems being equal to the current situation, as will be transport of cane and conversion into ethanol. There is no irrigation. In line with current practices, half of the cane is burned before harvesting (a practice that, according to Goldemberg et al. (2008), is currently being phased out in the Central-East region).

Under this scenario, 60% (0.6 million ha) of the land will be obtained by converting cultivated grassland, the remainder from natural grassland (0.2 million ha) and maize land (another 0.2 million ha). Losses in production from this land are compensated for by starting production on new land through conversion of forests in the Amazon region. One hectare of converted Cerrado grass (or maize) land is assumed to be compensated for by conversion of one hectare of Amazon forest. Total carbon released is 134 million tonnes (t, 1 tonne = 1000 kg), 135 tonnes/ha released due to clearing of tropical forest minus 1.4 million tonnes C sequestration when grassland and arable land is converted to cane plantations. Input use is in line with standard applications; thus, no irrigation is required.

GHG emissions

Energy use has been calculated using data presented from literature. Total energy use is 20 giga joule (GJ) per hectare or 20 peta joule (PJ) for 1 million hectare. The energy output:input ratio is 8.2. GHG emissions during cultivation and conversion amount to 3.4 tonnes of CO_2 equivalent (CO_2eq) per ha. Net GHG emission reduction (76% reduction compared to fossil fuel baseline) is close to 11 million tonnes of CO_2eq. Initial impact of land use change in the Cerrado and Amazon is, however, considerable (causing a release of 350 million tonnes of CO_2eq.). Payback time is 32 years.

Biodiversity

Cane expansion does not commonly lead to direct deforestation, but where it does, biodiversity will be affected negatively. As described above, the Cerrado is one of the biodiversity hotspots among the world's savannahs, and converting natural grassland into cane monocultures (replacing mixed farming systems) may be expected to affect local agro-biodiversity (Sawyer 2008). Obviously, in addition, the forest clearing in the Amazon can be expected to lead to biodiversity losses.

Competition for natural resources

Several researchers (Walter et al. 2006, Macedo 2008) claim there is sufficient room for expansion in the Central-South region. Others expect sugarcane expansion to reduce access to land and drive up food prices. Cane area expansion will lead to increased demand for water, but because cane is mostly rain-fed, this is not expected to seriously affect water availability. Amazon deforestation may reduce water availability and affect soil-water cycles (Lilienfein et al. 2003).

Potentially negative effects on the environment include reduction of soil fertility, run-off on cleared land (reduced water infiltration), and pollution by pesticides and fertilizer applications. Burning cane fields may, further, lead to air pollution by emission of smoke and dust (Sawyer 2008). The net impact on water is difficult to predict. The application of vinasse, a liquid byproduct of ethanol distillation that is rich in nutrients, may threaten soil and water quality. On the other hand, vinasse will replace fertilizers that also impact ground water and surface water. It will also reduce natural resource use, primarily natural gas (Walter et al. 2006).

Impact on local food prices

The establishment of bioenergy feedstock production can lead to increased local food prices. ILO (2008), for example, suggests that sugarcane expansion for ethanol may drive up prices of basic food crops. According to Macedo (2008), however, this is not the case for cane production in Cerrado areas. This is confirmed by Sawyer (2008), who suggests rising food prices may be attributed to increasing grain and beef demand.

Impact on prosperity

Currently, cane cultivation and harvesting is requiring approximately 1 million seasonal workers (Sawyer 2008). According to Krivonos and Olarreaga (2006), the combined sugar and alcohol sectors employed 765,000 people in 2002. Roughly half were working in cane cultivation, mostly in the Central-South region, and mechanization has reduced the demand for low-skilled workers, implying that the number of workers may be lower today compared to 2002. Wage levels in the sugarcane sector are relatively high (Walter et al. 2006), and cane expansion in the Cerrado region is an important source of economic growth (Sparovek et al. 2008). Still, working conditions in cane production are criticized, with conditions during harvest reported to be unhealthy, even leading to death by exhaustion (Sawyer 2008), and it is estimated that 25,000 to 40,000 people are working in conditions akin to slavery (ILO 2008).

Impact on well-being

Bioethanol production may enhance large-scale enterprises in the Cerrado, while income earnings are unevenly distributed over its inhabitants (Sawyer 2008). According to this author, displacement and seasonal labor has been reported to negatively affect multifunctional family farms and traditional communities. Others emphasize contributions of sugar mills in the provision of schooling, health and dental care, insurance and meals, at considerable costs (Goldemberg et al. 2008).

Scenario 2: Cane area expansion plus grassland improvement

In the second scenario (grassland), 1 million ha extra cane coincides with productivity increases in cattle production, so no indirect land use change or deforestation is expected. Cerrado land conversion and cane cultivation practices are similar to those of the first scenario. Cattle farms in Central Brazil are large, with an average stocking rate of 1 head/ha. Supplementary feeding is not common. Lilienfein et al. (2003) report doubling of grass production and 50% increase of meat gain per hectare on improved pastures, but such improvement cannot be expected on all soil types. We assume an average 20% yield improvement on grasslands.

Energy and annual GHG balance of cane for ethanol production in this scenario are not expected to show major changes, but enhanced grassland production will cause extra carbon sequestration. Because no indirect deforestation takes place in the Amazon in this scenario, the net effect of the expansion will be positive. Other impacts of cane area expansion are mostly similar to those described in the first scenario, but generally, improved grassland productivity is expected to have more positive economic and social impacts, along with some risk for nutrient leaching. The lack of deforestation in the Amazon is of course positive with regard to reducing impacts on biodiversity and water cycles, which is judged positive also for inhabitants. On the other hand, current poor economic perspectives for inhabitants might be improved following economic activities. The general impact, however, is expected to be positive.

Evaluating the scenarios

Based on how additional bioethanol is produced in either of the two scenarios, we have evaluated their performance along each of the sustainability dimensions. In the expansion scenario, extended ethanol production may lead to land displacement causing deforestation, seriously limiting positive outcomes with regard to reduction of GHG emissions and affecting biodiversity negatively. Positive economic and social effects (income generation, local economic growth) are unevenly distributed among the population (mostly excluding farmers and laborers not directly involved in the cane industry). Negative effects (enhanced competition for land, possible price increases) affect all inhabitants. The second scenario shows some major advantages over the expansion scenario. No displacement (deforestation) is needed; land and food prices are not affected, while economic gains are more evenly distributed.

The results have been translated into a series of sustainability labels (i.e., referring to changes in GHG reduction, biodiversity, competition for natural resources or food/land, on local prosperity and local well-being; Figure 2, left pane). Following the example given in Figure 1, high scores are depicted by blue lines far away from the center of the figure (thus close to the green outer lines that depict highest possible scores or A labels). Low scores are depicted by lines close to the center. The point where axes are crossing depicts the lowest possible score or G labels). An average (D) score would mean the blue lines would be in the middle, halfway between the center and the green line. The spider-web figures show that the first scenario scores well on the impact on local food and land prices (A label) and competition for natural resources (B label). A modest score (E label) on the biodiversity axis depicts the negative impact on biodiversity.

The second scenario has been evaluated using ratings and labeling rules similar to the first scenario. It shows a much better GHG balance (B label), because no carbon is

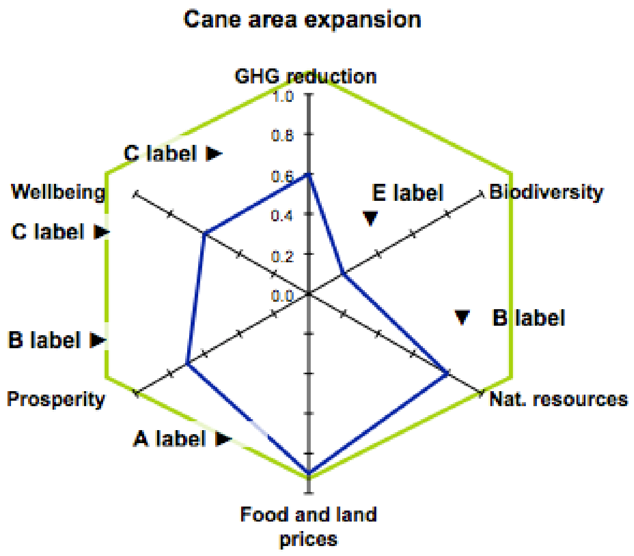
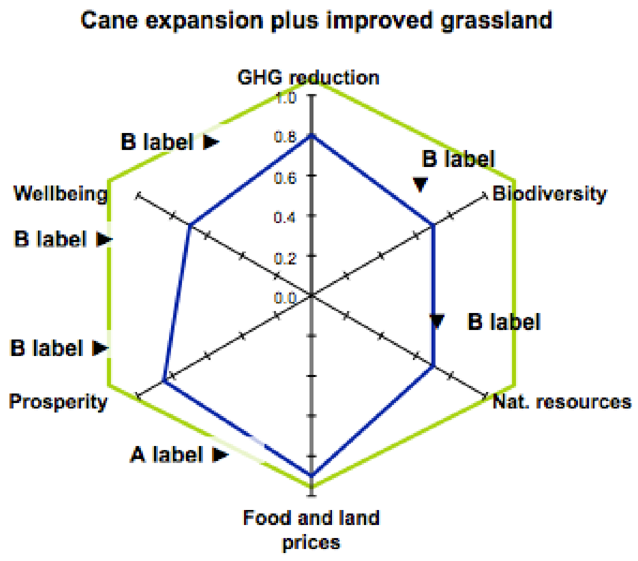


Figure 2. *Sustainability labeling of the area expansion (above) and grassland improvement (below) scenarios in Brazil. High scores are depicted by blue lines far out of the center of the figure (near the green lines). Information on labels is provided in Table 3 and in the text.*



released in the Amazon. Enhanced grassland productivity may be expected to increase carbon sequestration, especially below ground, but this needs to be compared with additional GHG emissions related to enhancing the productivity (nitrogen fertilizers, machinery) and of increased livestock numbers (methane emissions). Note that the big difference between the two scenarios is caused by the assumption that indirect deforestation takes place in the Amazon for Scenario 1. If other land types containing less carbon were instead converted, the difference would be much smaller.

The biodiversity impact of the second scenario (B label) is much smaller than in the first scenario, especially in the Amazon. No extra competition for land is expected, although consumption of water (rainfall) may increase (B label). The impact on local food and land prices is difficult to assess, but local prosperity is expected to be higher, mainly due to enhanced income in animal production and of smallholders. An A label has been assigned. Impact on local well-being (B label) will also be more positive than in the first scenario, with more equal income distribution among people and through different periods of the year.

Thus, increasing grassland productivity to release land for cane only marginally affects biodiversity, while other sustainability aspects are hardly affected. Comparing the scenarios, it is clear that the second scenario has less impact on biodiversity (no pressure on Amazon), causes less competition for land or water and has slightly more positive effects on local prosperity and local well-being.

Case 2: Biogas production from crop residues in the Netherlands

Current intensive agricultural practices in large parts of the Netherlands have negative impacts on the quality of ground waters and surface waters (Wolf et al. 2004), and major efforts have been made to reduce losses of nitrogen and phosphorus from arable and animal production systems through leaching, runoff and volatilization (Langeveld et al. 2007). A range of policies has been implemented to limit nutrient applications, especially on dry, sandy soils in the southeast of the country where fertilization generally is high. This has added to a trend of deteriorating economic conditions for farming, and farmers have been looking for alternative strategies to increase the incomes from their land use. Production of biogas from manure and biomass, which has been actively stimulated by the Dutch government, is offering one route for income improvements. Biogas production on farms has shown significant increases. In 2007, farmers generated almost 250 GWh of electricity from biogas.

Biogas production is based on anaerobic fermentation, conversion of organic material by micro-organisms into methane and carbon dioxide under oxygen-free conditions. Anaerobic fermentation occurs spontaneously (animal intestines, paddy fields). Biogas fermenters may be fed with (combinations of) animal manure, crop materials or waste. Optimal temperature and duration of fermentation depend on feedstock and micro-organisms involved. Manure (from cattle, pigs and poultry), available in large amounts, contains organic matter with low digestibility (30% to 40%). Easily degradable materials were already removed in the animal digestive tract, leaving material with low potential biogas yields requiring long residence periods, and addition of easily degradable biomass materials is needed. These could include dedicated crops, crop residues and industrial (food, feed or bioenergy) residues.

A considerable part of Dutch farm biogas production is based on co-fermentation of energy crops. Maize is presently the major crop in co-fermentation in the Netherlands. Its advantages include high crop and methane yields, relatively low production costs and low market price. Because it is chipped during harvesting, it requires no further pre-treatment. Biogas (methane) yields of alternative co-substrates are mainly determined by biomass composition (carbohydrate and fat content) and degradability. Important factors determining biogas yields include crop species and variety, harvesting period, crop management intensity, cutting size, and—if applicable—silage treatments. Highest methane yields were realized using manure from medium-productive cows fed a well-balanced diet of roughage and other crops.

Large-scale application of maize in biogas production may have major implications—e.g., high nitrogen applications and increased competition for land. These restrictions may not apply for industrial or crop residues, biomass from nature areas or from parks, roadsides, etc. An estimated 10 million tonnes of this type of biomass, potentially generating over 40 PJ, would be available for energy applications in the Netherlands (Koppejan et al. 2009). We will compare alternative biomass feedstocks for on-farm biogas to silage maize: sugar beet field residues and peelings originating in potato chip factories.

A study evaluating perspectives for biogas production from residues in the Southeast of the Netherlands (Zwart et al. 2004) concluded that, in principle, all crop residues—with the exception of straw—could be applied in co-fermentation processes, provided sufficient digestible dry matter is available. Residues of most vegetable crops do not contain sufficient dry matter. Sugar beet, potato and Brussels sprouts residues are more suited. As a rule, any pollution of residue material with sand will limit their suitability for fermentation. Economic perspectives of co-fermentation are rather favorable, crop residues adding extra methane production potential to manure. Still, electricity generation from biogas currently is not yet competitive. Also, residues may have other uses, such as application in co-firing plants. Removal of material high in proteins can help to reduce risks of nitrate leaching in sandy production areas (van der Voort et al. 2006).

Scenario description

Three scenarios have been defined based on the operation of a medium-scale farm digestion plant located in the Southeast of the Netherlands. Biogas is generated based on a mixture of pig manure and a range of biomass co-substrates. In the first scenario (silage maize), biomass substrates include silage maize plus silage grass, making up 30% and 20% of total dry matter, respectively. In the second scenario (beet residue), silage maize dry matter has been replaced by an equal amount of sugar beet residue dry matter. This refers to residues left on the field after harvest (beet leaves plus heads and tails). The third scenario (potato peelings) is using steamed potato peelings, a residual product of the potato chip industry that normally is applied as animal feed, to replace silage maize. These scenarios basically cover all elements related to the recent years' biofuels debate, including animal feed crops, dedicated energy crops, industrial residue streams applied as animal feed and crop residues normally left in the field.

Technical and environmental performance of the scenarios has been evaluated using key figures obtained from experts and literature, with data mostly referring to the Southeast of the Netherlands (basic data in Table 4). Data on general technical and economic performance of biogas production have been taken from Kool et al. (2005) and from Gebrezgabher et al. (2010). Additional parameters on biogas yield were taken from Zwart and Langeveld (2010). Data for removal of sugar beet residues impacts have been taken from De Ruijter et al. (2009).

Table 4. *Key figures for the Netherland case study.*

	Yield	
Feedstock	Crop (ODt /(ha × y))	Biogas (m^3/ODt)
Pig manure	-	322 (1
Energy maize	23.4 (2	629 (2
Silage grass	15.0 (3	430 (1
Sugar beet leaves	5.0 (4	467 (1
Sugar beet heads and tails	0.9 (4	698 (5

Note: ODt = oven dry tonne, ha = hectare and y = year.

Sources: 1) Calculated from FNR (2009), 2) Groten (2011), 3) Own assessment, 4) Corré and Langeveld (2008), 5) calculated from Kool et al. (2005).

Total biomass applied under the beet residue and potato peeling scenarios is exceeding that of the first scenario because dry matter contents of beet residues (especially leaves) and potato peelings are lower than that of silage maize (Table 5). However, only 16% or 17% of the biomass in these scenarios is produced for the purpose of biogas production. Total land use is moderate (96 ha) for the silage maize scenario. Land requirements for the beet residue scenario are much higher because the annual residue yield per ha (6 oven dry tonnes (ODt)) is very low. Again, only a small part of this is purely devoted to the biogas production (49 ha of silage grass). Potato peelings are obtained from industry and do not require land. Silage maize and silage grass were assumed to be cultivated on the farm or on farms nearby. Sugar beets were assumed to be less commonly cultivated because farmers require a production quota, while crop rotation generally is 1:4. Steamed potato peelings were assumed to be transported from a potato chip factory in the region.

Table 5. *Scenario definitions.*

Scenario	Feedstocks	Transportation distance 1) (km)
Basis	21,000 t of pig manure plus 731 ODt of silage grass	2.5
1: silage maize	Basis + 1096 ODt (2885 t fresh) of silage maize	2.5
2: beet residues	Basis + 1096 ODt (7814 t fresh) sugar beet leaves and residues	7.5
3: potato peelings	Basis + 1096 ODt (7308 t fresh) steamed potato peelings	30

Note: ODT = oven dry tonnes. 1) Average transportation distances single way for the scenario unique crop(s).

Biogas yield is showing surprisingly small differences. Total yield is 1.6 million cubic meters for maize silage and potato peelings. Beet residues are slightly less productive. Differences in economic returns are higher. While income generated is following biogas yield, costs associated with production of the co-substrates are showing huge differences. Costs for production, transport and silage of maize are estimated at 112,000 euro. High costs for the potato peelings scenario, mostly due to the high market price for this residue, are more than double. Beet residues have no cultivation costs associated but require more transport. Net GHG reductions are determined by the replacement of fossil fuels by biogas on the one hand and emissions associated with crop cultivation (silage maize, grass), transport (maize, grass, beet residues, potato peelings), and silage-making (maize, grass, beets) on the other hand. Biogas yields are almost similar. Emissions caused during cultivation/silage are highest for the silage maize/grass scenario. This is only partly compensated by higher emissions associated with transport for the other scenarios (five and 19 times higher, compared to silage maize). An evaluation of the six sustainability dimensions is presented below.

GHG

Following the calculation of the GHG balance as presented in Table 6, the first and third scenarios show a good biogas yield (fossil replacement). Net emission reduction for silage maize is, however, limited by high emissions associated with cultivation of the maize. Beet residues have no emissions for crop

Table 6. *Scenario outcomes*

	Scenario		
	1: silage maize	2: beet residues	3: potato peelings
Total biomass used (tonnes fresh)	4,346	9,276	8,770
Of which solely for biogas (tonnes fresh)	4,346	1,462	1,462
Area used to produce biomass (ha)	105	246	58
Of which solely for biogas (ha)	105	58	58
Biogas yield (million m^3/y)	1.6	1.5	1.6
Of which from co-substrate (million m^3/y)	1.0	0.9	1.0
Costs co-substrate production (euro)	112,000	89,000	265,000
Average transportation distance (km)	2.5	6.7	25.4
Transportation requirements (tonne-km)	10,866	62,259	222,894
Emission transport (tonnes CO_2eq)	1	5	19
Net GHG reduction (tonnes CO_2eq)	1,797	1,736	1,909

cultivation but require more transport (lower yield per ha) and show a slightly lower biogas yield. Highest emission reduction is realized in the potato peelings scenario, notwithstanding large transport requirements. Indirect effects of the scenarios have not been estimated.

Biodiversity

Implications of the scenarios on the (conservation of) biodiversity in the region depend on two developments. On the one hand, the reduced claim for (dedicated) land in the beet residue and potato peelings scenarios is allowing more land to become or remain available for nature conservation. On the other hand, these scenarios may lead to an increased (indirect) demand for beet and potato area because the economic performance of these crops will look better under the given scenario assumptions (higher value to residues and industrial waste). This holds especially for the beet scenario and may impact diversity of crops in the field. It is, however, expected that the net outcome on biodiversity will be limited (it may reverse a trend of declining beet areas due to low economic performance for farmers). Impacts of biodiversity in the fields are expected to be limited.

Competition for natural resources

Clearly, a 50% reduction of the land claim under the beet residue and potato peelings scenarios will have large implications for the land demand in the region. It is, therefore, expected that competition for land will be reduced. In the third scenario, however, land will be needed to produce crops that replace potato peelings, a popular animal feed now being used as a biogas co-substrate. It is judged that the demand for available water will not be affected much. Depending on the utilization of land not used for dedicated biomass cropping, more water may become available, but this is not necessarily the case. It may be expected only if the new land cover would require less water than maize—e.g., when a nature area is installed with low evapotranspiration capacity, which under normal conditions would imply sub-optimal vegetative growth.

A special note here on the impact the scenarios may have on quality of ground water and surface water. The cultivation of silage maize can affect water quality because it is receiving relatively large amounts of nutrients (more than grassland, for example). Beets and potatoes, on the other hand, require higher applications of agro-chemicals, but these are not attributed to crop (or industrial) residues. Removal of beet leaves, which are rich in nitrogen and must be expected to decompose during winter time, thus adding to problems of nitrate leaching, is seen as an efficient way to reduce groundwater nitrate loads in the region (Zwart et al. 2004). Finally, the use of digestate as fertilizer ensures return of nutrients (nitrogen and phosphate) and organic material essential to maintain soil fertility and productivity. Part of the organic matter is lost during fermentation.

Impact on local food prices

The impact of the scenarios on local food prices is expected to be very small. General food prices in the Netherlands are determined by international or local markets, while most dairy, vegetable and meat prices are the outcome of retailer and farmer negotiations. Changes of silage maize cultivation will likely affect land prices, which play a role in farmers' profits. Impacts on food prices may be expected only in the long term. The impact of the silage maize scenario is expected to be largest.

Impact on prosperity

Sales of biogas or electricity enhance profitability of the agricultural sector that currently is suffering from price volatility and often low economic results. Biogas production from crop residues is a safe method for valorization of products often having no or limited value. In practice, however, a considerable part of the biogas installations in the Netherlands are not providing positive returns, and the net impact will depend on a comparison of investment, operational and substrate costs on the one hand and returns on the other hand. A preliminary analysis of the economic implications of the scenarios suggests the net profitability is determined by costs for co-substrates. Costs for cultivation of silage maize are considerable, but collection of beet residues is only moderately (one-third) cheaper, while procurement costs for potato peelings are high. Depending on the price farmers receive for electricity, silage maize may even generate more revenues. It should be noted, however, that costs

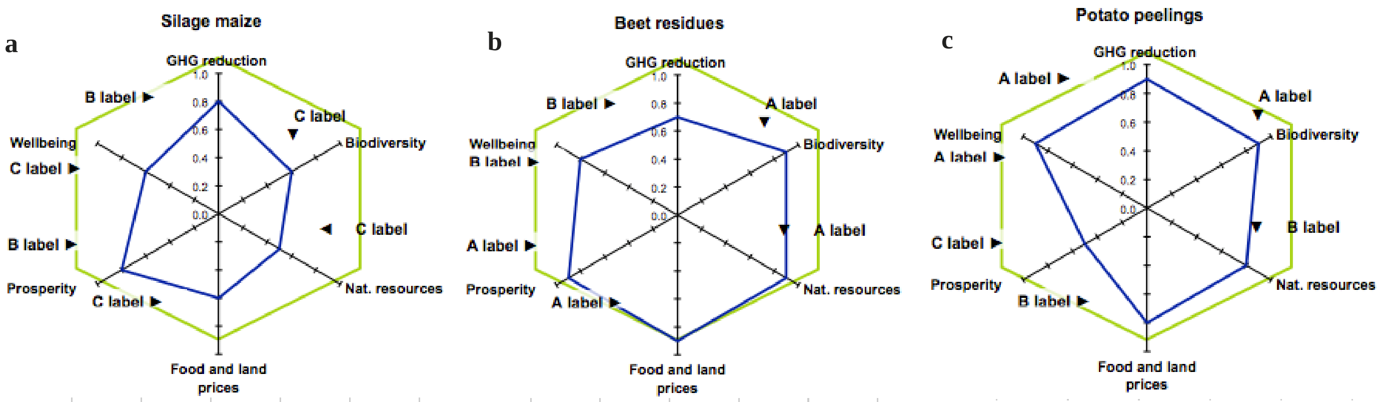


Figure 3. *Sustainability labeling of biogas production from energy crops (silage maize, Figure 3a), crop residues (Figure 3b) and industrial residues (Figure 3c) in the Netherlands. High scores are depicted by blue lines far out from the center of the figure (near the green lines). Information on labels is provided in Table 3 and in the text.*

for land procurement are not included in this analysis. Given high land prices in this region, it may well be that the beet residues are the most economic.

Impact on well-being

It is difficult to derive a balanced and uniform picture of the impact co-fermentation may have on the well-being of farmers and the rural area. Kool et al. (2005) evaluated heavy metal concentrations of several co-fermentation crops. Both silage maize and sugar beets have concentrations that remain well below legally allowed levels. Application of the digestate after fermenting manure plus sugar beets (at the maximum allowed phosphorus application level) may, however, lead to enhanced heavy metal concentrations at plots where digestate is used. Enhanced cultivation of silage maize may, on the other hand, lead to a more uniform (maize-dominated) landscape.

The second (silage maize, Figure 3a) and third (potato peelings, Figure 3b) scenarios generally show the best scores (mostly A and B labels, as depicted by blue lines near the green outer line of the figure). Beet residues' GHG reductions are, however, below those of the other scenarios, while potato peelings give more modest scores for prosperity and food prices. The use of silage maize as co-substrate is especially favourable for GHG reduction and economic performance. All other dimensions are given C label scores (Figure 3c).

Case 3: Crop production intensification for bioenergy in Ukraine

With a total land area of 58 million hectares, a crop area of 34 million ha to be potentially expanded to 43 million ha, Ukraine has the highest biomass potential in Europe. At present, however, this potential is largely untapped. Since independence in 1990, the country has undergone a large decline in both industrial and agricultural productivity (Elbersen et al. 2009). While wheat yields decreased 26% between 1992 and 1999, their recovery has been only very modest.

About half of the agricultural area consists of high-quality Chernozem soils. The most important farming system is large-scale cereal cultivation. In 2005, the overall volume of agricultural production was still at two-thirds of the 1990 level (Elbersen et al. 1990). The decline was mainly the result of reduced input applications such as fertilizers and pesticides. Wheat fertilizer applications were 149 kg/ha in 1990 and 26 kg/ha in 2003. The number of abandoned farms appears to be small. Wheat productivity declined from 3.5 tonnes per hectare to 2.4 tonnes per hectare in 2006.

Recovery of crop yields is projected, provided proper management and input use, with wheat yield increases being suggested at 150% (FAO 2006). Already, agricultural development is gaining momentum. Meanwhile, food availability is moderate, with undernourishment still being observed. Increases in food production efficiency may significantly decrease the agricultural land area, thereby freeing land for bioenergy production, without endangering food supply or further deforestation (Smeets et al. 2007). Western Europe is considered a potential import market for a surplus in biomass feedstocks.

We consider a business-as-usual scenario where agricultural production recovers slowly. Input use and cereal yields show modest increases over the next 10 years, enough to support population growth but not leading to significant increases of available amounts of food. Some bioenergy production will emerge, mostly low-tech and oriented at local and domestic consumption. Slow agricultural and food availability increases have their impact on economic prosperity and well-being, which recover slowly. Because yields remain low, all land will be kept in use. The situation is expected to improve after 2020, when a gradual recovery will lead to increased agricultural and economic productivity. Part of this will be based on domestic biofuel (first-generation) production.

The alternative scenario includes considerable efforts in research, extension and input availability. Consequently, agricultural production is expected to recover. Cereal yields may increase by 2% on an annual basis, leading to an increase with some 1.5 t/ha over a period of two decades. This allows for the conservation of 10% of the current area as nature (biodiversity) reserve. As initial growth is much faster, food availability and (rural) economic development are to improve in the rather short term. Bioenergy production first focuses on fuel production for domestic use, changing gradually into cereals for bioethanol exports when food availability has recovered.

Later, when the local bioenergy industrial infrastructure has had time to mature, technological improvement and innovation are to increase both domestic productivity and efficiency. Economic development and well-being profit from agricultural production increases and growth in domestic and export markets. Because yield increases sparked this development, no negative impact on food prices is expected. Biodiversity losses are limited. Figure 4 depicts sustainability scores of both scenarios. The BAU scenario is showing moderate to poor performance (C or D labels). The second (accelerated) scenario performs better on all dimensions.

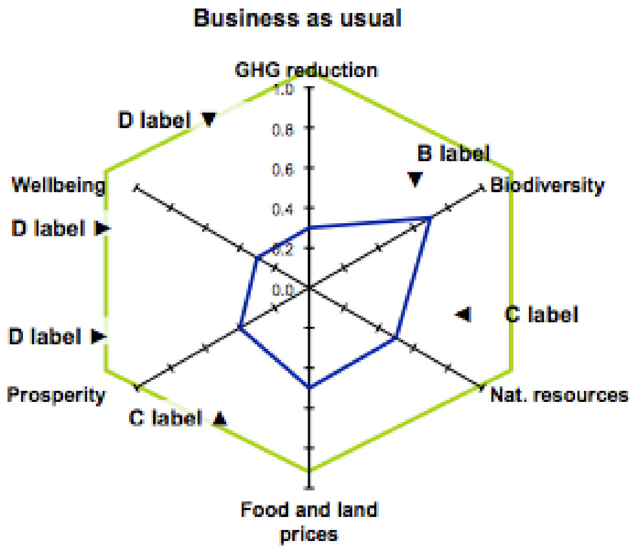
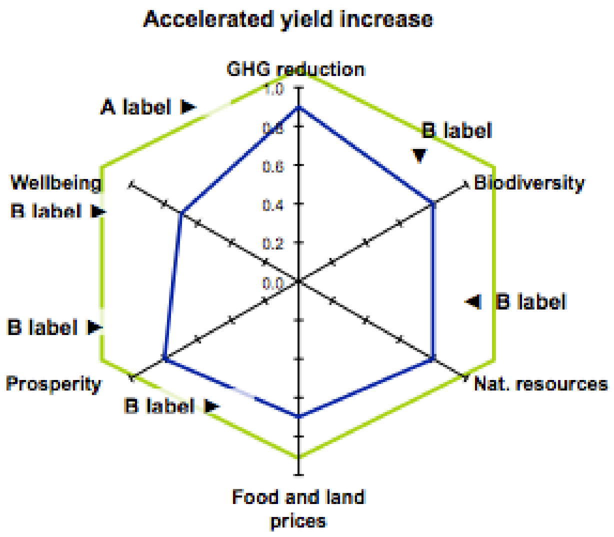


Figure 4. *Sustainability labeling of business-as-usual (above) and accelerated enhanced cereal production in Ukraine (below). High scores are depicted by blue lines far out of the center of the figure (near the green lines). Information on labels is provided in Table 3 and in the text.*



Discussion

The approach of organizing and evaluating alternative scenarios for bioenergy development that is presented here was applied to three bioenergy production chains. Defining alternative development routes, it allowed the evaluation of alternative scenarios under prevailing bio-physical and socio-economic conditions. The Brazilian case study depicted how development of sugarcane through uncontrolled expansion of land area in the Cerrado may affect biodiversity while triggering unbalanced local economic development. The alternative scenario linked cane expansion to intensification (and concentration) of animal production on grasslands in the same region. From the analysis, it follows that the second scenario offers better scope on a range of dimensions, including GHG balance, maintaining biodiversity, prosperity and well-being. This is in line with detailed local studies presented by Sparovek et al. (2008) and do Amaral et al. (2008).

Findings are, further, supported by census and regional land use data presented by Nassar (2010), which show that the amount of pasture area in the Cerrado (Center-West) indeed has declined since 1996, while stocking rates have gone up. It is also in line with census data collected by IGBE (also presented by Nassar 2010) suggesting that expansion of agricultural crops occurred at the expense of grasslands rather than forests in the Amazon. Still, many authors suggest that direct land use changes in the Cerrado are followed by indirect changes in the Amazon region (e.g., Lapola et al. 2010), who also confirm that this trend could be reversed by improvement of grazing systems.

Scenarios that were compared for the Netherlands represent strategies that are commonly propagated to enhance bioenergy production in industrialized countries: (i) cultivation of dedicated crops, (ii) use of crop residues, or (iii) conversion of industrial waste. The cultivation of silage maize for biogas production is showing moderate-to-good scores, where especially the GHG reduction may be higher than often is assumed. In terms of impact on biodiversity, competition for natural resources, impact on food and land prices and even well-being, the use of crop residues (beet leaves and heads) is to be preferred. The use of potato peelings, presently used as animal feed, is more effective in terms of GHG emission reduction. It is, however, also more costly while it may inflict indirect land use change (not included in the scores).

There are many studies discussing the potential of crop residues for bioenergy production (e.g., Dornburg et al. 2010). Synchronous evaluation of alternative feedstock pathways (dedicated crops, crop residues, industrial waste), in contrast, are very rare. In most cases (e.g., Gallagher 2008), the impact of waste feedstocks in bioenergy is evaluated in terms of land requirements and GHG emissions. Evaluations of economic conditions or impacts on well-being are less common. Gan and Smith (2010) present one of the few examples of multidimensional analysis, reflecting on the impact of wood residue removal on soil quality, erosion and GHG emission reduction.

For Ukraine, the scenarios that are evaluated represent an ambitious biofuel policy and a less aggressive and more balanced policy supporting agricultural development through investments in research. The multidimensional analysis clearly suggests that the latter is to be preferred. To our knowledge, there are few studies that compare similar development pathways on a national level. One specific feature in this country, like many more former Communist states in Eastern Europe, is the reduction of crop yields that have occurred since the regime change. Perspectives of yield improvement (yield gap reduction) in this region can be considerable (Foley et al. 2011).

Together, the three case studies presented above include seven scenarios, four crop types and a range of alternatives for biomass production. The outcomes suggest it is possible to evaluate diverse production conditions using indicators that represent insights from biological, physical, economic and social sciences. The evaluation tool that has been implemented facilitates an integrative assessment of bioenergy production systems by providing a systematic comparison of alternative development scenarios. It allows for inclusion and evaluation of scientific and other data from a range of disciplines and their integration in a normalized weighing process. In this way, data and other factual knowledge are processed into a form suitable for multidimensional evaluation. The tool is scale neutral and can be applied to all kinds of bioenergy chains. We have presented applications to biogas and bioethanol production assessing alternative scenarios for regional (Brazil), national (Ukraine) and farm level (the Netherlands) bioenergy development. As a major outcome of the evaluation is clearly displayed, this facilitates communication with stakeholders such as policy-makers, researchers, companies and NGOs.

It was not easy to obtain sufficient objective and high-quality quantitative data that are needed for this analysis. We have been able to obtain a substantial amount of data referring to the Brazilian and Dutch case studies, but even here in some areas, more data is needed (especially on economic, social and legal aspects of sugarcane ethanol production). More exhaustive literature searches may improve the basis for the evaluation, especially concerning non-technical data referring to social and economic impacts of land use change, which appear the most difficult to obtain.

The use of a multidimensional model for information collection and analysis of all kinds of land use change impacts—including social, economic and legal (non-technical) —has advantages, as well as disadvantages. Bringing all kinds of sustainability elements into one figure offers the opportunity to simultaneously judge all dimensions, including those that usually receive less attention in the debate. This can facilitate decision-making on (improved) bioenergy production systems and their related land use practices. Disadvantages of this approach (imbalances in data availability, the need to weigh outcomes of analyses that have completely different characters) are by and large similar to those commonly found in life cycle assessment (LCA) studies.

As was discussed elsewhere (Langeveld et al. 2012), selection of the indicators, their implementation and (graphical) presentation of the results is not a value-free exercise. Description and evaluation of alternative scenarios have been done in a transparent and coherent way, but this does not guarantee the outcome is not biased, or that other scientists would come to the same conclusions. The influence of subjective decisions taken during the process could be assessed by presenting alternative approaches (e.g., presenting different indicators, or presenting them in an alternative order), but this would be going beyond the scope of this paper. Presenting results in spider-web figures may, further, suggest more precision and accuracy than can be defended rigorously. As was mentioned above, in most cases, neither the analysis nor the resulting figures are intended to present purely quantified outcomes. The method that has been chosen is based on diverse information sources, often not (sufficiently) quantified, and generally not suited for a pure mathematical analysis. The use of sustainability labels (rather than presenting quantified scores) can—at least partly—overcome this limitation. It is emphasized, however, that results in many cases are based on expert judgments. Further, axis scales are not quantitatively equal among the six variables that are displayed. The reader should not try to compare scores (e.g., B labels) of one with similar results presented for another case study.

While keeping the limited scope of the analysis in mind, we can draw some conclusions. Outcomes of case studies presented here suggest that in many cases biofuel development scenarios are imbalanced. While the environmental—and, sometimes, economic—performance may be satisfactory, implications (on markets, on economic or social development) can be considerable. This is best demonstrated by the Brazilian and Ukrainian case studies. In Brazil, cane for biofuel development ideally is accompanied by programs for pasture improvement, while enforcement of existing policies and legislation protecting forests and other native vegetation still requires attention. While biofuel policies in Ukraine still are in an infant stage, the outcome of the analysis suggests that an ambitious pursuit of biofuel development in this country best should be integrated in a wider agricultural stimulation policy.

The outcome of this study suggests that biomass production may coincide locally with other forms of land use in sophisticated and well-balanced production systems, provided the right policies are followed. Identification of innovative ways to combine bioenergy and food, feed or fiber production requires tools that allow for systems evaluation along a wide range of technical, environmental and socio-economic dimensions. The outcome of the case studies is illustrative of the way the presented evaluation tool can be used to inform the reader on the impact that expanded biomass production may have. One outcome is especially clear—alternative development scenarios for a given bioenergy application can have very different impacts on environmental, economic and social conditions, depending on the way the scenarios fit in specific local conditions. It is recommended, therefore, that alternatives are always evaluated on a range of dimensions, integrating different values. Such an evaluation should preferably be done in an early stage in order to identify (possible) negative effects of bioenergy production alternatives in a timely way.

The systematic collection and analysis of data on different dimensions of alternative bioenergy scenarios allows for a thorough and comprehensive evaluation of effects that are relevant for policy. It helps policy-makers in assessing to what level a given scenario helps to reduce GHG emissions and fossil dependency, as in the identification of the (possible) impact it may have on other policy agendas, such as biodiversity conservation or social equality. The strong visual and schematic representation of the outcome helps to represent a broad range of impacts of a given solution in a systematic and comprehensive way. This ability makes the tool an effective and powerful instrument in policy-related processes.

Conclusions

Bioenergy can reduce GHG emissions, as well as dependency on fossil fuels. Realizing the potentials of bioenergy involves risks that require careful consideration. Information needed in the process is often unbalanced, complex and sometimes conflicting. We have presented a generalized, integrative assessment tool that can help to evaluate the impacts of alternative bioenergy development scenarios for different countries, at different scales and under very different conditions. Application of the method shows that it can help to present data collected on issues of GHG emissions, biodiversity, competition for natural resources and impact on food and land prices, as well as impacts on economic development and social well-being.

This tool should be useful, considering the broad scope that logically is used in policy evaluations, and considering different elements of the policy agenda while evaluating solutions that often apply a much smaller technical and problem-oriented focus. This brings the risk that no adequate choices are made with respect to scientific and technological research, while progress in such research is in our view essential in bringing forward solutions that can combine both bioenergy production and other forms of land use without scarifying other societal objectives. Examples presented here are only a small sample of possible approaches to solve the perceived dichotomy between bioenergy production on the one hand and room for food, nature and well-being on the other hand. Smart, innovative systems that combine both require local knowledge and ingenuity. IEA Bioenergy can help to spread the results of such innovative developments.

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