The impact of sustainability criteria on the costs and potentials of bioenergy production

An exploration of the impact of the implementation of sustainability criteria on the costs and potential of bioenergy production, applied for case studies in Brazil and Ukraine

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Summary

Biomass can be used as a renewable (green or CO_2 neutral) energy source, locally and readily available in large parts of the world. Many studies have been carried out that quantify the potential of the world to produce bioenergy (e.g. (Leemans *et al.* 1996; Fischer *et al.* 2001a; Hoogwijk *et al.* 2004; Smeets *et al.* 2004a, b). Results indicate that various world regions are in theory capable of producing significant amounts of bioenergy crops without endangering food supply or further deforestation.

A prerequisite for the large-scale production and trade of biomass (biotrade) is that production and trade is beneficial with respect to the social well being of the people (people), the ecosystem (planet) and the economy (profit).

The goal of this study is to make a first attempt to analyse the impact on the potential (quantity) and the costs (per unit) of bioenergy that the compliance with various sustainability criteria brings along. This nature of this work is exploratory, because of the broad set of issues covered very little work has been published on which we could build. Ukraine and Brazil are used as case studies, because both regions are identified as promising bioenergy producers (Smeets *et al.* 2004b).

This study is part of the FAIRBiotrade project, which is aimed to identify and quantify the impact of sustainability criteria on the potential of bioenergy. Previous work includes an identification of sustainability criteria relevant for bioenergy (Lewandowski and Faaij 2004), an assessment of the environmental and economic costs of long distance biotrade (Hamelinck *et al.* 2003) and an assessment of bioenergy production potentials in 2050 in various world regions (Smeets *et al.* 2004c). This work is funded by NOVEM (Netherlands Organisation for Energy and the Environment) and the Dutch electricity company Essent N.V.

Poplar production in Ukraine and eucalyptus production in Brazil are used as case studies, because both regions are identified as promising bioenergy producers (Smeets *et al.* 2004b). For both regions cost calculations are included for a representative intensive commercial short rotation forestry management system. The year 2015 was chosen as a target, because this allows a 10-year period required to implement changes in land-use, establish plantations and develop a framework to implement criteria.

A list of 127 criteria relevant for sustainable biomass production and trade is composed based on an extensive analysis of existing certification systems on e.g. forestry and agriculture Lewandowski (Lewandowski *et al.* 2004). To be able to analyse the impact of these criteria on the cost and potential of bioenergy, the various criteria needed to be translated into a set of concrete (measurable) criteria and indicators that have an impact on the management system (costs) or the land availability (quantity). 12 criteria are included in this study, because not all criteria could reasonably be translated into practically measurable indicators and/or measures and many criteria are related and/or overlap, see table 1.

Because there is no generally accepted definition of sustainability, a strict and loose set of criteria and indicators is defined, to represent the difference in individual perceptions of sustainability. The stricter set of criteria is more difficult to implement than the loose set, because the restrictions for production and other activities in the

chain are more severe. Table 1 shows the loose and the strict versions of the sustainability criteria included in this study.

Table 1. The sustainability criteria included in this study.

Area of concern	Loose set of criteria	Strict set of criteria
Food supply	The production of bioenergy is not allowed to endanger food supply. The theoretical potential to generate surplus agricultural land in 2015 was estimated, following the methodology of Smeetss (2004a).	
Deforestation	The production of bioenergy is not allowed to result in deforestation. The theoretical potential to generate surplus agricultural land in 2015 was estimated, following the methodology of Smeetss (2004a).	
Soil erosion	Soil erosion rates are not allowed to increase compared to conventional agricultural land use. Soil erosion rates are compared based on crop/vegetation specific management factors and if required additional soil erosion prevention measures (no tillage, ridge ploughing) are implemented.	Soil erosion rates are not allowed to increase compared to conventional agricultural land use and must be decreased compared to the natural soil regeneration capacity. Soil erosion rates under various land cover types (including bioenergy crops) are calculated using the Universal Soil Loss Equation. Additional soil erosion prevention measures are implemented if required. E.g. ridge ploughing, which result in higher labour and machinery costs.
Depletion of fresh water resources	Depletion of fresh water resources is not allowed. The risk of groundwater depletion is estimated by means of a water balance, in which the evapotranspiration is compared with the (effective) rainfall. Irrigation is not allowed, for ecological and economical reasons; yields are based on rain-fed production. No additional costs to reduce the water use are included, due to a lack of data.	
Nutrient losses and soil nutrient depletion	Soil nutrient depletion must be prevented by means of the sufficient application of fertilizers.	Soil nutrient depletion must be prevented by means of the sufficient application of fertilizers. Nutrient leaching must be prevented by increasing the nutrient uptake efficiency as far as reasonably is achievable. E.g. by increasing the fertilizer application rate, which results in higher labour and machinery costs.
Pollution from chemicals	Pollution from agricultural chemicals must be avoided by means of good management as far as reasonably is achievable. No costs are included.	Pollution from agricultural chemicals must be avoided as far as reasonably is achievable by means of substitution of chemicals by manual and mechanical operations, which result in higher labour and machinery costs.
Employment	The production and trade of bioenergy must contribute to employment. By definition, bioenergy crop production contributes to employment. No costs are included.	The production of bioenergy is not allowed to result in a decrease in employment compared to the baseline situation measured economy-wide. No costs are included due to a lack of data and suitable methodologies to calculated overall employment effects.
Wages	Wages must be based on at least the minimum wages and must be above the international poverty line.	Wages must be based on the average wage.
Child labour	Child labour is not allowed. No costs are included.	Child labour is not allowed and parents are compensated for the loss of family income and for the costs of education.
Education	Education is the responsibility of society in general. No costs are included.	Education is (partially) the responsibility of the bioenergy crop producer. The average costs for education for an average family are added up to the hourly labour costs.
Health care	Health care is the responsibility of society in general. No costs are included.	Health care is (partially) the responsibility of the bioenergy crop producer. The average costs for education for an average family are added up to the hourly labour costs.
Biodiversity	Biodiversity must be protected.	

Figure 1 shows the impact of the various criteria on the cost-supply curve.A reference scenario is included that represents the situation in which no criteria are included, which is largely similar to the loose set of criteria. Results for the criteria related to employment and land use are excluded and described below.

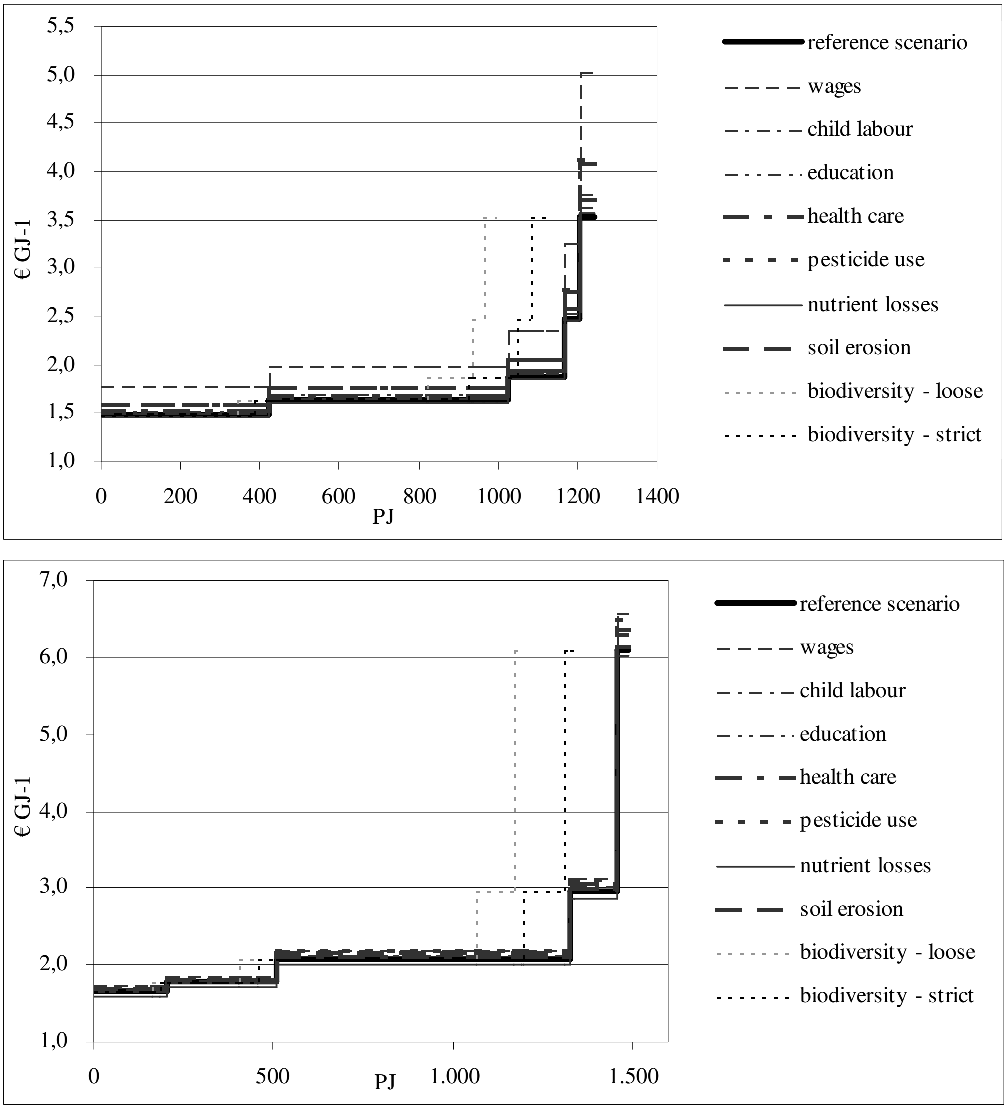

Figure 1. Cost supply curve for bioenergy crop production is a loose and strict set of criteria in Brazil (Rio Grande do Sul; top figure) and Ukraine (bottom figure) in 2015 (€ GJ^{-1}).

The total costs for bioenergy crop production in Brazil and Ukraine are calculated at 1.5 € GJ^{-1} to 3.5 € GJ^{-1} and 1.7 € GJ^{-1} to 6.1 € GJ^{-1} dependant on the land suitability class (and respective yields), including the impact of basic levels for the various sustainability criteria. The criteria are grouped into three clusters:

Land use patterns

Land use patterns include criteria related to the avoidance of deforestation, competition with food production and protection of natural habitats. The theoretical potential to generate surplus agricultural land in 2015 was estimated, following the methodology of Smeetss (2004a). This methodology includes, among other variables, population growth, income growth and the efficiency of food production. Results indicate that (in theory) large areas surplus agricultural land could be generated without further deforestation or endangering the food supply. However, additional investments in agricultural intensification may be required to realise these technical potentials.

Socio-economic criteria

Socio-economic criteria include criteria related to e.g. child labour, (minimum) wages, employment, health care and education. Compliance with the various criteria results in additional (non) wage labour costs, which are a separate cost item in the calculation of the production costs of biomass. The loose set of criteria does not influence the costs or quantity of bioenergy crop production. The strict criteria related to child labour, health care and education has a very limited impact on the costs of bioenergy crop production, between up to 8% in Ukraine and up to 14% in Brazil (see figure 1). The impact of the strict criterion related to wages is larger, which results in an increase of the costs of bioenergy crop production of up to 8% in Ukraine to up to 42% in Brazil. In general, the impact of the strict set of criteria is limited, because labour costs account for maximum two-fifth of the total production costs.

Another key socio-economic issue is the generation of direct and indirect employment. The direct impact of bioenergy crop production on employment is calculated based on the labour requirement for the various management activities. The indirect impact of bioenergy crop production consists of two aspects. First, the employment effect of the increase in demand for agricultural machinery and other inputs due to bioenergy crop production and the intensification of food production. Second, the investments in agriculture require increasing the efficiency of food production, which may lead to more mechanisation and a loss of employment. Indirect (employment) effects of increased agricultural productivity and additional biomass production are very likely to be positive though. Due to a lack of data and suitable methodologies the indirect employment effects could not be calculated in the framework of this study, but these indirect effects could be significant and require further study.

Environmental criteria

Environmental criteria include criteria related to e.g. soil erosion, fresh water use, pollution from the use of fertilizers and agricultural chemicals. Compliance with various environmental criteria requires an adaptation of the bioenergy crop management system, e.g. an increase in mechanical and manual weeding to avoid the use of agricultural chemicals. For the loose set of criteria no additional costs were required. The impact of the strict criteria related to soil erosion is limited to 15% and 4% maximum in Brazil and Ukraine, respectively. The impact of the strict set of criteria related to pollution from chemicals is up to 16% in Brazil and up to 6% in Ukraine. The strict set of criteria related to nutrient leaching and soil depletion results in a cost decrease of up to –2% in Brazil and up to –4% in Ukraine, which is the combined effect of increasing labour and machinery costs and decreasing fertilizer costs. For the protection of biodiversity protection, 10 to 20% of the surplus agricultural land could be set aside, although we acknowledge that this may be insufficient for the protection of biodiversity and that additional or other requirements for the plantation management may be required. Due to a lack of data and suitable methodologies, indirect effects from the intensification of agriculture were not included, but these are potentially significant. A logical consequence would be that similar criteria should be in please for conventional agriculture as for biomass production.

The total costs increase by 35% to 88% in Brazil and 10% to 26% in Ukraine, dependant on the land suitability class (yield). The highest impact on costs (in € odt^{-1}) can be found on the lowest productive areas, because a large share of the costs are fixed, while the yield level depends on the land suitability class. For many of the areas of concern included in this study, data and methods used to quantify the impact of sustainability criteria on costs or potential are crude and therefore uncertain. The ecological criteria require a more site-specific analysis with specific attention for e.g. soil type, slope gradient and rainfall. The social oriented criteria require more reliable and detailed data e.g. at a household level data and better methodologies to analyse indirect effects. Further research in this area is needed to provide more accurate estimates of the impact that various sustainability criteria may have on the costs and potential of bioenergy crop production.

Overall, the results of this study indicate that:

- In several key world regions biomass production potentials can be very significant on foreseeable term (10-20 years from now). Feasible efficiency improvements in conventional agricultural management (up to moderate intensity in the case regions studied) can allow for production of large volumes of biomass for energy, without competing with food production, forest or nature conservation. The key pre-condition for such a development are improvements in the efficiency of agricultural management.
- it seems feasible to produce biomass for energy purposes at reasonable cost levels and meeting strict sustainability criteria at the same time. Setting, strict, criteria that generally demand that socio-economic and ecological impacts should ***improve*** compared to the current situation will make biomass production more expensive and will limit potential production levels (both crop yield and land surface) compared to a situation that no criteria are set. However, the estimated impact on biomass production costs and potential is far from prohibitive. For the case studied (SE Brazil and Ukraine) estimated biomass production costs under strict conditions are still attractive and in the range of 2 Euro/GJ for the largest part of the identified potentials.
- It should be noted that such improvements, when achieved, also represent an economic value, which could be considerable (e.g value of jobs, improvement of soil quality, etc.). Such ‘co-benefits’ could especially be relevant for the less productive, marginal lands. Such a valuation has however not been part of this study.
- The results are indicative, based on a desktop approach (and not on field research) and pay limited attention to macro-effects as indirect employment and both potential negative and positive impacts on conventional agriculture. More work to verify and refine the methodological framework developed is therefore needed, preferably involving specific regional studies and including regional/national stakeholders.

The approach proposed does however provide an original and quantitative framework that can be used as a basis for designing sustainable biomass production systems and monitoring existing ones. Besides more detailed and refined approaches, the framework may also be developed into a more simplified quickscan method to identify and monitor biomass production regions. It is recommended to develop and deploy such a quantitative framework for future biomass production projects in different settings.

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1. Introduction

Biomass is receiving more and more attention as a renewable (green or CO_2 neutral) energy source, locally and readily available in large parts of the world. Since early 90's many studies have been carried out that quantify the potential of the world to produce bioenergy (e.g. (Leemans *et al.* 1996; Fischer and Schrattenholzer 2001a; Hoogwijk *et al.* 2004; Smeets *et al.* 2004a, b). Results clearly indicate that various world regions are in theory capable of producing significant amounts of bioenergy crops without endangering food supply or further deforestation.

Also in the Netherlands biomass is projected to play a key role in the future energy supply. Recently, the Dutch government announced that in 2040 30% of the primary energy use should come from biomass. This equals some 1000 PJ and requires some 5 million hectares land for the production of bioenergy crops. However, due to the (relative) scarcity of agricultural land and consequently high prices in the Netherlands, domestically produced biomass is (relatively) expensive. Various studies indicate that the import of biomass from e.g. South America to the Netherlands is economically attractive and the energy use for transport of biomass is limited to 15% of the primary energy for woody biomass and much less if transported in more compact from (e.g. fisher-tropsch fuel; (Hamelinck *et al.* 2003). Already at this moment, the Netherlands and Sweden import small amounts of biomass for electricity generation (Hamelinck *et al.* 2003).

A prerequisite for the large-scale production and trade of biomass (biotrade) is that production and trade take place in a sustainable way. This means that the production and trade should be beneficial with respect to the social well being of the people (people), the ecosystem (planet) and the economy (profit).

At this moment, bioenergy production certification schemes are under development to ensure environmentally and socially sound production systems. Lewandowski (Lewandowski and Faaij 2004) identified a set of 127 criteria relevant for sustainable biomass production and trade based on an extensive analysis of existing certification systems on e.g. forestry and agriculture. In addition, a wide variety of studies has been carried out over the years that analyses the economic performance (e.g. (Faundez 2003; Hoogwijk *et al.* 2004; Nord-Larsen *et al.* 2004), ecological performance (e.g. (Kort *et al.* 1998; Borjesson 1999; Berndes 2002) and/or social implications of bioenergy production (e.g. (Van den Broek *et al.* 2000a; Hillring 2002). However, no studies are available that analyse the possibilities and limitations resulting from the implementation of a certification system specifically aimed for bioenergy production and trade.

The goal of this study is to make a first attempt to analyse the impact on the potential (quantity) and the costs (per unit) of bioenergy that the compliance with various sustainability criteria brings along. This nature of this work is exploratory, because of the broad set of issues covered very little work has been published on which we could build. Ukraine and Brazil are used as case studies, because both regions are identified as promising bioenergy producers (Smeets *et al.* 2004b).

This study is part of the FAIRBiotrade project, which is aimed to identify and quantify the impact of sustainability criteria on the potential of bioenergy. Previous work includes an identification of sustainability criteria relevant for bioenergy (Lewandowski and Faaij 2004), an assessment of the environmental and economic costs of long distance biotrade (Hamelinck *et al.* 2003) and an assessment of bioenergy production potentials in 2050 in various world regions (Smeets *et al.* 2004c). This work is funded by NOVEM (Netherlands Organisation for Energy and the Environment) and the Dutch electricity company Essent N.V.

In section 2 the approach is presented which is used to select and quantify the impact of sustainability criteria on bioenergy production. In section 3 the selection of the various sustainability criteria is described in detail, followed by a detailed description of how the various socials, ecological and economical sustainability criteria are operationalised. In section 4 (intermediate) results are presented for each sustainability criteria. In section 5 final results are presented, followed by a discussion and by conclusions (section 6).

2. Approach

The goal of this study is to explore the impact of these sustainability criteria on the costs and potential of biomass for energy use for concrete case study regions. It tries to find ways to quantify these impacts and show how these various impacts influence the costs and/or potential of biomass (for bioenergy use) production. Lewandowski (Lewandowski and Faaij 2004) identified a set of 127 sustainability criteria relevant for the production and trade of biomass (table 1 in Appendix A).

To be able to analyse the impact of these criteria on the cost and potential of bioenergy, the various criteria needed to be translated into a set of concrete (measurable) criteria, accompanying indicators and measures that are necessary to meet the criteria. However, not all areas of criteria identified by Lewandowski could reasonably be translated into practically measurable indicators and/or measures. For example the criterion ‘woman should not be discriminated and their rights have to be respected’ is not included in this study, because no hands-on criteria and indicator could be found. Further, many criteria are related and/or overlap. Therefore, criteria can be grouped into ‘areas of concern’, which are analysed by means of one or a linked set of indicators that require a similar or overlapping method of research. Examples are:

- Land use patterns, which includes criteria related to the avoidance of deforestation, competition with food production and protection of natural habitats.
- Socio-economic criteria, which include criteria related to e.g. child labour, (minimum) wages, employment, health care and education.
- Environmental criteria, which includes criteria related to e.g. soil erosion, fresh water use, pollution from the use of fertilizers and agricultural chemicals.

Sustainability is a very broad concept, which includes ecological, economical, social aspects. There is no generally accepted definition of sustainability, including for bioenergy systems. As a result, the practical implication of each sustainability criterion remains subject to individual perceptions and is context specific. If for example water pollution from agricultural chemicals is the area of concern, than some people may only accept organically produced food as sustainable, others may be satisfied with a less restrictive and demanding form of agriculture as long as ‘striving for doing better’ is the vision. These differences in perception of the definition of sustainability are dealt with in this study by means of defining and applying a strict and loose set of criteria and indicators. Broadly spoken, the scope of the loose set of criteria remains limited to the site (farm or factory) that produces biomass. The approach of the loose set matches with many of the existing certification systems. The strict set of criteria also includes aspects not directly related to the site of production, such as the access of workers to health care and education and the quality of the infrastructure in the bioenergy exporting region. Therefore, the stricter set of criteria is more difficult to implement than the loose set, because the restrictions for production and other activities in the chain are more severe.

The sustainability criteria included in the loose and strict set of criteria are translated into a set of concrete criteria, accompanying indicators and measures necessary to meet these criteria. These measures have an impact on the cost-supply curve of biomass production:

- Three types of costs are included:

  - Costs for production. Production includes the bioenergy crop establishment and harvesting, chipping of the harvested biomass, technical assistance and overhead.
  - Costs related directly to certification procedure. A verifying body is asked to certify the biomass producer that results in costs related to the verification itself (checking of the books, on-site inspections). This also includes costs related to various analysis required by the verifiers, such as a risk assessment of the food production system or soil erosion sensitivity analysis. These costs are from now on referred to as certification overhead costs. These costs are especially relevant for issues that do not directly lead to increased production costs. These costs are excluded in this study.
  - Costs related to the administrative organisation of biomass producer required by the certification system and that allows verification, e.g. book keeping costs. These costs are included in the production overhead costs. These costs are excluded in this study.

  The focus is in this study on the production costs and the consequences that various criteria may have on those costs, e.g. due to the decreasing yields and more expensive management (from establishment to the delivery of the chipped biomass to the site of the field).

- The potential of bioenergy crop production, i.e. the yield and the land area available for bioenergy production. Various criteria formulated may result in a reduced productivity of bioenergy crops or the exclusion of areas for bioenergy production (e.g. steep slopes may be qualified as unsuitable for bioenergy production due to the high susceptibility for soil erosion).

3. Methodology

Lewandowski (Lewandowski and Faaij 2004) identified 127 sustainability criteria relevant for the production and trade of biomass. Of these 127 criteria, some 50 are partially or completely included in this study, as described in table 1 in Appendix A. The remaining 77 were excluded, because these could not be operationalised into quantitative measures, but this does not imply that these are not important. The remaining 50 criteria are aggregated into 12 criteria, due to the overlap in scope of these 50 criteria. The 12 criteria are translated into measures necessary to meet these criteria. These measures have an impact on the land availability, yield or crop management system and subsequently on the cost-supply curve of biomass production, as shown in figure 1.

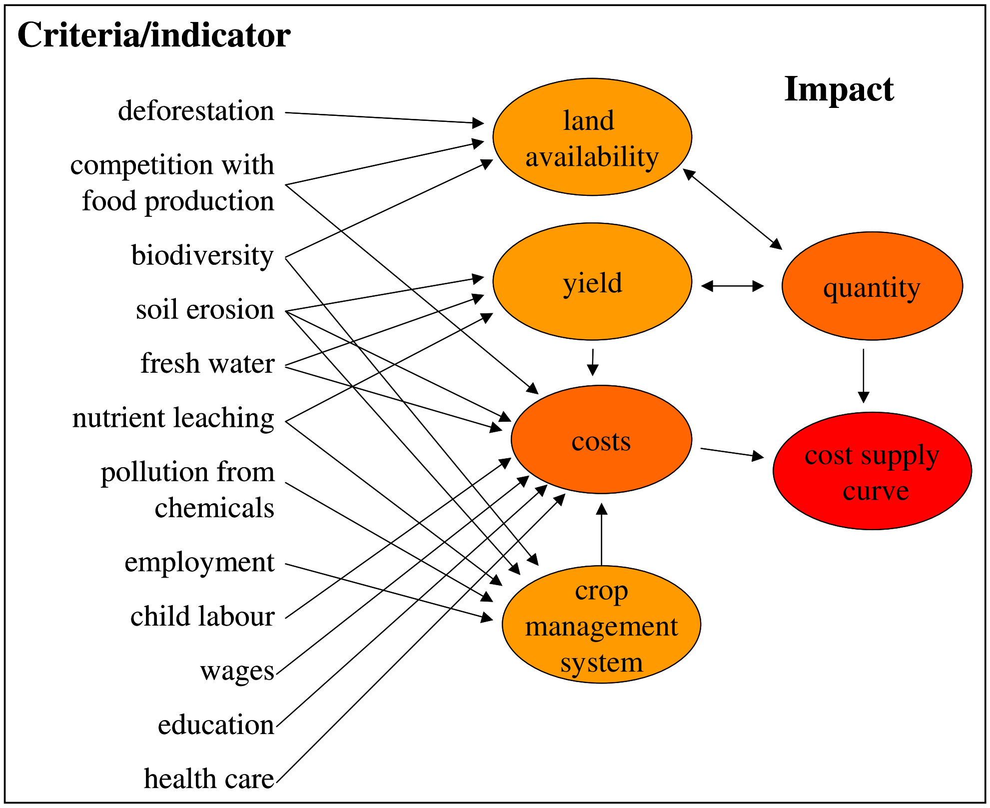

Figure 1. Possible relations and impacts of various sustainability criteria on the cost and potential of bioenergy crop production.

For each of the 12 criteria, a strict and a loose set of criteria and measures is included, as described in detail in the remaining of this chapter. Results are considered reasonable for the year 2015, because this allows a 10-year period required to implement changes in land-use, establish plantations and develop a framework to implement criteria.

In section 3.1 the method used to calculate bioenergy crop production costs is discussed, followed by sections describing the methodologies to quantify the impact of selected socio-economic criteria (section 3.2) and environmental criteria (section 3.3).

3.1 Costs of bioenergy crop production

Figure 1 showed that criteria could have very different effects on the cost of bioenergy crop production. In order to quantify those, the costs of biomass production should be described with enough detail to allow for varying the costs of the various cost items as well as the yield. A general but rather detailed methodology is used to estimate costs of perennial short rotation woody crop (SRWC) production system, depicted by the equation below (adjusted from Van den Broek (2000a).

$$C = \frac{\sum_{i=1}^{i_t} \left(ecc_i \sum_{y=1}^{n} \frac{f_i(y)}{(1+dr)^y} \right)}{yld\ \ rot \sum_{y=1}^{n} \frac{f_{yld}(y)}{(1+dr)^y}}$$

C = costs of biomass
yld = yield of the energy crop (section 3.1)
rot = rotation cycle (section 3.1)
n = number of years of plantation lifetime (section 3.1)
ecc_i = cost of energy crop cost item I
$f_i(y)$ = number of times that cost item i is applied on the plantation in year y
dr = discount rate
f_{yld} = binary number, harvest (1) or not (0) in year y

Data on the costs of short rotation woody crop production are derived from literature. Table 1 shows the cost items included in the calculations and the application of these during the plantation lifetime. The data represent an intensive management system in commercial short rotation forestry, although in reality not all cost items are always required. E.g. pest and disease control is frequently not required. The data exclude the impact of various criteria.

Table 1. Application of various cost items included in the calculations.

Plantation year Cost item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Soil preparation	x																				
Fencing	x																				
Planting	x																				
Weed control	x							x							x						
Fertilisation		x	x						x	x						x	x				
Pest and disease control	x							x							x						
Land rent	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Harvesting							x							x							x
Stump removal																					x
Technical assistance	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Administration and other overhead	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

For each cost item in table 1 an estimate is made of the share of labour, materials (e.g. planting materials and chemicals) and machinery (includes depreciation, maintenance and fuel) in the total costs. All costs and benefits are spread out equally over the years[1]. All data in euros in this report refer to the present value (NPV) in euros of 2002, unless stated otherwise.

The silvicultural management scheme and rotation cycle depicted in table 1 is applicable for both eucalyptus production in Brazil and poplar production in Ukraine. We are aware that in reality the cost factors of eucalyptus production in Brazil and poplar production in Ukraine may be different. However, considering the explorative character of this study, we consider a relatively rough assessment of costs a suitable methodology. Differences in economic performance between eucalyptus and poplar production are the result of differences in the price of the various cost items and differences in yields for which country and region specific data are used. Input data for the cost price calculations are shown in Appendix B.

Yield levels for poplar plantations in Ukraine and eucalyptus plantations in Brazil are dependant on numerous variables, such as the climate profile, the soil characteristics, the rotation cycle and the management system. In this study we use data on short rotation forestry plantations, based on a high input management regime under rain-fed conditions, because these systems are commonly used in commercial forestry plantations. Such a management system includes e.g. site preparation before planting (ploughing, disking), chemical or mechanical weeding, fertilizer application, mechanised harvesting. Representative rotation cycles and annual average yield levels are used based on data found in literature[2].

3.2 Socio-economic criteria

Competition with food production

The production of bioenergy crops requires land. Therefore, the production of bioenergy crops could compete with food production and could consequently endanger food security.

In both the *strict and the loose set of criteria* bioenergy crop production is only allowed on surplus agricultural land not needed for food production. Agricultural land consists of arable land and permanent pastures, as defined in Appendix C. To “generate” surplus land, any increase in food demand must be met by a larger increase in the efficiency of food production. The clearing of land under forest cover for agriculture is not allowed, see section 3.3. The efficiency of food production includes the efficiency of crop production (crop yields) and the efficiency of the animal production system.

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[1] To spread out costs equally over the years, we converted the costs into annuities. However, also the benefits, based on the production of wood as an intermediate product and electricity as a external product, is not equally distributed over time. Eucalyptus and poplar are harvested once every seven years. This production (the "benefits") can be converted into annuities, in the same way as the costs. Converting physical units into annuities may be uncommon but, because they do represent monetary values, the concept is basically the same as converting costs into annuities. Since the annuity factor (to derive the annual costs from the present value) is the same for both costs and benefits, it can be left out. Adjusted from (Van den Broek *et al.* 2000a).

[2] In reality coppice yields often increase or decrease between rotations; reasons are the timing of the harvesting and the length of cutting interval (Ribeiro *et al.* 1995).

The potential of Ukraine and Brazil to generate surplus agricultural land is analysed in three steps. First, the suitability for crop production of the total land area and of the present area agricultural land are compared with the present area arable land, to indicate the potential for crop production. Second, projections of agricultural land use and the efficiency of food production to 2015 found in literature are analysed. Third, the potential to increase the efficiency of food production above the levels projected in literature for 2015 is calculated.

Data on the suitability for crop production of the area agricultural land presently in use and the total land area derived from the FAOSTAT database (FAO 2002b) and from the crop growth modelling Geographic Information Systems (GIS) database operated by the International Institute of Applied Systems Analysis (FAO 2002c). Projections of agricultural land use the efficiency of food production in 2015 are based on work of the Food Agricultural Organisation (FAO 2003b). The potential to increase the efficiency of food production is calculated using an Excel spreadsheet model, following the approach proposed by Smeets *et al.* (Smeets *et al.* 2004a), which includes scenarios on food demand in combination with various levels of advancement of agricultural technology, which in turn determines the efficiency of food production.

The main difference between FAO projections and the approach proposed by Smeets, is the difference in the efficiency of food production in 2015. The FAO projections are based on an estimate of the (assumed) most likely food production efficiency and land use patterns in 2015, while the spreadsheet tool allows an assessment of the land use patterns and food production efficiency based on various levels of advancement of agricultural technology (from now on also called level of agricultural technology), without taking into account socio-economic constraints. I.e. the spreadsheet model indicates the technological potential to increase the efficiency of food production and consequently the technical potential to generate surplus agricultural land (Smeets *et al.* 2004a).

In the spreadsheet tool the efficiency of food production is calculated for both the efficiency of the production of crops and of animal production. Increases in the efficiency of crop production, i.e. increases in crop yields, are calculated using an Excel spreadsheet tool in which the production of food crops is allocated to the most productive areas. The remaining least productive areas are available for bioenergy crop production. Data on crop yields and areas suitable for crop production are dependant on the level of (agricultural) technology. Six levels of advancement of technology for crop production are defined (low to super high) as shown in table 2.

The efficiency of the animal production system is dependent on the feed conversion efficiency and the animal production system. The feed conversion efficiency is the total demand of biomass (dry weight) per kg animal product and is dependant on the level of agricultural technology.

The animal production system refers to the feed composition. Three production systems are included: pastoral, landless and mixed. In a pastoral system, most feed comes from fodder and grazing from permanent pastures. In a landless (industrialized) production system all animals are kept in stables and all feed comes from feed crops and residues. This production system is the opposite of the pastoral production system. A mixed production system is a combination of a landless and pastoral production system. In general, the highest feed conversion efficiency is reached in a landless production system, the lowest in pastoral systems. For all three animal production systems, three levels of advancement of agricultural technology are defined (low to high) following the definition presented in table 2.

Table 2. Various levels of advancement of agricultural technology included in the spreadsheet tool. Source: (Smeets *et al.* 2005).

Level of agricultural technology	Water supply	Description
Low	Rain-fed	No use of fertilizers, pesticides or improved seeds or breeds, equivalent to subsistence farming as in rural parts of e.g. Africa and Asia.
Intermediate	Rain-fed	Some use of fertilizers, pesticides, improved seeds or breeds and mechanical tools.
High	Rain-fed	Full use of all required inputs and management practices as in advanced commercial farming presently found in the USA and EU.
Very high[3]	Rain-fed	Use of a high level of technology on very suitable and suitable soils, medium level of technology on moderately suitable areas and low level on moderately and marginally suitable areas. The rationale is that it is unlikely to make economic sense to cultivate moderately and marginally suitable areas under the high technology level, or to cultivate marginally suitable areas under the medium technology level.
Very high	Rain-fed/ Irrigated	Same as a very high input system, but including the impact on irrigation on yields and areas suitable for crop production. No data were available on the areas under irrigation in this production system, only total suitable areas are.
Super high	Rain-fed/ Irrigated	A high and very high level of technology exclude the impact of future technological improvements other than implementation of the best available technologies included in the high and very high scenario. We assume that technological development can add 25% above the yield levels in a very high input system (ceteris paribus), see further (Smeets *et al.* 2004a).

The lower the level of agricultural technology, the lower the efficiency of food production, the larger the area agricultural land required to meet the demand for food and the smaller the surplus agricultural area available for bioenergy crop production or the larger the shortage of agricultural land needed for food production. In this study, the lowest level of agricultural technology and the least intensive animal production system required to generate surplus agricultural land are included (see further sections 4.1.2 and 4.2.2). The area surplus agricultural land would be higher in case higher levels of advancement of agricultural technology and/or more intensive animal productions system are being used. However, this requires a higher increase in the efficiency of food production, which is more difficult to be realised on shorter term.

We acknowledge that under present economic conditions (without strict central planning), a demand for food and bioenergy could lead to competition for various resources such as land, labour, capital, water etc. Therefore, 10% of the present agricultural land use is specifically reserved for bioenergy production, including 10% of the most suitable areas. A prerequisite remains however that the demand for food is met. Of the remaining 90% also some areas may be made available for bioenergy production in case the efficiency increases are sufficiently large as the spreadsheet tool shows. These additional surplus areas are however not the best areas, because the most productive areas are allocated to food crop production (see Smeets *et al.* for further details (Smeets *et al.* 2004c).

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[3] This level of technology is called '*mixed input system*' in the original IIASA classification, but is dubbed 'very high' production system to avoid confustion with the term mixed (animal) production system and because it is generally the more efficient than a high level of technology production system.

The calculation of the area land available for bioenergy production is carried out at a national level. In particularly in Brazil large regional differences are present with respect to land use pattern, agricultural production, income, soil quality, level urbanisation etc. Therefore, we aim at a homogenous sub-national region for further analysis. Two criteria are used to select a region:

- The present agricultural land use. Regions with large shares of agricultural land are thus potentially interesting, because of the presence of agricultural enterprises and and facilitating (agricultural) services from which the implementation of bioenergy crop production could benetif from.
- The suitability of land for crop production and the suitability of the surplus areas as calculated by the land use model.

The national surplus area agricultural land calculated by the spreadsheet tool is translated into a regional surplus area based on the share of the area agricultural land of the region in the national agricultural land. We assume that the suitability of the surplus agricultural land is the same for the case study region as for the country as a whole.

Child labour

Child labour as defined by the International Labour Organisation (ILO) includes all children below 12 years of age working in any economic activities, those aged 12 to 14 years engaged in harmful work, and all children engaged in the worst forms of child labour. According to ILO Convention 138 only light work that does not negatively affect their health and development is permitted for children between 12 to 14 years old (ILO 1973).

In both the *loose and the strict set of criteria* child labour as defined in national laws is not allowed and should therefore be prevented.

In the *loose set of criteria* costs to avoid child labour are excluded, because the prevention of child labour is considered as the responsibility of the parents, the government or society in general. Consequently, the costs of labour for the production of bioenergy, which are included in the cost calculations, are based on the costs of adult labour only. The total costs of adult labour are calculated as described in the following section.

In the *strict set of criteria* the bioenergy producer is considered responsible for the costs to prevent child labour. Two types of costs are included. First, parents are compensated for the loss of family income as a result of the prohibition of child labour. It was assumed that all children of the workers are involved in child labour, because no estimates were available on the occurrence of child labour in bioenergy crop plantations and thus to avoid an underestimation of the costs to abolish child labour. It was also assumed that only the worker of the bioenergy plantation receives compensation for the loss of income, because the other parent may not be employment at the bioenergy plantation and consequently may not receive compensation. Wages for child labour in 2015 are calculated using data on the projected increase in per capita GDP. The total costs per family are added to the labour costs of a worker. Second, parents receive money for education, so that the parents are not required to stay home and take care of the children instead of going to work, which could reduce the income of the family more than the compensation for the loss of family income due to the ban on child labour. The costs for education are analysed separately, in one of the following sections.

Data on the wages for child labour, the average number of children per family and the increase in wages to 2015 are derived from literature (CR 2004), (UNPD 2003) and (WB 2003), respectively.

Wages

The acceptance of bioenergy crop production in a region by the population in that region will (partially) depend on the economic benefits resulting from the bioenergy crop production. Wages and employment are an important component of these economic benefits (the latter issue is analysed in the following section).

Labour costs, which include wages, are a separate cost item in the bioenergy crop production cost calculations. A distinction is made between field workers and supervisors. Field workers do manual work such as ploughing, the application of fertilizers and pesticides, the harvesting and chipping of the crop (including all required tractors and harvester operations). Supervisors are required for more complicated jobs, such as supervision and administration. The wage of a supervisor is higher than that of a field worker.

The *loose set of criteria* requires that at least minimum wages are paid, because it is assumed that minimum wages ensure a minimum subsistence level. In case wages are higher than the minimum wage, existing wages are included.

Data on existing wages are taken from the LABOURSTA database (ILO 2003) or calculated based on other data. Data on minimum wages are based on literature (USILA 2002; DB 2003). Wages for the year 2015 are calculated using the wage levels in 2002 and the average annual per capita GDP growth to 2015 derived from World Bank projections (WB 2003). The total labour costs are estimated by multiplying wages by the wage to total labour cost ratio in the manufacturing industry in 2002, because no data are available for the agricultural and forestry sector. The difference in total labour costs and wages arises from costs associated to e.g. pension, health insurance, social welfare, training and wage administration (ILO 2003). No projections are available on this ratio to 2015, so this ratio is assumed constant. The inclusion of these non-wage labour costs, could lead to double counting, because the costs for education, health care are included separately. However, to avoid an underestimation of costs, this factor was included anyway.

In the *strict set of criteria* wages of the field workers are increased to the national average wage level. Wages of the supervisors are increased by the same factor. We state that average wages are fair wages, because they are ‘average’: fair remuneration levels and poverty lines are generally established in relation to the general level of material welfare in a region.

Average wages are taken from the LABOURSTA database (ILO 2003). Wages for the year 2015 are estimated using the same calculation procedure as used in the loose set of criteria.

We acknowledge that the wages calculated as described above could be below the poverty line. To check if wages are sufficient to ensure a minimum subsistence level, wages are compared to the international poverty line of 1 US $ and 2 US $ (WB 2004c) and to the nationally defined poverty line if sufficient data were available.

Employment

The *loose set of criteria* requires that the production of dedicated bioenergy crops contribute to employment. The scope of loose set of criteria is (geographically) limited to the bioenergy crop plantation thus only the direct employment effect is included, i.e. employment effects other than the employment generated at the bioenergy crop plantation are excluded. I.e. all indirect employment effects are excluded. Compliance with the loose set of criteria has no impact on the cost-supply curve, because the production of bioenergy crops by definition requires labour inputs.

The *strict set of criteria* requires that the net employment effect of the production of dedicated bioenergy crops is positive. The net employment effect is the sum of all direct and indirect employment effects. The direct effect is by definition positive. Indirect effects can be both positive (e.g. the generation of employment in the agricultural machinery producing sector, which supply agricultural equipment to the bioenergy crop plantation) and negative (e.g. the loss of employment due to the increase in efficiency of food production, which is required to generate surplus agricultural land). Ideally, the net employment effect is estimated and in case the net employment effect is negative, measures are required to compensate the loss of employment e.g. by the use of more labour intensive production systems in agriculture. Several attempts are undertaken to estimate indirect employment effects, however, due to a lack of data and suitable methodologies, no estimates of the total net employment effect could be made that were sufficiently accurate and complete to draw conclusions on. E.g. one method is Input-Ouput (IO) analysis. IO analysis can be used to estimate economy-wide (employment) effects due to direct investments in agriculture from the production of bioenergy. A table of purchase and sales transactions between sectors in the economy is used to calculate intermediate (indirect) transactions. Another method aims for an estimation of the employment effects of the increase in the efficiency of food production, using historic data on the employment in agriculture and the efficiency of food production (this methodology is further discussed in Appendix D).

Education

In the *loose set of criteria*, education is considered the responsibility of the government, the parents and society in general and not of the bioenergy crop producer. Therefore, no costs are included.

The *strict set of criteria* includes a wider definition of the responsibilities of the bioenergy producer, in which the costs of education of children from workers are included. In addition, education is also required to prevent child labour in the strict set of criteria. The costs for education are added up to the labour costs, which is a cost factor in the production of bioenergy.

The costs for education are based on the average annual costs per pupil (Matz 2002), the average number of children per family (UNPD 2003) and assuming one wage earner per family. We acknowledge that the average costs per pupil are a very crude approximation of the true costs of education.

Health care

In the *loose set of criteria* health care is considered the responsibility of the government and the workers themselves, so no additional costs are included.
In the *strict set of criteria* health case is considered the responsibility of the bioenergy producer. The costs related to health care are added up to the labour costs, which are included the calculations of the costs of bioenergy crop production. As a proxy for the costs of health care the average annual expenditures per person on health care are included (WB 2004b). The total costs per worker are based on the average number of children per family (UNPD 2003). We are aware that this approach ignores the complexity related to estimating the costs required to ensure good quality health care.

3.3 Environmental criteria

Deforestation

In both the *strict and the loose set* of criteria deforestation for the purpose of land clearing for food production or bioenergy crop production is not allowed. I.e. bioenergy crop production is only allowed on areas not under forest cover and which are not required for food production (see the criterion on competition with food production). This issue is included in the criterion related to competition with food production.

Soil erosion

Soil erosion is the loss of topsoil. Soil is naturally removed by the action of water or wind and is naturally formed by soil formation[4]. Soil erosion can be accelerated though tilling the soil or removing of the canopy cover and can become a problem if it outpaces the natural rate of soil formation. Accelerated soil erosion can result in e.g. reduced soil fertility and reduced crop production potential, eutrophication of surface water, damaged drainage networks.

The *loose set of criteria* requires that soil erosion rates are equal to or are decreased compared to the soil erosion rate of land cover the bioenergy crop production replaces. Soil erosion is analysed in two steps. First, the most important type of soil erosion and the extend and severity of soil degradation is analysed. Second, a comparison is made of the risk of soil erosion of woody bioenergy crop production compared to various other land use types, using data on the crop/vegetation and management factor included in the Universal Soil Loss Equation (USLE). The crop/vegetation and management factor is the ratio of soil loss from land under specified crop/vegetation conditions to the soil loss from land under tilled, continuous fallow conditions.

Data on the extend and severity of soil degradation are based on the Global Assessment of Human Induced Soil Degradation (GLASOD) database (LPDAAC 2003). The

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[4] Soil formation begins with the weathering (breakdown) of rock by physical processes (e.g. ice, plant roots) or chemical weathering (e.g. chemical reactions with oxygen or acids thereby dissolving rock).

GLASOD database has been criticised frequently for being crude and inaccurate and for bringing only bad news (White 2000). The authors acknowledge that the assessment was a compromise between speed of development and scientific credibility and that it partially based on a subjective assessments (Oldeman and Van Lynden in (White 2000) en UNEP 1997 in (White 2000). At this moment however, it is the only global study on soil erosion and also the critics concede that viable alternatives are difficult to produce (Thomas 1993 in (White 2000). Data required for the USLE calculations (including data on the C factor) are derived from literature, see further described in Appendix D.

The *strict set of criteria* requires in addition to the criterion in the loose set of criteria, that soil erosion rates are reduced to rate of soil formation under natural conditions. This is analysed in two steps. First, the rate of soil erosion is calculated. Soil erosion rates are influenced by both the natural circumstances (soil type, rain-fall, slope gradient and length) and the land use type and management (the extremes being natural forest cover and the production of annual crops). These factors are included in the Universal Soil Loss Equation (USLE) originally proposed by Wischmeier and Smith (Wischmeier *et al.* 1965, 1978). The USLE is an empirically derived method to calculate soil erosion rates due to water erosion (which is the most important form of soil erosion) expressed in ton topsoil lost ha^{-1} y^{-1}. See Appendix D for a further explanation of the USLE. Second, in case erosion rates are above the natural rate of soil formation, erosion prevention measures are required to reduce the rate of soil erosion. Erosion control measures are e.g. the construction of rainfall runoff detention basins, slope grade control structures, contour slope cropping and ploughing, ridge tillage or the use of cover crops.

The natural rate of soil formation (from chemical or physical weathering of rock particles into smaller pieces or into various chemical substances) is 1 t ha^{-1} y^{-1}[5] (OTA 1993). No data are available on the regional variation. For comparison: the average rate of soil erosion in the US is 7.7 ha^{-1} y^{-1} in 1997 (USDA 2000). Data on the average costs of erosion prevention measures in the U.S.A. are estimated at 2.3 € t^{-1} reduced soil loss for a reduction of soil erosion from 17 to 1 t ha^{-1} y^{-1} (Pimentel *et al.* 1995). Detailed data on the costs of the implementation of erosion control technologies in terms of man-hours, tractor hours per technology were not available.

Depletion of fresh water resources

In both the *loose and strict set of criteria* the production of bioenergy crops is not allowed to result in a depletion of fresh water resources (groundwater and surface water). In this report the focus is on groundwater, because the direct use of surface water by bioenergy crops is limited. The water use of trees can be avoided in many ways, e.g. by reducing the soil disturbance to reduce surface evaporation, by increasing ground cover which avoid runoff, by placing hedges to reduce the wind speed and thereby water use, by optimal species selection and by cultivating tree crops with

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[5] 1 t ha^{-1} y^{-1} is the rate of soil formation under natural conditions (OTA 1993). Under cultivation the rate of soil formation increases somewhat, but data on the increase of land under SRWC production are not available. Therefore, the rate of soil formation under natural conditions is used in this report. The rate of soil formation of 1 t ha^{-1} y^{-1} is substantially lower than the 2 to 11 t ha^{-1} y^{-1}, which is used as an acceptable long-term rate of soil erosion by the United States Department of Agriculture in which crop yields are not affected.

undergrowth. However no costs are included in the loose and the strict set of criteria, because no data could be found on the costs to limit the water use of SRWC's. Irrigation as a way to avoid (temporary) water shortages under rain-fed conditions as further discussed in Box 1. Therefore, yield levels included in this study are based on rain-fed conditions.

Box 1. Irrigation and short rotation forestry

Irrigation is not included as a source of water because of two reasons. First, irrigation could lead to salinisation, water logging and decreasing groundwater tables. Second, the establishment of irrigation infrastructure is unlikely (economically) profitable for most areas. E.g. in Latin America irrigation development costs are estimated at 3021 € ha^{-1} and for Europe 3652 € ha^{-1} (Jones 1995). Data on costs of operation and maintenance of irrigation facilities in various Asian countries are estimated at 18 € ha^{-1} maximum. The interest rate is set at 7% and a lifetime of 30 years is assumed. Costs for water are excluded, because water used for irrigation is often free of charge (OECD 1999). Based on a market price of 1.5 € GJ, yields would have to increase at least by 11 odt ha^{-1} y^{-1} in Latin America and by 13 odt ha^{-1} y^{-1} in Ukraine to compensate for the increase in costs due to the application of irrigation. For comparison the eucalyptus yield under rain-fed production in Brazil is 5 to 23 odt ha^{-1} y^{-1} and the rain-fed poplar yield under rain-fed production in Ukraine is 2 to 16 odt ha^{-1} y^{-1} [6]. To what extend yields could increase as a result of the application of irrigation depends to what extend water is growth limiting which in turn depends on regional conditions and could not be calculated. However, compared to the range in rain-fed SRWC yields in Brazil and Ukraine, we estimate that the required increase in yield to compensate for the increase in costs for application is unlikely high for most areas. Nonetheless, dependant on the costs and benefits of irrigation, irrigation could be economically profitable for some areas.

Instead, we analyse the water use of SRWC's in two steps, in order to indicate the risk of a depletion of ground water.

First, the impact of energy crops on the hydrology of an area is judged in relation to the land cover that is replaced. The relative demand for water of bioenergy crops is compared to various land cover types based on the crop and vegetation specific water demand factor (the crop evapotranspiration[7] coefficient or K_c[8]) The K_c is the ratio between the actual non-water limited water demand to the reference evapotranspiration (ET_0). ET_0 is the evapotranspiration for a well-managed (disease free, well-fertilized) hypothetical grass species grow in large fields and for which water is abundantly available. Note that the comparison based on the K_c, indicates the relative difference in water demand under non-water limited conditions, rather than the actual water use.

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[6] Both the costs of irrigation development and the reveneus of irrigation developments (the increase in yield) is converted into present value following the argumentation is section 3.1.

[7] Evaporation is the process of vaporisation of liquid water from surfaces as lakes, rivers, pavements, soils and wet vegetation. Transpiration is the process of vaporisation of water through leaf stomata.

[8] Crop evapotranspiration differs from ET_0 because of differences in crop height, albedo (reflectance) of the crop-soil surface, canopy resistance and evaporation from the exposed soil. The K_c factor is largely independent of climate data and can be used across climate zones and soil types. K_c factors vary with growth stage and are empirically derived.

Second, a water balance is used to estimate the potential water shortage or surplus is calculated, defined as the evapotranspiration under not water limiting conditions minus rainfall (in mm month^{-1} or mm y^{-1}). The total rainfall is divided into effective and non-effective. Non-effective rainfall is rainfall lost from the upper soil layer through deep percolation or runoff. Non-effective rainfall can be used by SRWC's who have developed a sufficiently deep rooting system to allow the uptake of groundwater. In case the annual groundwater extraction exceeds the non-effective rainfall, the groundwater table will decrease (assuming there is not additional influx of groundwater). In case the annual groundwater extraction is below the non-effective rainfall, the groundwater table could decrease, dependant on the rate of groundwater drainage to rivers, lakes and oceans. Effective rainfall is available for crop production in the upper soil layers. Three water shortage/surplus categories are composed that vary with respect to the risk of groundwater depletion.

- High risk of groundwater depletion. The evapotranspiration is higher than the total rainfall. If so, than the total rainfall is a limiting factor for crop growth, which could lead to a depletion of ground water resources in case the SRWC's are capable of groundwater uptake.
- Medium risk of groundwater depletion. The evapotranspiration is lower than the total rainfall, but higher than the effective rainfall. In such case, the use of non-effective rainfall from groundwater resources could avoid water stress. However, there is a risk of groundwater depletion, dependant on the rate of groundwater drainage to river, lakes and oceans.
- Low risk of groundwater depletion. In case the annual groundwater extraction is below the effective rainfall, no net use is made of the groundwater resources.

Note that the comparision would change completely in case plants would prefer to use easily accessible water in the upper soil levels above groundwater.

Data on the crop evapotranspiration coefficient (K_c) are derived from literature (FAO 1998a, 2000; NMCC 2001). The reference evapotranspiration is calculated using the CROPWAT software tool of the FAO (FAO 1998a). Climate data are derived from various databases (FAO 1994; IPCC-DCC 2004; Sperling 2004).

Nutrient losses and soil nutrient depletion

Nutrient depletion may trigger a downward spiral of reduced tree growth, lower ground leaf cover and loss of soil organic matter, higher rates of erosion, loss of fertile topsoil and reduced tree growth. Nutrient losses could lead to an increase of certain species at the expense of other species (eutrophication) and is also linked to a variety of direct and indirect toxic effects. Nutrient losses include all nutrient emissions to the soil, air and water, which are not used for crop growth. Nutrient depletion and nutrient losses are closely linked processes: depletion can be avoided by the application of fertilizers, while the application of fertilizer can lead to nutrient losses.

The *loose set of criteria* requires that the application of fertilizers is sufficiently high to avoid soil nutrient depletion. The avoidance of soil depletion is given priority above soil nutrient depletion, because of the in potential severe and irreversible direct consequences for the bioenergy crop plantation.

The input of fertilizers needed to avoid soil nutrient depletion is calculated by means of a nutrient balance. A nutrient balance is a comparison of the input and output of nutrients (in kg ha^{-1} y^{-1}). The input of fertilizers is calculated based on the nutrient content of the harvested biomass, the yield and the nutrient recovery coefficient (the portion of the applied fertilizer available for plants). Note that in reality, the fertilizer application rates are chosen so that profit of maximised, instead of soil depletion is minimised. Therefore, the data should be regarded as a rough approximation. The costs of fertilizer application are included in the cost calculations. Inputs from nitrogen fixation, atmospheric deposition and planting material are excluded, because of the limited contribution to the total input. The most important output is the removal of biomass. The remaining is lost to the soil (accumulation), air (voltalisation and denitrification) or water (nutrient leaching). These calculations are only crude approximations, because actual nutrient losses are a result of e.g. soil type, climate and the type of fertilizer.

The nutrient balance is based on the methodology and data proposed by Biewinga and Van der Bijl (Biewinga *et al.* 1996) and discussed in detail in Appendix J. Data on the nutrient content of woody bioenergy crops are based on literature. Data on fertilizer prices are derived from the FAOSTAT database (FAO 2003a). Data on the nutrient recovery fraction are derived from literature (e.g. (McLaughlin *et al.* 1987; Biewinga and Van der Bijl 1996; Rogner 2000; Lewandowski 2004); see further Appendix J).

The *strict set of criteria* requires that nutrient losses are prevented as far as reasonably is achievable and soil nutrient depletion is prevented. The loss of nutrients can be reduced in by the harvesting of the biomass when the nutrient content is the lowest, by allowing the decomposition on the field of nutrient rich parts of the plant (twigs, leaves, branches), by using nitrogen-fixing species and by the use of slow-release fertilizers and by increasing the application of fertilizers which increases the nutrient recovery coefficient. A more frequent application results in an increase in the labour and machinery costs and a decrease in the costs of fertilizers.

Data on the application fertilizer application frequency and the impact on the soil nutrient recovery factor are derived from literature (e.g. (Stape *et al.* 2004). The fertilizer application rate is increased from two times per rotation cycle to once per year, for further details see Appendix J. The resulting impact on labour and machinery costs is calculated using the cost assessment described in section 3.1 and Appendix B.

Pollution from agricultural chemicals

To protect crops from weeds, plagues and diseases, the use of agricultural chemicals is common practice in agriculture around the world, including SRWC plantations. The use of these (toxic) chemicals has various environmental impacts as a result of losses to soil, air and water.

In the *loose set of criteria* no requirements are included on the use of agricultural chemicals, because no criterion could be formulated which could be operationalised, other than the strict set of criteria.

The *strict set of criteria* requires that pollution from agricultural chemicals is avoided as far as reasonably is achievable.

However, first we analyse the pollution from agricultural chemicals compared to the original agricultural land use to give an impression of the impact of woody bioenergy crop production compared to the reference agricultural land use. The relative toxicity of the use of agricultural chemicals (herbicides, fungicides, insecticides and other pesticides) for the production of bioenergy crops are based on data found in literature. Figures on the toxicity of various chemicals are based on the amount of pesticide applied and a score for harmfulness that accounts for the toxicity (Biewinga and Van der Bijl 1996). Data are given for actual practice and attainable practice. The latter includes the impact of mechanical weed control, optimised cultivar selection and crop rotation and the use of less harmful pesticides.

The use of herbicides can be reduced by biological control and high planting densities of more than 10000 plants per hectare, which reduce light intensity underneath the canopy and thereby weed growth or by means of mechanical and manual weed control. The use of pesticides, fungicides and herbicides can be avoided by various prevention management strategies (planting resistant clones, spacing, avoiding injuries to trees and removing infected trees). However, large-scale monculture bioenergy crop production is likely to increase the susceptibility for diseases and pests, which may increase the need for pesticides.

Active weed control is however essential for the productivity of SRWC plantations. In this study, we assume that the costs of cultivar selection are covered by the costs for technical assistance and that the additional costs of the use of less harmful pesticides are zero. Only the additional costs related to the replacement of the use of herbicides by manual and mechanical weed control are included: the costs related to the use of pesticides decrease to zero, but the costs of labour and machinery for mechanical weeding increase.

Chemical weed control is effective for 6 weeks to 12 weeks (McNabb 1994), mechanical weed control is effective for 10 days to 2 weeks (IEA 1997). We use an average of 9 weeks for chemical weed control and 12 days for mechanical weed control. The frequency of mechanical and manual weeding is increased by a factor 6 and chemical weed control is no longer applied.

Loss of biodiversity

Various studies have been published on the biodiversity in SRWC plantations (e.g. (Christian *et al.* 1998; Tolbert *et al.* 1998). Most studies are based on field observations or review other studies. We summarize some of the conclusions here. These conclusions are based on poplar plantations, but may also be valid for eucalyptus. These studies indicate that biodiversity is higher than in row crops, lower than in forests, but equal to grasslands (Tolbert and Wright 1998). Obviously, the specific characteristics of the plantation (e.g. height and leaf cover), the specific habitat requirements of the species (e.g. leaf cover protection) and the presence of other land use types (e.g. forests and arable land) determine the dynamics of biodiversity changes. E.g. open-habitat species were found to be present during the first years after plantation establishment. After canopy closure, bird species are found to use plantations the same as natural forests. Further, heterogeneous patches due to failed clones and the abundance of weeds showed increased small mammal biodiversity. Note that in commercial plantations, trees of various age classes are present, which allows the existence of diverse species.

In the *loose and the strict set of criteria* biodiversity should be protected. Methods to improve or create suitable habitats for wildlife include the placement of shelterbelts, windbreaks, fencerows, artificial nesting structures and for micro organisms the leaving be of dead trees and a reduction of the use of agricultural chemicals. Disruption of the biodiversity from harvesting could be prevented by chosen the harvesting cycle so that a continuous range of ages for habitat is present. The costs of these activities are difficult to estimate and the data on the correlation between these various activities on biodiversity are virtually not existent. Therefore, we use a much cruder approach based on nature conservation targets. At the global level, 10% to 20% of the total land, consisting of a representative selection of the range in ecosystems found on the world, is required for nature conservation (WBGU 2001). In the loose and strict set of criteria, 10% and 20%, respectively, of the plantation area is allocated to nature conservation/biodiversity protection[9].

We acknowledge that the protection of 10% or 20% of the total may be insufficient for the protection of biodiversity (Soulé *et al.* 1998) and that the inclusion of these criteria does not indicate that bioenergy crop production can refrain from best practice management. However, it is the only (indirect) valuation of biodiversity protection we could find in literature, to date.

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[9] In Brazil, environmental regulations require that 25% of the plantation area is left in natural vegatation to help to preserve biodiversity and provide other ecosystems functions (Kartha *et al.* 2000).

4. Results

In sections 4.1 and 4.2 results are presented for Brazil and Ukraine, respectively. Each section starts with a further demarcation of the case study region (section 4.1.1 and 4.2.1), an analysis of the availability of land for bioenergy crop production (section 4.1.2 and 4.2.2), a description of the bioenergy crop production system in terms of yield levels and rotation cycle (section 4.1.3 and 4.2.3) and the impact of the various sustainability criteria in terms of production costs (section 4.1.4, 4.1.5 and 4.2.4 and 4.2.5).

4.1 Brazil

4.1.1 Demarcation of case study region

The focus in this study is on the Atlantic Forest region situated on the east coast as shown in figure 2. At this moment, only some 10% of the original Atlantic Forest remains as a result of industrial and agricultural development. The main drivers for this expansion are economic development and a subsequent increase in demand for land for e.g. infrastructure and food and fibre production. Saturated markets and low prices (e.g. in the case of coffee) and protectionism of the traditional markets of industrialised countries (e.g. in the case of sugar) limit the export of conventional agricultural commodities by Brazil. The low prices have resulted in a continued pressure to increase agricultural output through expanding the area under production, particularly for small farmers. To aggravate this situation, various outlook studies indicate that food prices will remain stable or decrease during coming decades (e.g. (IFPRI 2001), which could limit the potential of the agricultural sector to generate income and jobs. Bioenergy plantations may provide a new or more stable source of income for farmers, which could reduce the pressure to increase the agricultural output by expansion of the area under production. After all, the potential market for (bio)energy is enormous; the developing regions have a competitive advantage due to low labour costs and land costs because the trade of bioenergy (biotrade) is presently a free and unregulated market.

In this study the focus is on the southern part of the Atlantic Forest region, because this region is one of the two main agricultural production centres in Brazil (figure 2) and the availability of agricultural infrastructure and services this area make this area suitable for bioenergy crop farming. Rio Grande do Sul has a relatively good transportation infrastructure, a developed agricultural sector and a relatively high level of education compared to other states in Brazil. The two dominant agricultural production systems in this region are the intensive mixed and the cereal livestock production system[10].

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[10] *'The intensive mixed agricultural production system represents the haertland of Brazilian agriculture and occupies an estimated 81 million ha with an agricultural population of almost 10 million. There are approximately 13 million ha of cultivated land, of which about eight percent is irrigated. Coffee, horticulture and fruit are important products. Poverty levels are relatively low in this system. The Campos represent a gradation in moisture and often soil quality, from the intensive system described above. Covering just over 100 million ha in Southern Brazil and Northern Uruguay, the cereals livestock production system on these areas has an estimated rural population of about seven million, and is strongly oriented to livestock and rice production. There are an estimated 18 million ha of cultivated land, of which 10 percent is irrigated. Poverty is low to moderate'* (quoted and adjusted from (Dixon *et al.* 2001).

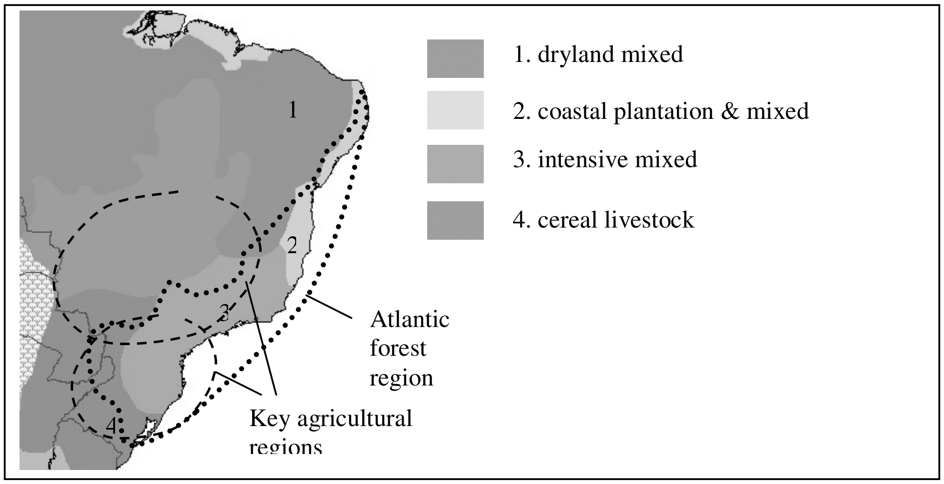

Figure 2. The Atlantic Forest Region in Brazil and the dominant agricultural production systems and centres. Source: (Dixon *et al.* 2001; LPDAAC 2003).

4.1.2 Land availability for bioenergy crop production

Historic land use

Brazil covers in total 855 million hectares of land. Figure 3 shows the land use pattern of Brazil from 1961 to 1998.

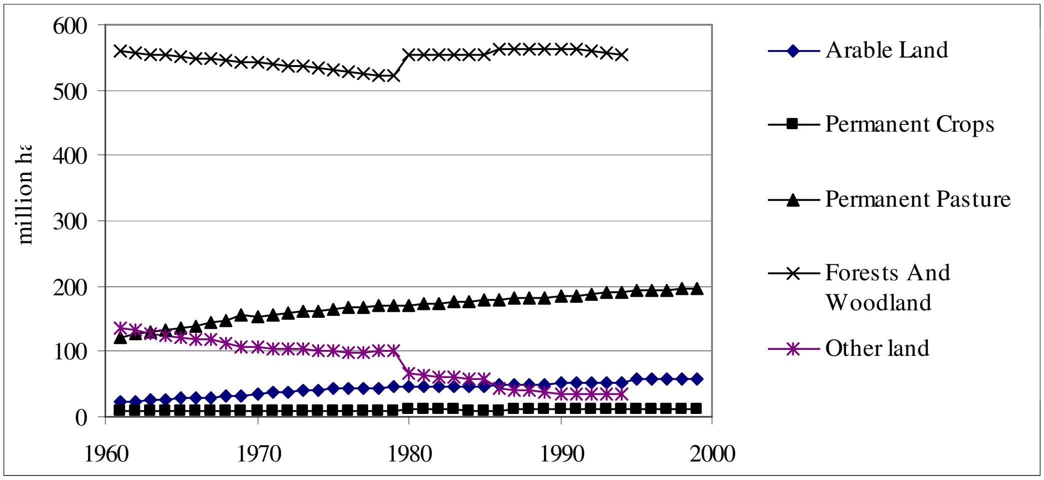

Figure 3. Land use in Brazil from 1961 to 1998[11]. Source: (FAO 2002b). The FAO stopped reporting data on forests and woodland starting from 1995.

According to the FAO's Forest Resources Assessment 2000 report, the forest cover in Brazil was 64% in 2000, the annual rate of deforestation is 0.4% (FAO 2001). The forest area has decreased steadily during the previous decades. Note that the abrupt change in forest area (and area other land) in 1980 and 1986 are (likely) the result of a change of the definition of forest area. The primary cause for deforestation is clearing

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[11] The category Other land includes, among other land use types, build-up land, whichs accounts for 5.8 million hectares (FAO 2000), equal to 0.7% of the total land surface or Brazil.

for agriculture. Until 1985, the government provided financial incentives for expansion of agricultural land, mainly pastures, at the expense of forests (César in (FAO 2003b). As a result the area permanent pasture has increased from 122 million hectares in 1961 to 196 million hectares in 1999. The area arable land increased in the same period from 22 million hectares to 58 million hectares. The growth of the area arable land is mainly caused by crops for export, such as cocoa, cotton, rice, sugarcane, oranges, corn, soybean and wheat, mainly cause the growth in area arable land. Particularly the area soybean increased rapidly, from 0.2 million hectares in 1961 to 13 million hectares in 1999 (FAO 2002b). The area under production and yields of traditional crops such as manioc (cassava), bananas and coffee remained stable or decreased during the last decades. The growth in agricultural production allowed Brazil to become one of the world's largest soybean producers and exporters. It also allowed the substitution of sugarcane alcohol for imported oil (Schnepf *et al.* 2001).

Land resources

Figure 4 shows a comparison of the present agricultural land use (arable land and permanent pastures) and the suitability for crop production. Appendix G shows a map of the suitability for crop production in Brazil.

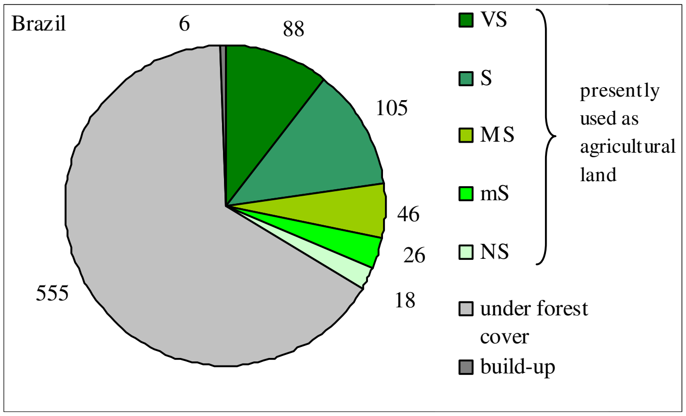

Figure 4. Present agricultural land use in Brazil and the suitability for crop production[12]. VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable and NS = not suitable. Sources: (FAO 2000, 2002b).

A comparison of the areas suitable for crop production under forest cover and the total agricultural area show that Brazil has the potential to double the area arable land. We do not want to imply that the expansion of the areas agricultural land at the expense of forests is a sustainable option. However, the socio-economic and institutional (land tenure, etc) conditions prevailing in many developing countries cause that increases in output are obtained mainly through land expansion, where the physical potential for doing so exists (FAO 2003b). The expansion of the area agricultural land, particularly

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[12] The classification of the areas very suitable to not suitable are based on a crop growth model. An area classified as very suitable is defined as the area where at least one crop (of the 19 included in the crop growth model included in the database) has a yield of 80% or more of the maximum constraint free yield (MCFY; temperature and radiation limited yield). For areas classified as suitable the yield is between 60-80% of the MCFY. The data are based on a rain-fed mixed production system as defined in section 3.2.

the *cerrado* (savannah) areas of the Brazilian Central Plateau, is a clear example of this.

In total some 265 million hectares is used as agricultural land. Of this 265 million hectares 195 million hectares is permanent pasture area (74%) and 70 million hectares (26%) is allocated to crop production. Figure 4 shows that most of the land area not under forest cover consists of land suitable for crop production.

Future land use and land availability for bioenergy crop production

The two most important drivers that determine the demand for food and thus indirectly land use patterns are per capita consumption and population growth. Per capita consumption has increased during the last decades. Presently, Brazil reached fairly high levels of consumption of 3002 kcal per capita per day on average in 2001 (FAO 2002b). Most of this increase is due to the increasing consumption of meat, which increased from 28 kg per capita in 1961 to 74 kg per capita or 320 kcal per capita per day in 2001. Despite the spectacular increases in average consumption, 10% of the population or 17 million people in Brazil are undernourished (UNEP 2003), particularly in the North East of the country. The prime cause of under nourishment in Brazil is not a lack of food or agricultural land in general, but poverty. In this respect it is perhaps interesting to point to the historical very unequal income distribution in Brazil, one of the highest in the world. The attainment of fairly high levels of consumption results is a deceleration of consumption growth in the future compared the growth rates of the past decades. In 2015 the average consumption is projected to increase some 5% based on a daily intake of kcal. Another important driver is population growth. Population growth is also expected to slow down and possibly even decrease after 2030 dependant on the scenario as indicated in figure 5.

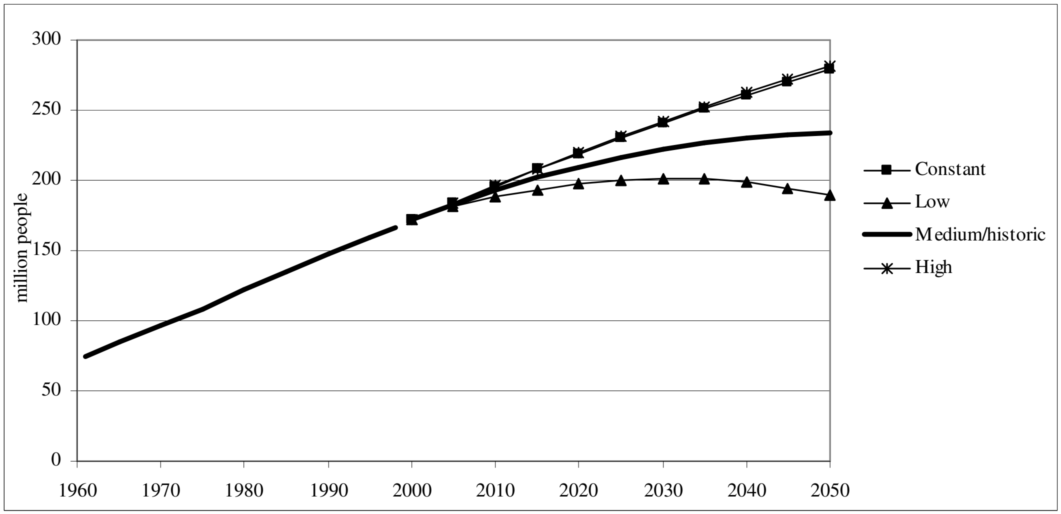

Figure 5. Historic and projected population in Brazil 1961 to 2050 in various scenarios (high, medium and low and constant fertility). Source: (UNPD 2003)

Figure 5 shows that the total range in projections is considerable, indicating the present relatively high birth rates and the uncertainty about the decrease. This uncertainty is however much smaller for the time frame considered in this study (2015) compared to range in 2050.

As a result of the increasing population and consumption to 2015 in combination with the availability of large areas suitable and relatively accessible scrubland (*cerrados*), the agricultural area is projected to expand at least in the coming decade and beyond (Schnepf *et al.* 2001). According to the FAO, the area arable land in Brazil is projected to increase by 18% to 2015 and by 37% in 2030 compared to 1998 (FAO 2003b). For pastures no projections are given, but the general suitability of the areas permanent pasture for the production (fodder)crops *could* result in an expansion of the area arable at the expense of permanent pastures.

However, the increase in agricultural land use can be avoided or turned into a surplus agricultural land use if yields increase much faster than projected by the FAO. Results from our land use model applied for Brazil (described in Smeets et al. (2004) indicate that there is considerable potential to increase production through higher efficiencies, dependant on the level of advancement of agricultural technology applied. Table 3 shows the average increase in yields and production efficiency for Brazil based on various levels of advancement of agricultural technology and including the projected demand for crops in 2015. The data indicate the increase factor in yield or efficiency (1998=1). Despite the potential of the natural resources in Brazil to sustain much higher yields than presently and the deceleration of consumption growth, the area agricultural land is likely not going to decrease.

Table 3a. Average potential increase in crop yields in 2015 compared to 1998 in Brazil based on various levels of technology.

(1998=1) Crop	Average of all crops	Cereals	Roots and tubers	Sugar crops	Pulses	Oilcrops
Level of technology						
Mixed, rain-fed and/or irrigated	3.6	3.5	2.9	3.9	5.7	1.9
Mixed, rain-fed	3.1	3.4	1.3	3.6	5.3	1.7
High, rain-fed	2.9	3.0	2.0	3.6	4.2	1.7
Intermediate, rain-fed	2.2	2.4	1.3	2.7	3.5	1.1

Table 3b. Increase in feed conversion efficiency in 2015 in Brazil based on various levels of technology.

(1998=1) Animal product	Bovine meat	Milk	Pig meat	Poultry meat and eggs
High feed conversion efficiency	4.5	2.7	1.1	1.3
Intermediate feed conversion efficiency	2.1	1.6	1.0	1.2

The data show that Brazil has a considerable potential to increase yields, up to a factor between a factor 2.2 on average in an intermediate input system up to 3.6 in a mixed, rain-fed/irrigated production system. Particularly the yields of cereals, sugar crops and pulses are presently well below what is attainable given the climatological and soil conditions. Note that due to various methodological uncertainties and uncertainty in the data, the increases should be considered as rough indicators. The data are in line with data from the FAO that indicate that the average wheat yield is 1.8 ton per hectare, while the average attainable yield is 3.3 ton per hectare, with a variation of 3.3 to 4.5 ton per ha dependant on soil type and climatological conditions (FAO 2003b).

The potential to increase the efficiency in the animal production system is also considerable. The largest efficiency gains can be reached in the bovine meat production and milk production sector, with efficiency gains of a factor 1.5 to 4.2. In Latin America some 56% of the bovine meat comes from pastoral production systems. The bulk of the feed in a pastoral production system comes from permanent pastures (grazing). Grazing is however an inefficient way of feed collection, resulting in low feed conversion efficiencies compared to more intensive production systems. E.g. a maximum feed conversion efficiency in a mixed production systems is around 15 kg dm per kg bovine meat, feed conversion efficiencies in a pastoral (grazing) production system has a maximum efficiency of around 35 kg dm feed intake per kg meat (Bouwman *et al.* 2003). Production systems for pig meat and poultry are more uniform throughout the world since these are mainly based on concentrated feed and potential increases in efficiency are consequently less, between a factor 1 to 1.3 for Brazil.

The area available for bioenergy production is assumed to be at least 10% of the present agricultural land use as described in section 3.3. Of the remaining 90% some areas may be available for bioenergy production, if the chosen level of agricultural technology results in surplus agricultural land not needed for food production. The higher the level of agricultural technology, the larger the surplus agricultural area available for bioenergy crop production. Data are shown in table 4.

Table 4. Potential surplus agricultural land in 2015 in Brazil based on various levels of advancement of agricultural technology (million ha).

Level of technology	VS	S	MS	mS	NS	TOTAL
Mixed, rain-fed and/or irrigated	50	53	30	13	2	148
Mixed, rain-fed	48	53	25	13	2	140
High, rain-fed	1	45	53	30	13	142
Intermediate, rain-fed	13	23	8	3	7	54

In case a low level of technology is applied than food shortages occur and results are therefore excluded. The total increase in yields and efficiency results in a total decrease of the area not under forest cover or build-up land by 51%, 49%, 50% and 19% in a mixed (rain-fed/irrigated), mixed (rain-fed), high and intermediate production system respectively. These data include the 10% specifically allocated to bioenergy crop production. In case a low level of technology is used, food shortages occur. These percentages correspond with a surplus area of 148 million hectares in a mixed (rain-fed/irrigated) to 54 million hectares in an intermediate production system. The latter figure is included in this study. The difference between a mixed, rain-fed and a mixed, rain-fed and/or irrigated production system is limited, because the suitability is defined as the percentage of the maximum constraint free yield, which is dependant on the level of technology. I.e. the average yield level in VS areas in a mixed, rain-fed system is lower than the average yield in VS areas in a mixed, rain-fed production system is lower than the average yield in a VS areas in a rain-fed and/or irrigated system

The results clearly show that the natural resources such as land and water that are presently used are capable of supplying much more food than presently if more efficient management systems are applied. The potential figures are calculated for Brazil as a whole. In this study the focus is on south Brazil, so the surplus areas are translated into regional data as described in section 3.3.

In this study we use the lowest figure of 19% (based on a medium level of technology), which requires the lowest increase in efficiency considered here, which seams more feasible on the shorter term. The 19% equals a surplus of 3.3 million hectares in South Brazil. Figure 6 shows the present land use and the land suitability profile of the potential surplus agricultural land.

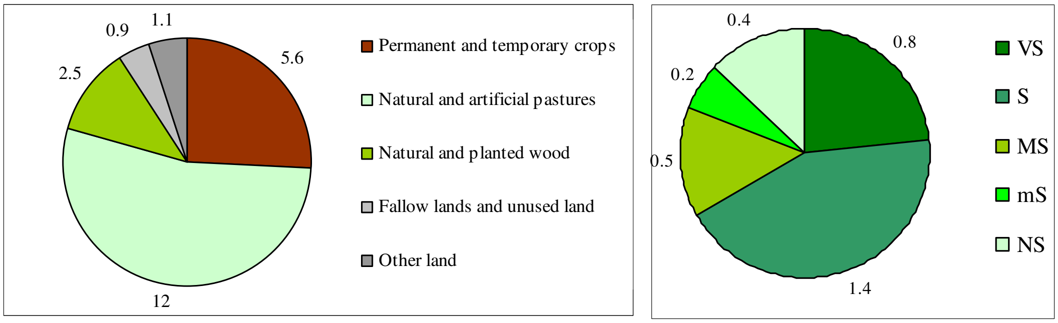

Figure 6. Present land use in Rio Grande do Sul (left) and the suitability profile of the potential surplus agricultural land (right).

Figure 6 shows that present land use and most important agricultural crops in Rio Grande do Sol. More than half of the land is classified as permanent pastures; permanent and temporary crops mainly occupy the remaining. The most important crops are soybeans, maize, rice and wheat.

4.1.3 Eucalyptus yields

Existing yields for high input eucalyptus plantations in Brazil are ca. 22 oven dry ton (odt) ha^{-1} y^{-1} (IEA 1997). We assumed that this yield level is representative for suitable (S) areas in south Brazil and calculated yields for other land suitability classes based on the difference in percentage of the maximum constraint free yield of each land suitability class[13]. The calculated yield levels range between 0 to 29 odt ha^{-1} y^{-1}, dependant on the land suitability. Table 5 shows various yield levels expressed in oven dry ton (odt) ha^{-1} y^{-1}. The rotation cycle is set at 7 years, which is the most commonly used plantation rotation cycle in Brazil (IEA 1997) and a plantation lifetime of 21 years.

Table 5. Yield of eucalyptus short rotation bioenergy crops in Brazil for various land suitability classes (odt ha^{-1} y^{-1}). Sources: (IEA 1997) (FAO 2000), own calculations.

	VS	S	MS	mS	VmS	NS
Brazil	29	22	16	10	5	0

The (range in) yield in table 5 levels could be underestimated, because yields range between 8-10 odt ha^{-1} y^{-1} in less intensive management and poorer sites, up to 41 m^3 to 58 m^3 in very productive plots (IEA 1997).

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[13] Yield levels are estimated for five land suitability classes, which are classified based on the percentage of the maximum constraint free yield (MCFY; (FAO 2000). The MCFY is determined by the temperature and radiation regime. The five land suitability classes are: very suitable (VS) 80–100% of the MCFY, suitable (S) 60–80%, moderately suitable (MS) 40–60%, marginally suitable (mS) 20–40%, very marginally suitable (VmS) 5–20%, not suitable (NS) 0-5%. Yields for NS areas are not given, because these areas are regarded as economically unattractive for bioenergy crop production.

4.1.4 Socioeconomic criteria

Child labour

In Brazil child labour is not allowed under the age of 16; only trainees can be employed at the age of 14 or above. Despite these regulations, child labour is widespread. Data on child labour in Brazil found in literature vary significantly as a result of differences in the definition of child labour and uncertainty in estimates. The total number of working children aged 14 or below decreased from 3 million in 1999 to 2.2 million in 2002 (USDS 2003a) or 12% to 6.5% of the total number of children in this age group. Data on the occurrence of child labour in various age classes is uncertain, but according to the United States Department of State 0.6 million children of 5 to 9 years works in 1999 (USDS 1999). Child labour is particularly prevalent in the northeast; although in Rio Grande do Sul child labour is occurring in e.g. the tobacco production and shoe industry.

In the *strict set of criteria* the wage of the workers on the bioenergy plantation is increased by the average wage of child labour to reduce the necessity of income from child labour. The average wage of children is ca. 3.4 € per week in the sugar cane industry and ca. 2.3 € per week for fruit picking (CR 2004), while roughly half of the children receive no payment for their work (USDS 2003a). To avoid an underestimation of the costs to eradicate child labour, a wage of 3.4 € per week was included. Further, this figure was increased by the average increase in per capita GDP to 2015 (WB 2003). The costs for the compensation for the loss of family income in 2015 is 0.25 € h^{-1} (based on an average of 2.1 children per family (UNPD 2003), an average 44 hour working week (ILO 2003) and one wage earner per family). Second, the cost of education of children is included to promote education and allow parents to go to work. The costs of education are analysed separately, because education is also a separate sustainability criterion.

Wages

Input data for the calculation of wages and labour costs are shown in table 6. The wage of a field worker and supervisor in 2002 was 0.9 $€_{2002}$ h^{-1} (ILO 2003). The wage of a supervisor is calculated at 2.4 € h^{-1} by multiplying the wage of a field worker and the ratio of supervisor to field worker ratio in Brazil, because no national data are available. The minimum wage in Brazil in 2002 was 0.5 € h^{-1} (USILA 2002).

Table 6. Input data for the calculation of wages and labour costs in Brazil in 2015.

Parameter	Value	Unit	Source
Field worker	0.9	$€_{2002}$ h^{-1}	(ILO 2003)
Supervisor	2.4	$€_{2002}$ h^{-1}	(ILO 2003)
Ratio average wage to field worker wage	2.6	dimensionless	(ILO 2003)
Labour costs to wages ratio[14]	1.6	dimensionless	(ILO 2003)
GDP growth rate	2.6[15]	% y^{-1} (2005-2015)	(WB 2003)

Existing wages are higher than the minimum wage, thus existing wages comply with the *loose set of criteria.* The total labour costs in 2015 are calculated at 2.0 € h^{-1} and 5.5

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[14] Unweighed average of the labour cost to wages of all sectors.

[15] Average of Latin America.

€ h^{-1}, for a field worker and supervisor, respectively. For a field worker this equals a wage of more than 10 US $ day^{-1} in 2015, which is above the international poverty lines of both 1 US € day^{-1} and 2 US $ day^{-1}(WB 2004d). Note that this comparison is however not entirely correct, due to differences in base year and definition. For comparison: in 2001 8.2% of the population lives below the poverty line of 1 US $ day^{-1}and 22% below the international poverty line of 2 US $ day^{-1}(WB 2004d).

In the *strict set of criteria* wages of both field workers and supervisors are increased by a factor 2.6, which represent the ratio between the average wage and the wage of a field worker. The total labour costs in 2015 are calculated at 5.4 € h^{-1} and 15 € h^{-1}, for a field worker and supervisor, respectively.

Employment

The *loose set of criteria* requires that bioenergy crop production contribute to the employment (excluding indirect effects). In this section the contribution is calculated. For each of the activities required for the growing (ploughing, planting, fencing, fertilisation, weeding, pest and disease control) and harvesting and processing of eucalyptus (harvesting, chipping and transportation to the border of the plantation) and overhead (technical assistance and administration) labour requirements in terms of h t^{-1} or h ha y^{-1} are included. Data are derived from literature (e.g. (WSRG 1994; IEA 1997; Tuskan 2000; Van den Broek *et al.* 2000a; Faundez 2003); detailed data and sources are presented in Appendix B.

Figure 7 shows the total labour requirement of eucalyptus production for various land suitability classes.

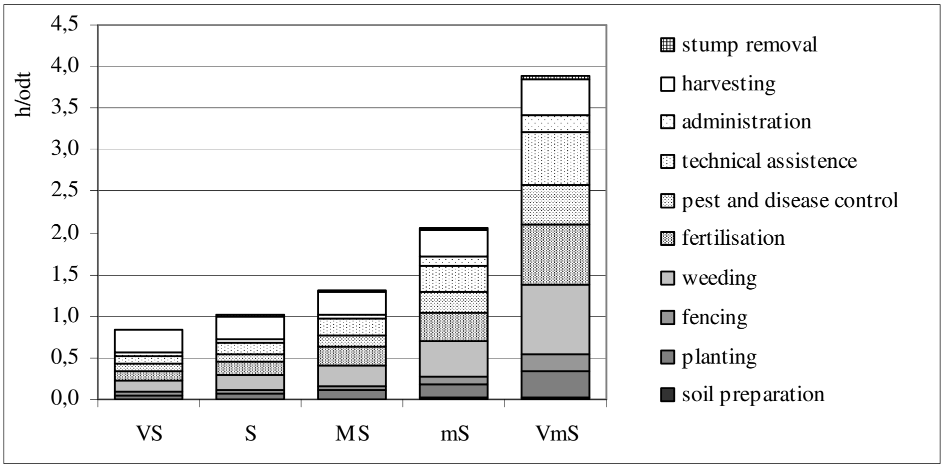


Figure 7. Total labour input for the production and harvesting of eucalyptus (h odt^{-1}). VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable and NS = not suitable. Sources: various, see Appendix B.

The labour input ranges roughly between 0.8 h odt^{-1} to 3.8 h odt^{-1}, dependant on the land suitability class (the yield level). Costs can be divided into fixed costs and variable costs. The first category is independent of the yield level (is fixed in terms of h ha^{-1}); the latter category increases as a result of lower yield levels. The labour input (in h odt^{-1}) is higher in VS areas compared to mS areas.

In reality, the labour input is dependant on the price of labour compared to the price of machinery and other non-labour inputs and on various other factors that determine the selection of a management system and harvesting method, such as the soil type, the climate, and the accessibility of the plantation and the availability of infrastructure. E.g. in case a completely manual harvesting system without the use of heavy equipment, the labour intensity is estimated at 13 h odt^{-1} to 20 h odt^{-1}, compared to the 0.27 h odt^{-1} to 0.42 h odt^{-1} included in this study. If such harvesting would be used for eucalyptus production, than the harvesting costs would more triple, which shows that these harvesting systems are only feasible in areas with very low wages or in remote or difficult to access areas.

The direct employment due to the production, harvesting, transport and chipping of woody bioenergy is estimated at 22 thousand full time jobs, compared to a total agricultural employment of 0.7 million in 2015.

Education

In the *strict set of criteria* the bioenergy crop production is required to ensure that the children of the workers are able to receive education and to avoid child labour. Therefore, wages are increased by the average expenditures per child, which are estimated at 592 € y^{-1}(Matz 2002). The total labour costs increase by 0.7 € h^{-1}, assuming an average of 2.1 children per family (UNPD 2003), an average 44 hour working week (ILO 2003) and assuming that the family is dependent on one wage earner. Note that these costs are considerably higher than the 'bosca escola' (school attendance promotion fee), which is given to poor families if their children attend school. The bosca escola was 7.6 € per child per month in 2002 (BM 2002).

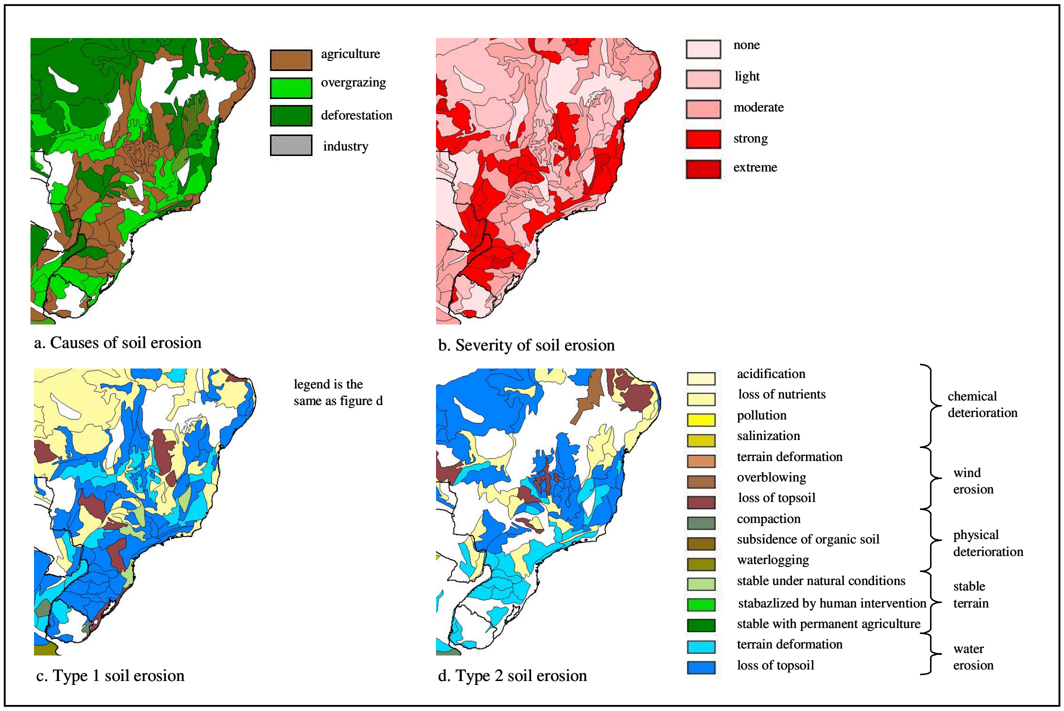
Health care

To ensure sufficient health care for the workers and their family members, wages are increased by the annual health care expenditures per capita in the *strict set of criteria.* The average annual health care expenditures were 222 € in 2002 (WB 2004b). This equals an increase of the labour costs by 0.5 € h^{-1}, based on the same assumptions as included in the criterion related to education.

4.1.5 Ecological criteria

Soil erosion

Figure 8 shows the extend, severity, causes and type soil erosion in the Atlantic Forest region in Brazil.


a. Causes of soil erosion

b. Severity of soil erosion

c. Type 1 soil erosion

d. Type 2 soil erosion

Figure 8 a to d. Soil erosion in the Brazil. Causes of soil erosion (a), severity of soil erosion (b), type soil erosion (c and d). Source: (LPDAAC 2003)

Moderate to strong soil erosion affects large parts of the Atlantic Forest regions. The main causes of soil erosion are overgrazing and agriculture and to a lesser extend deforestation. The two prevalent types of soil erosion are loss of topsoil and terrain deformation due to water erosion. Therefore, the focus in this study is on water erosion.

The *loose set of criteria* requires that (the risk of) soil erosion of land under woody bioenergy crop production is equal to, or decreased compared to the land use that is replaced by the bioenergy crop production. Table 7 shows the relative change in soil erosion for the conversion of various land use types to eucalyptus production.

Table 7. Relative change in erosion sensitivity due to the conversion of various land cover types to eucalyptus production. A value of 0.14 means that the soil erosion risk in eucalyptus plantations is 0.14 times the soil erosion risk of cereals. A value of 1 means that there is no change in soil erosion rate.

Original land cover	Eucalyptus
Fresh clean-tilled seedbed	0.06
Seasonal horticultural crops	0.10
Orchards/nurseries	0.10
Cereals (spring & winter)	0.14
Pasture/hay/grassland	1.00
Mixed forest	1.00
Deciduous forest	7.14

The data in table 7 show that eucalyptus plantations are likely to reduce soil erosion, particularly compared to seasonal horticultural crops, orchards/nurseries and cereals. Compared to pastures and grassland, poplar and eucalyptus production can result in similar erosion sensitivity. This is particularly important, because surplus permanent pastures represent an important part of the potential surplus agricultural land in Brazil.

The mechanisms through which bioenergy crops reduces soil erosion is a combination of better soil structure (higher organic matter content and improved permeability) (OTA 1993; Joslin *et al.* 1997; Borjesson 1999) and an higher ground cover from leaves and litter (Joslin and Schoenholtz 1997; Borjesson 1999).

The *strict set of criteria* requires that the absolute level of soil erosion is reduced to the natural rate of soil formation, which is estimated at 1 t ha^{-1} y^{-1} (OTA 1993). Soil erosion rates are estimated using the Universal Soil Loss Equation as described in section 3.3. Results are shown in table 8.

Table 8. Soil erosion rates (t ha^{-1} y^{-1}) in mature eucalyptus plantations in Brazil for various combinations of rainfall, soil texture and slope.

Rainfall (mm y^{-1})	Fine soil texture				Medium soil texture			
	Slope (%)				Slope (%)			
	2	4	6	10	2	4	6	10
1000	1	1	3	5	2	4	8	15
1250	1	2	4	8	2	6	11	22
1500	1	3	5	10	3	8	14	30
1750	1	3	6	13	4	10	18	38
2000	2	4	8	16	5	12	23	47

Table 8 shows that soil erosion rates vary with slope, soil texture and rainfall, roughly between 1 and 47 t ha^{-1} y^{-1}. Note that the soil erosion rates in table 8 are averages: the soil erosion sensitivity is higher during the plantation establishment phase, when ground cover is limited, than during the mature crop phase, when the ground is cover by the crown cover.

Erosion prevention measures are required in the strict set of criteria to reduce soil erosion rates to the natural rate of soil formation of 1 t ha^{-1} y^{-1}. The average costs are estimated at 2.3 € t^{-1} reduced soil loss. Table 9 shows the expected costs per hectare to reduce soil erosion to 1 t ha^{-1} y^{-1}.

Table 9. Average costs to prevent soil erosion for various soil classes and rainfall regimes in Brazil (€ ha^{-1} y^{-1}).

Rainfall (mm y^{-1})	Fine soil texture				Medium soil texture			
	Slope (%)				Slope (%)			
	2	4	6	10	2	4	6	10
1000	2	4	6	10	2	4	6	10
1250	0	0	4	10	0	7	15	33
1500	0	0	6	15	3	11	22	48
1750	0	4	9	21	5	15	30	65
2000	0	5	12	27	7	20	40	83

In the remaining of this study, the average costs to prevent soil erosion are based on the average costs for areas with a slope of 6 to 10% and a medium soil texture, which are calculated at 49 € ha^{-1} y^{-1}.

Depletion of fresh water resources

In the *loose and strict set of criteria* the production of bioenergy crops is not allowed to result in a depletion of fresh water resources. The water use of eucalyptus plantations is compared to the vegetation it replaces and compared to the annual rainfall to estimate the risk of groundwater depletion.

Figure 9 shows the water use of eucalyptus plantations compared to conventional agricultural land use (arable land and permanent pastures), based on the K_c factor; see further section 3.3 and Appendix I.

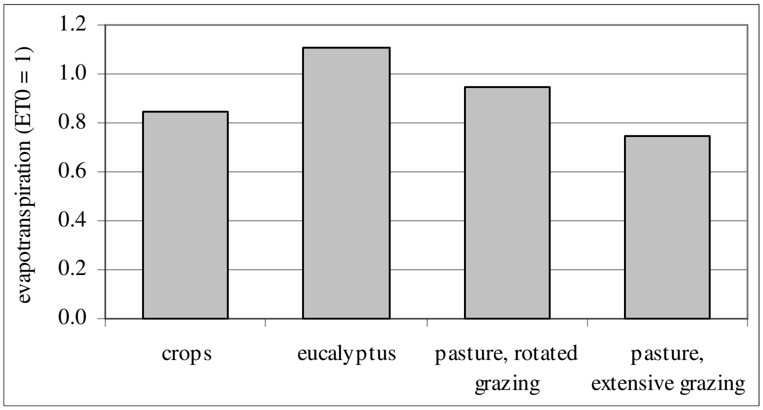


Figure 9. Potential evapotranspiration of euclayptus plantations compared to the reference evapotranspiration (ET_0) and compared to conventional agricultural crops (cereals) and permanent pastures. Sources: (FAO 1998a, 2000; NMCC 2001), own estimates.

Figure 9 shows that eucalyptus plantations require more water for optimal growth than land under crop production or land use as permanent pastures. These data should be regarded as an indicator of the potential water use, because in reality water use is dependant on many more variables, such as the soil texture, rainfall patterns, wind speed, cropping pattern, species. Consequently, the K_c factors found in literature vary roughly between 0.7 to above 1.5 (Worledge *et al.* 1998). In general, eucalyptus is known to consume much water and eucalyptus (and other SRWC's) are sometimes specifically used to lower groundwater tables (FAO 2002a), but are also responsible for reduced fresh water resources (Carrere and Lohmann, 1996 in (Kartha and Larson 2000).

Figure 10 shows the potential water use of eucalyptus plantations compared to the annual rainfall. Data are calculated for the city Passo Fundo in the North of Rio Grande do Sul.

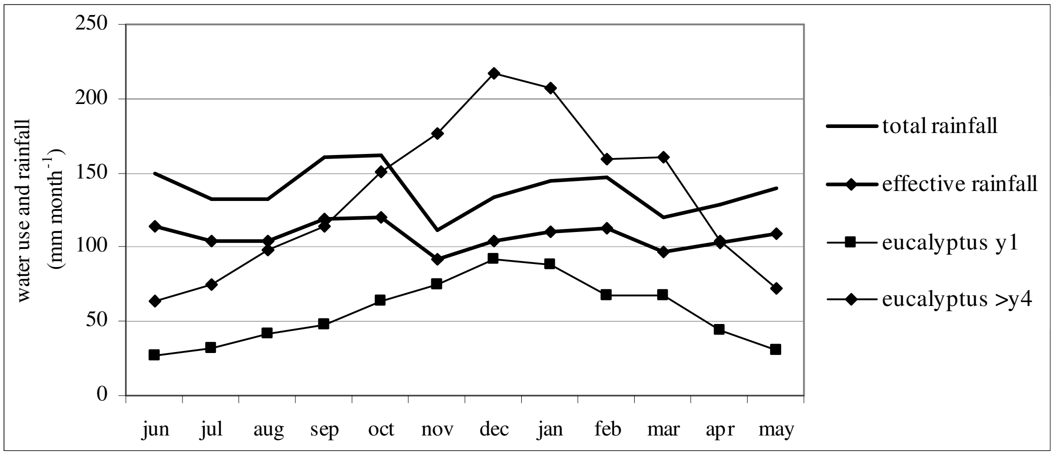


Figure 10. Evapotranspiration of eucalyptus plantations and various other types of vegetation cover in South Brazil (Passo Fundo) (in mm month^{-1}).

Table 10 shows the total annual evapotranspiration and the (effective rainfall), which gives an indication of the risk of groundwater depletion.

Table 10. Evapotranspiration of eucalyptus plantations in year 1 and year 4 and the total (effective) rainfall (in mm y^{-1}).

	mm y^{-1}
Evapotranspiration eucalyptus - year 1	676
Evapotranspiration eucalyptus – year 4 and above	1597
Total rainfall	1659
Effective rainfall	1288

The evapotranspiration is estimated at 676 mm y^{-1} to 1597 mm y^{-1}, dependant on the plantation age. These data are broadly in line with data found in literature: according to Hall (Hall *et al.* 1993) plants in general require 30 mm y^{-1} t^{-1} to 100 mm y^{-1} t^{-1} rainfall. In Brazil the rainfall requirement would be 870 mm y^{-1} to 2900 mm y^{-1}, based on a yield level of 29 odt ha^{-1} y^{-1} or 593 mm y^{-1} to 1925 mm y^{-1}, based on an (unweighed) average yield of 19 odt ha^{-1} y^{-1}.

The data in table 10 show that the effective rainfall is sufficient to meet the (potential) evapotranspiration of first year eucalyptus plantations all through the year. Consequently, the risk of groundwater depletion is low. In full-grown eucalyptus water is a potential limiting factor for the hotter parts of the year (particularly November, December and January and partially February and March). The total evapotranspiration is above the effective rainfall, but below the total rainfall, which indicates that there is a medium risk of groundwater depletion. Note that the risk of grondwater depletion can be reduced by reducing the water consumption as outlined in section 3.3, which are excluded in these calculations. Further, the risk of groundwater depletion could be reduced in case (ground)water is supplied from areas with a surplus of water to areas with a shortage. After all, only a limited percentage of the total area is planted with eucalyptus and the remaining is under other (less water demanding) vegetation cover.

Nutrient losses and soil depletion

The *loose set of criteria* requires that soil depletion is avoided by the application of fertilizers. The required input of N, P and K is calculated at 144-219 kg ha^{-1} y^{-1}, 1-8 kg ha^{-1} y^{-1} and 11-68 kg ha^{-1} y^{-1}, respectively. The range is dependant on the amount of biomass removed or the yield level, which is dependant on the land suitability class (the figures refer to the mS and VS areas). The total fertilizer costs range from 98 € ha^{-1} y^{-1} to 179 € ha^{-1} y^{-1} in mS and VS areas, respectively.

The *strict set of criteria* requires that the nutrient loss in eucalyptus plantations is reduced as far is reasonably is achievable and at the same time soil depletion is prevented. The nutrient uptake efficiency on mS to VS areas is 30% to 60%, in case of a fertilizer application frequency of twice per rotation cycle (7 years). In case the fertilizer application frequency is increased to once per year, the nutrient uptake efficiency on mS to VS areas increases to 42% to 84%. The value of fertilizers required to prevent soil depletion is decreased to 76 € ha^{-1} y^{-1} to 145 € ha^{-1} y^{-1} in mS and VS areas, respectively. The costs of labour and machinery for fertilizer application are increased by 14 € ha^{-1} y^{-1}.

As a result, the average loss of nitrogen ranges is reduced from 87-100 kg ha^{-1} y^{-1} to 25-60 kg ha^{-1} y^{-1} in VS-mS areas. Phosphor and potassium losses are zero, because the nutrient uptake efficiency is 100%.

Pollution from agricultural chemicals

The *strict set of criteria* requires that pollution from agricultural chemicals is avoided as far as reasonably is achievable.

First the relative toxicity of the use of agricultural chemicals (herbicides, fungicides, insecticides and other pesticides) for the production of bioenergy crops is compared with the relative toxicity of the use of agricultural chemicals of the agricultural land use it replaces, see table 11.

Table 11. Sustainability score for the use of pesticides (dimensionless) of various agricultural land use types and for poplar cultivation in the Netherlands. Source: (Biewinga and Van der Bijl 1996).

Crop	Sustainability score - actual practice	Sustainability score - attainable practice
Winter wheat	5.5	0.5
Sugar beet	5.6	0.7
Sweet sorghum	13	1.1
Silage maize	9.0	0.6
Grass fallow	0.0	0.0
Poplar/eucalyptus[16]	0.9	0.1

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[16] Data on the pesticide use for eucalyptus plantations are based on the use pesticides for poplar production, because a detailed analysis of the type of chemicals applied, application rates and harmfullness goes beyond the scope of this research. For herbicides, which account for more than 80% of the total harmfull score in poplar production is seems a valid assumption, because Faundez (Faundez 2003) reports that the use of herbicides in eucalyptus and poplar plantations is comparable during the first year.

The results show that the toxicity from the use of agricultural chemicals for SRWC production is less than of conventional agricultural crops. Only in case grassland is converted to poplar plantations, the loss of pesticides is increased when shifting to SRWC cultivation. In case the use of herbicides is completely replaced by manual and mechanical weeding, than the costs of chemical fertilizer application decrease from an average of 12 € ha^{-1} y^{-1} [17]to zero, while the costs for manual and mechanical weeding increase by a factor 6 to 66 € ha^{-1} y^{-1}.

4.2 Ukraine

4.2.1 Demarcation of case study region

The Ukraine covers some 58 million hectares land, of which 51 is not under forest cover or build-up. The regional differences in e.g. climate, level of industrialisation and agricultural production system within the Ukraine are relatively limited (at least compared to those of the Brazil). Figure 11 shows the major farming systems and the key agricultural region in Ukraine.

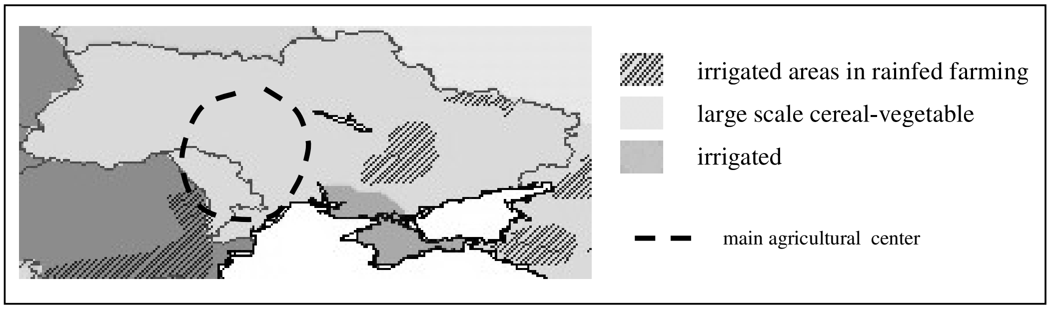

Figure 11. Major farming systems in the Ukraine. Source: (Dixon *et al.* 2001)

Figure 11 shows that the variation in farming system in Ukraine is limited: by far the most important farming system in the Ukraine is the large-scale cereal-vegetable farming system[18] (Dixon *et al.* 2001). Within this system, the middle of the Ukraine is the main agricultural centre in the Ukraine (the dashed circle in the middle; figure 11).

Central Ukraine may be the most suitable region for bioenergy production, considering the availability of infrastructure and agricultural services. Most of the industries and urban centres are situated East of the Dnepr river and in the far South West of the country. However, in the remaining of this study no further regional demarcation is included considering the relatively homogenous agricultural production system in Ukraine and considering the large projected demand for bioenergy in the Netherlands in 2040 which requires some 5 million hectare (compared to a total surplus of 7.7

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[17] Values in €'s are not converted into present value in this section.

[18] *'The large-scale cereal-vegetable farming system is typical for the less advanced transition countries with good agro-ecological conditions (e.g. Ukraine). Most farms range in size from 500 to 4000 ha, but there are still examples of huge farms exceeding 10000 ha. The large farms are associated with large rural communities of 500 to 800 persons, many of who are employed there. In the process of economic reforms, oversized and complex farms have been split into smaller, specialised and more manageable units. The percentage of rural population of the total population in the system is high, about one third and this percentage is likely to decrease only slowly. Farm employees also work their household plots. The main crops are wheat, barley, maize, sunflower, sugar beets and vegetables; sugar crops and cereals'* (modified from (Dixon *et al.* 2001).

million hectares based on an intermediate level of agricultural technology). I.e. all calculations are based on averages for Ukraine.

4.2.2 Land availability for bioenergy crop production

Historic land use patterns

Ukraine covers an area of 60.4 million hectares, of which is 57.9 million hectares land, he remaining inland water bodies. Figure 12 shows the land use from 1970 to 1999.

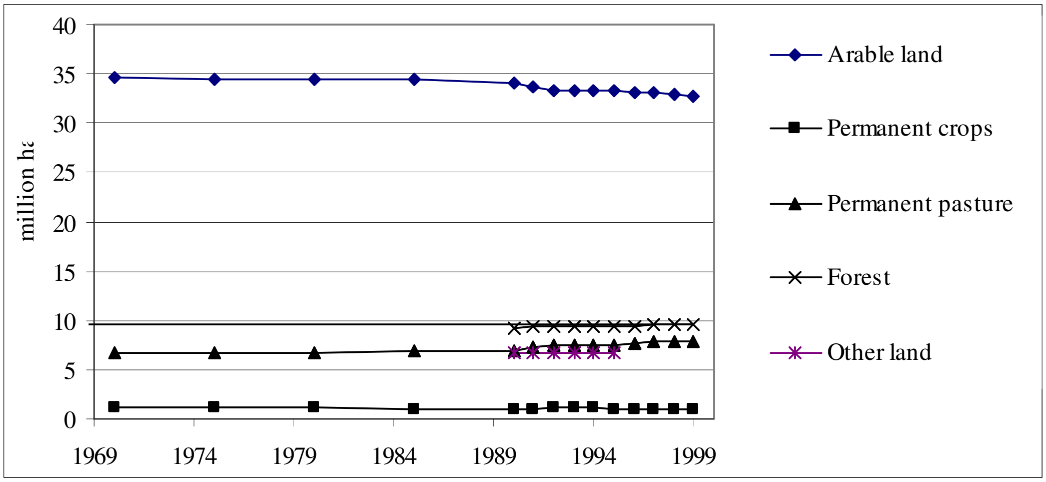

Figure 12. Historic land use pattern 1961 to 1998. Sources: (FAO 2002b; UNEP 2002).

In total some 69% of the Ukraine consists of agricultural land (FAO 2003a). The agricultural area decreased from 1970 to 1999. Particularly the collapse of communism in 1992 and the following economic restructuring (market liberalisation, farm restructuring, abandonment of agricultural subsidies) caused an increase of food prices. On the demand side, the economic reforms caused a decrease of the real GDP of more than 60% between 1990 and 1997 (Liefert *et al.* 2002). The aggregated effect has been a decrease in food consumption. The effect has been a relatively small decrease in the area arable land from 33.4 million hectares in 1992 to 32.7 million hectares in 1999 and permanent crops from 1.0 million hectares in 1992 to 0.94 million hectares in 1999. The area permanent pastures increased slightly from 7.5 million hectares in 1992 to 7.8 million hectares in 1999. The largest impact of the economic reforms has been on yields, e.g. wheat yields decreased by 26% between 1992 and 1999, barley yield dropped 37%, rye yields 36%, sugar beet yields 20% and potato yields 30% to name some of most important crops (FAO 2002b). The area build-up land in the Ukraine is estimated at 0.6 million hectares (FAO 2000) in 1995 and is unlikely to have changed since than considering the decreasing population and slow economic recovery.

Land resources

Most of the area of Ukraine consists of flat, treeless, very fertile steppe areas that are bordered by the Carpathian Mountains in the West (shown on the map as forested area) and the Donets ridge in the South East. The climate is temperate continental and Mediterranean only on the southern coast of the Cremean Peninsula. Precipitation is disproportionately distributed, the highest in west and north resulting in surplus water and less in the east and southeast, resulting in water shortages. The winters vary from cool along the Black Sea to cold farther inland; summers are warm across the greater part of the country and hot in the south. Figure 13 shows the areas suitable for crop production and the areas presently under forest or under crop production or used as permanent pasture. In Appendix G a map of the land suitability is shown.

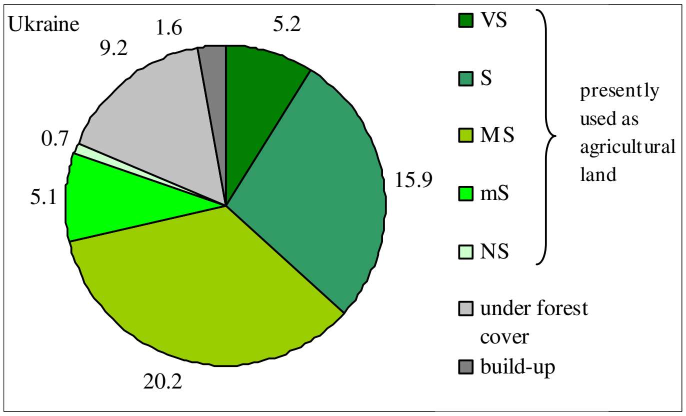

Figure 13. Areas land suitable for crop production and present land use in Ukraine in 1998. Sources: (FAO 2002b), (FAO 2000).

Figure 13 shows that most of the land surface of Ukraine is occupied by agricultural land and is classified as very suitable, suitable and moderately suitable. The area under crop production could expand from 34 million hectares to 43 million hectares at the expanse of permanent pasture area and/or land classified as other land, without further deforestation.

Future land use and land availability for bioenergy crop production

The two key drivers behind changes in consumption are population growth and income growth. The population in the Ukraine is expected to decrease during the coming decades, as has been the case since the early 90's (figure 14).

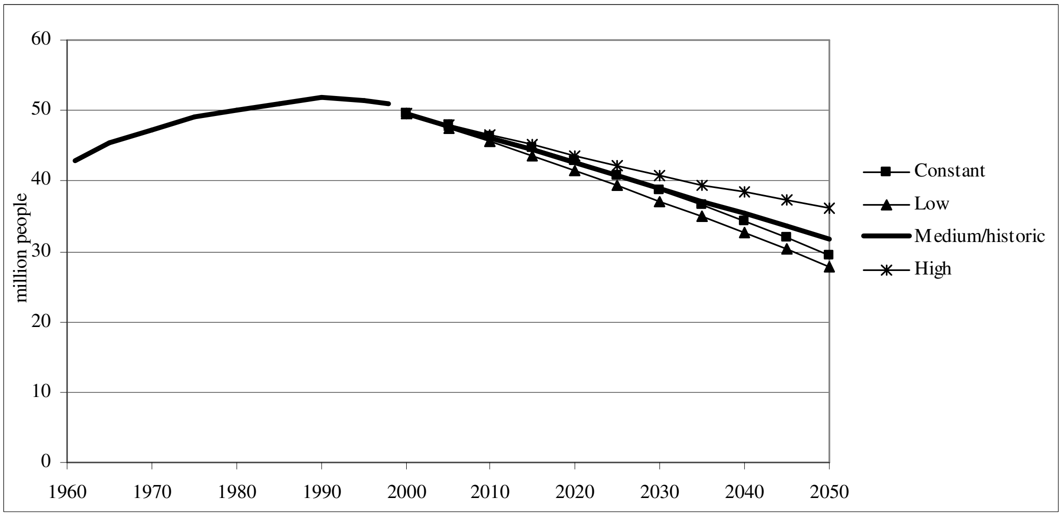

Figure 14. Historic and projected population in the Ukraine from 1961 to 2050 in various scenarios (high, medium and low and constant fertility). Source: (UNPD 2003)

Note that the range in projections of the four scenarios is limited, which indicates that the projections are relatively certain. Per capita consumption levels have decreased since the fall of communism, particularly in the Ukraine. Daily average food intake expressed in kcal cap^{-1} day^{-1} decreased from 3362 kcal in 1992 to 2773 kcal cap^{-1} day^{-1} in 1996 and increased again to 3008 kcal cap^{-1} day^{-1} in 2001 (FAO 2002b). Particularly the consumption of meat decreased rapidly, from 288 kcal cap^{-1} day^{-1} in 1992 to 150 kcal cap^{-1} day^{-1} in 2001 (FAO 2002b). Undernourishment is limited to 5% of the population, equal to 3 million people. Consumption levels are presently increasing again, but it will take several decades before the high food consumption levels of the communistic period are reached.

Based on the steep drop in consumption and production and the slow recovery, the FAO projects a very small decrease (-1%) of the area arable land until 2015 and small increase till 2030 of some 4% compared to 1998 (FAO 2003b). The decrease in yields since 1992 also shows that the Ukraine is presently making inefficient use of its natural resources and its proven ability to apply more intensive production systems. If however, yields increase faster than projected by the FAO, the area agricultural land is reduced more than projected by the FAO. Table 12 shows the potential increases in yields (12a) and feed conversion efficiencies (12b) based on various levels of technology as calculated by the Excel spreadsheet tool described in Smeets et al. (2003). The data include the projected demand for food in 2015. The data indicate the increase factor in yield or efficiency. (1998 efficiency or yields are set at 1).

Table 12a. Average potential increase in crop yields in 2015 compared to 1998 in Ukraine based on various levels of technology.

(1998=1) Crop	Average of all crops	Cereals	Roots and tubers	Sugar crops	Pulses	Oilcrops
Level of technology						
Mixed, rain-fed and/or irrigated	3.8	5.1	3.9	5.0	2.1	3.0
Mixed, rain-fed	2.5	2.4	2.7	3.9	1.6	1.9
High, rain-fed	3.5	3.8	3.3	4.9	2.9	2.8
Intermediate, rain-fed	1.9	2.3	1.6	3.0	1.0	1.5

Table 12b. Increase in feed conversion efficiency in 2015 in Ukraine based on various levels of technology.

(1998=1) Animal product	Bovine meat	Milk	Pig meat	Poultry meat and eggs
High feed conversion efficiency	1.4	1.4	1.2	1.3
Intermediate feed conversion efficiency	0.7	0.8	1.1	1.1

The potential to increase crop yields is on average considerable, between a factor 1.9 and 3.8; the potential to increase the feed conversion efficiency is also considerable, between 1.2 to 1.4 in a high feed conversion efficiency. The potential of the Ukraine as a bioenergy producing regions lies in the favourable fertile chemozems soils (black soils), some of the world's most fertile soils that are particularly suitable for grain farming. The crops with the highest potential yield increases are cereals and sugar crops. The FAO reports a potential increase of wheat yields from 2.5 ton per ha to 6.2 ton ha, while a variation of 3.6 on the most suitable soils to 1.8 on moderately suitable areas (FAO 2002c). The FAO reports that typical average yields achieved by the collective and state-owned farms during the 1980's, were 3 ton per hectare for winter wheat and 25 to 30 ton per hectare for sugar beet. These yields have declined to as low as 2 ton per hectare for cereals and 10 ton for sugar beet. Experience has shown that cereal yields, even on large collective farms, can reach 7 to 8 ton per hectare and can be maintained at that level without any apparent negative effects on the environment. Sugar beet yields can reach 60 ton per hectare with relatively simple technologies (Dixon *et al.* 2001). The potential to increase the productivity of the animal production sector is less dramatic, because production systems in the Soviet period have been fairly efficient with feed conversion efficiencies, because only intensive (mixed/landless) production system is applied.

The area available for bioenergy production is at least 10% of the present agricultural land use as described in section 3.3. Of the remaining 90% some areas could be available for bioenergy production, if the chosen level of agricultural technology results in surplus agricultural land not needed for food production. The higher the level of agricultural technology, the larger the surplus agricultural area available for bioenergy crop production or the larger the shortage of agricultural land needed for food production. Results are shown in table 13.

Table 13. Potential surplus agricultural land in 2015 in Ukraine based on various levels of advancement of agricultural technology (million ha).

Level of technology	VS	S	MS	mS	NS	TOTAL
Mixed, rain-fed and/or irrigated	0.8	11.5	12.4	1.9	0.5	27
Mixed, rain-fed	0.5	5.8	14.5	2.5	0.5	24
High, rain-fed	4.8	4.0	14.0	2.7	0.5	26
Intermediate, rain-fed	0.7	1.2	4.1	1.1	0.7	7.7

In total the agricultural area can be reduced by some 53%, 46%, 50% and 15% in agricultural production system based a mixed (rain fed/irrigated), mixed (rain fed), high and intermediate level of technology (including the 10% specifically allocated to bioenergy production). These percentages equal to 27 million ha (mixed rain fed/irrigated) to 7.7 million ha (intermediate). These results clearly indicate that increases in the production efficiency of food production may significant decrease the agricultural land area, thereby freeing land for bioenergy production, without endangering food supply or further deforestation. In this study a surplus area of 7.7 million is included. Based on the national average suitability profile, 9% is classified as VS, 15% S, 53% MS, 14% mS and 9% NS. I.e. of the 7.7 million hectares surplus land, some 5.9 million hectares is classified as VS to MS for crop production.

Note that based on the favourable soils and climatological conditions in some of the transition countries, various researchers pointed out the potential of Ukraine as a large and very competitive producer of particularly cereals. These projections have not yet become reality, due to the various institutional barriers, lack of foreign investments and slow economic reforms of particularly the agricultural sector (Liefert and Swinnen 2002), but may limit the availability of land for bioenergy crop production.

4.2.3 Poplar yields

For Ukraine poplar is taken the preferred bioenergy crop. Data on poplar yields for various land suitability classes in a high input system are based on crop growth modelling data from the International Institute of Applied Systems Analysis (Fischer *et al.* 2001b), see table 14. The data are averages for Ukraine. The rotation cycle is set at

7 years and the total plantation lifetime is set at 21 years (Biewinga and Van der Bijl 1996).

Table 14. Yield of eucalyptus short rotation bioenergy crops in Ukraine for various land suitability classes (odt ha^{-1} y^{-1}). Sources: (Fischer *et al.* 2001b).

	VS	S	MS	mS	VmS	NS
Ukraine	16	14	11	6	2	0

4.2.4 Socio-economic criteria

Child labour

In Ukraine the minimum age for employment is 16, but in non-hazardous sectors of the economy children of the age of 14 or 15 years are allowed to work under certain condition (USDS 2003b). Child labour was uncommon, but has increased due to the deterioration of the social institutions as a result of the Government's financial deficits following the end of the Soviet era. In 1999, some 1% of children in the age of 7 to 12 years, was economically active (ILO/SSCU 2001).

In the *strict set of criteria* the wage of the workers on the bioenergy plantation is increased by the average wage of child labour, which is estimated at 16 € per month in 1999 (ILO/SSCU 2001). This figure was increased by the projected average increase in per capita GDP to 2015 (WB 2003). The labour costs increase by 0.26 € h^{-1} (based on an average of 1.2 child per family (UNPD 2003), a 40 hour working week (ILO 2003) and one wage earner per family). Considering the low occurrence of child labour, this figure is likely an overestimation. Second, the cost of education of children is included to promote education and allow parents to go to work. The costs of education are analysed in a separate section.

Wages

Input data for the calculation of wages and labour costs are shown in table 15. The wage of a field worker in Ukraine in 2002 was 0.2 € h^{-1} (ILO 2003), which was 15% above the minimum wage in 2002 (DB 2003).

Table 15. Input data for the calculation of wages and labour costs in Ukraine in 2015.

	Value	Unit	Source
Field worker	0.2[19]	€ h^{-1}	(ILO 2003)
Supervisor	0.6[20]	€ h^{-1}	(ILO 2003)
Ratio average wage to field worker wage	2.0	dimensionless	(FedEE 2004; MW 2004)
Labour costs to wages ratio[21]	1.4	dimensionless	(ILO 2003)
GDP growth	3.5[22]	% y^{-1}	(WB 2003)

The *loose set of criteria,* which requires that at least minimum wages are paid, is met. The total labour costs in 2015 are estimated at 1.4 € h^{-1} and 0.5 € h^{-1}, for a supervisor and field worker, respectively. The wage of a field worker in 2015 is ca. 3 US $ per

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[19] Average wage in agriculture, hunting and forestry.

[20] Based on the ratio in field worker wage and supervisor wage in Brazil.

[21] Unweighed average of the labour cost to wages of all sectors.

[22] Average of Eastern Europe for 2005-2015.

day, which is more than the international poverty lines of 1 US $ day^{-1} or 2 US $ day^{-1} [23]. Note that this comparison is however not entirely correct, due to differences in base year and definition. In 1999 3% of the population in Ukraine lived on less than 1 US $ day^{-1} and 46% on less than 2 US $ day^{-1}. We acknowledge that in case an average family of two adults and 1 child is dependant on the income of one field worker, the family average per capita wage could fall below the poverty line of 1 US $ day^{-1}.

The *strict set of criteria* requires that wages are based on the national average wage level. The ratio between average wages to field worker wages is a factor 2. The resulting labour costs for a field worker and a supervisor in the strict set of criteria in 2015 is thus 2.8 € $h^{-1\ \text{and}}$ 1.0 € h^{-1}, respectively.

Employment

The *loose set of criteria* requires that bioenergy crop production contributes to employment, excluding indirect effects. The direct employment effect was calculated as described in 3.3. Figure 15 shows the total labour requirement for poplar production for various land suitability classes.

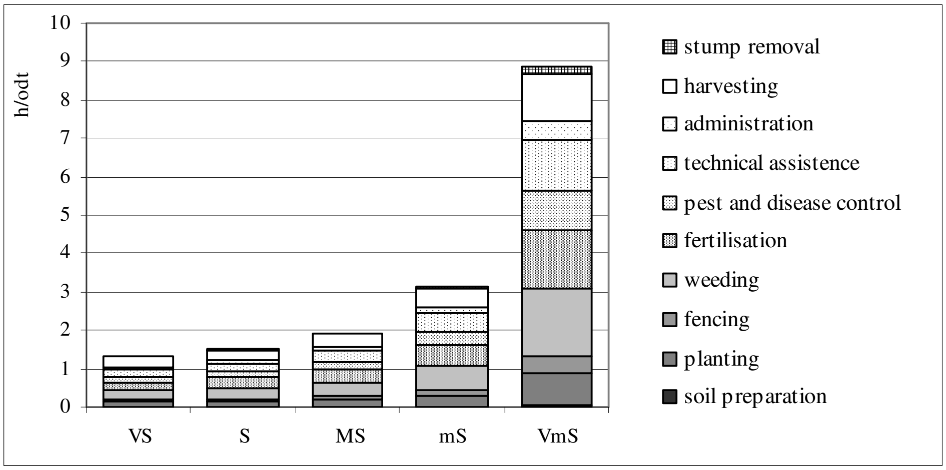

Figure 15. Total labour input for the production of poplar (h odt^{-1}). VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable and NS = not suitable. Sources: various, see Appendix B.

The labour input ranges roughly between 1.3 h odt^{-1} to 8.7 h odt^{-1}. The labour input (in h odt^{-1}) varies, because a large share of the labour input (in h ha^{-1} y^{-1}) is fixed, while the yield level is dependant on the land suitability class. The labour input is calculated at 20 h ha^{-1} y^{-1} to 21 h ha^{-1} y^{-1}, dependant on the land suitability class. Data found in literature range from 7.5 h ha^{-1} y^{-1} in the Netherlands (Rijk, 1999) to 22 h ha^{-1} y^{-1} (FUS 2004).

In practice, the labour input is dependent on the chosen production and harvesting system. E.g. in this study, the labour requirement for fertilisation and weed, pest and disease control is estimated at 9 h ha^{-1} y^{-1}. Van den Broek *et al.* (Van den Broek *et al.*

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[23] According the government of Ukraine, the subsistence minimum for Ukraine for able bodied adults is ca. 1.9 times the minimum wage in 2004 (MW 2004), which is ca. 1 US $ day^{-1}.

2000a) reported a labour input of ca. 30 h ha^{-1} y^{-1} for fertilisation and weed, pest and disease control in eucalyptus plantations in Nicaragua. The total direct impact of bioenergy crop production is estimated at 50 thousand jobs, compared to the present agricultural labour force of ca. 1.2 million.

Education

In the *strict set of criteria* the bioenergy crop producer is responsible for creating the possibility for children of the workers to go to school. Wages are increased by the average expenditures per child, which is 472 € y^{-1}(Matz 2002). This equals an increase of the labour costs by 0.3 € h^{-1} (based on an average of 1.2 child per family (UNPD 2003), a 40 hour working week (ILO 2003) and one wage earner per family).

Health care

In the *strict set of criteria* the wages of the workers and their family members, wages are increased by the annual health care expenditures per capita. The average annual health care expenditures were 222 € in 2002 (WB 2004b). This corresponds to an increase of the labour costs by 0.5 € h^{-1} (assuming an average of 1.2 child per family (UNPD 2003), a 40 hour working week (ILO 2003) and one wage earner per family).

4.2.5 Ecological criteria

Soil erosion

Figure 16 shows the total extend and type of soil erosion in the Ukraine according to the GLASOD database.

Figure 16 indicates that large areas in the Ukraine suffer from moderate to strong soil erosion[24]. Overall, some 35% of Ukraine's arable land is considered to be threatened by wind or water erosion (UNECE 1999). The most common types of erosion are loss of topsoil, terrain deformation, compaction and overblowing[25]. Water erosion is the dominant source of erosion, which is caused by deforestation and/or agriculture (intensive ploughing, production on areas less suitable for crop production such as slopes, natural pastures, peat land, wetlands or dry lands) and overgrazing the south and southeast of the country. Irrigation is mentioned as another important factor: 14% of the irrigated area is threatened by erosion due to overirrigation (5%), salinisation (11-25%), acidification (43%), excess moisture (11%) and waterlogging (13%) (UNECE 1999).

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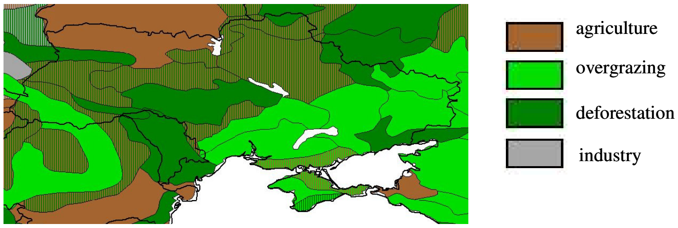
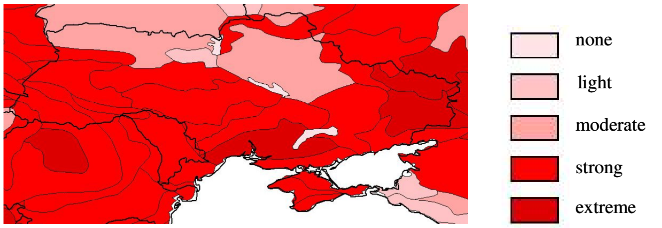
[24] The data in figure 18 include the degree of soil degradation and the extent of soil degradation in each mapping unit and do not indicate the total area affected by soil erosion.

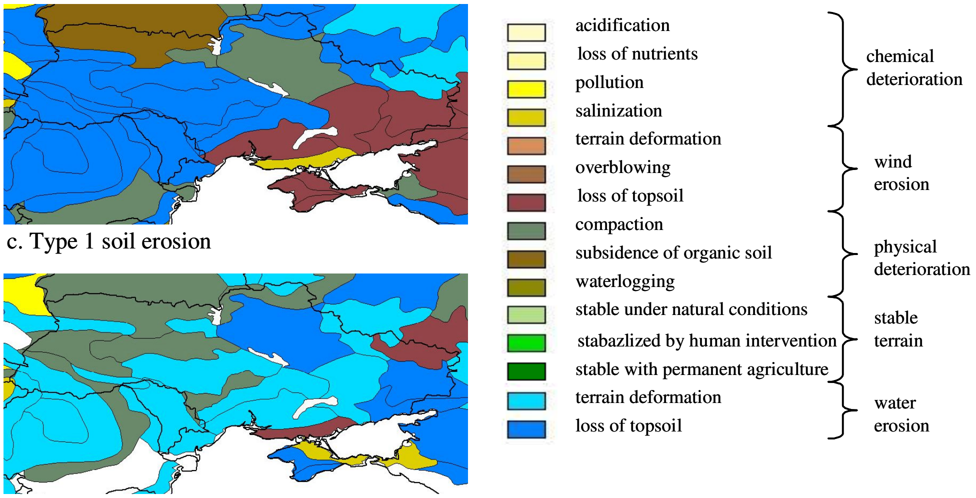
[25] Overblowing is the desposition of wind-carried particles and coverage of nutrient rich topsoil



a. Causes of soil erosion



b. Severity of soil erosion



c. Type 1 soil erosion

d. Type 2 soil erosion

Figure 16 a to d. Soil erosion in the Ukraine. Causes of soil erosion (a), severity of soil erosion (b), type soil erosion (c and d). Source: (LPDAAC 2003)

The *loose set of criteria* requires that (the risk of) soil erosion is the same or is reduced compared to the land use it replaces. Table 16 shows the soil erosion rate when growing woody bioenergy crops compared to various land cover types.

Table 16. Relative change in soil loss from water erosion due to the conversion of various land cover types to poplar production. A value of 0.22 means that the soil erosion risk in poplar plantations is 0.22 times the soil erosion risk of cereals. A value of 1 means that there is no change in soil erosion sensitivity.

Original land cover	Poplar
Fresh clean-tilled seedbed	0.10
Seasonal horticultural crops	0.16
Orchards/nurseries	0.16
Cereals (spring & winter)	0.22
Pasture/hay/grassland	1.55
Mixed forest	1.55
Deciduous forest	11.09

The data in table 16 show that soil erosion in poplar plantations is lower than in land under horticultural crop or cereal production. Compared to pastures and grassland, the soil erosion rate could increase. However, considering the relatively large uncertainties in the C values included in the calculations, the difference is not significant, see Appendix E for a discussion on these uncertainties. Further, various other reports indicate that soil erosion rates under woody bioenergy crop production are likely similar to those of permanent pastures (e.g. (OTA 1993). This is an important issue, because permanent pastures represent an important part of the surplus areas in Ukraine.

The *strict set of criteria* requires a decrease in the absolute rate of soil erosion to the natural soil rate of soil generation of 1 t ha^{-1} y^{-1}. Soil erosion rates are calculated using the Universal Soil Loss Equation (USLE) as described in section 3.3.

Table 17. Soil erosion rates (t ha^{-1} y^{-1}) in mature poplar plantations in the Ukraine for various combinations of rainfall, soil texture and slope.

Rainfall (mm y^{-1})	Fine soil texture				Medium soil texture			
	Slope (%)				Slope (%)			
	2	4	6	10	2	4	6	10
400	0	0	1	2	1	1	3	6
600	0	1	2	4	1	3	5	11

Table 17 shows that soil erosion rates in poplar plantations in the Ukraine range between 0 to 11 t ha^{-1} y^{-1}, which is above the limit of 1 ton ha^{-1} y^{-1}. The average costs to reduce soil erosion rates are estimated at 2.3 € ha^{-1} y^{-1} per ton avoided soil loss. Table 18 shows the total costs of these erosion prevention measures.

Table 18. Costs to prevent soil erosion for various soil classes and rainfall regimes in Ukraine (€ ha^{-1} y^{-1}).

Rainfall (mm y^{-1})	Fine soil texture				Medium soil texture			
	Slope (%)				Slope (%)			
	2	4	6	10	2	4	6	10
400	0	0	0	0	0	0	4	10
600	0	0	0	6	0	4	10	22

In the final results, a cost of 12 € ha^{-1} y^{-1} to reduce soil erosion is included, which is the average of a 6% and 10% for medium textured soils.

Depletion of fresh water resources

The *loose and strict set of criteria* requires that depletion of fresh ground water resources is prevented. The water use of poplar plantations is calculated and compared to the land use it replaces and compared to the annual rainfall to indicate the risk of groundwater depletion. This criterion could not be operationalised any further due to a lack of data.

The annual evapotranspiration (ET) of bioenergy crops is compared with that of other land use types based on the average K_c value, as described in detail in section 3.3 and Appendix I; results are shown in figure 17.

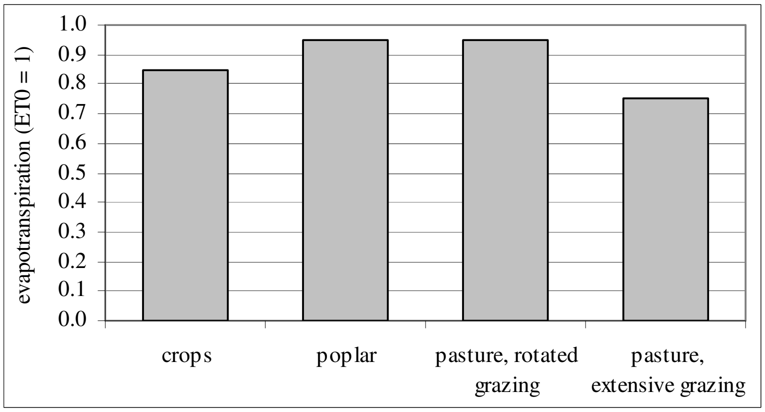


Figure 17. Potential evapotranspiration of poplar plantations compared to the reference evapotranspiration (ET_0) and compared to conventional agricultural crops (cereals) and permanent pastures. Sources: (FAO 1998a, 2000; NMCC 2001), own estimates.

Figure 17 shows that poplar plantations have a comparable water demand compared to permanent pastures under a rotated grazing management scheme. However, the water demand is higher compared to other types of conventional agricultural land use, such as crop production and extensive grazing. In general, tree plantations have a higher water use than shorter vegetation types, such as grasses and scrubs. Consequently, fast growing SRWC plantations have in many cases resulted in reduced fresh water resources (Carrere and Lohmann, 1996 in (Kartha and Larson 2000). Note that K_c values are however uncertain and values range from 0.3 to more than 1.

The demand for water in poplar plantations is compared with the supply of rainfall, to estimate the risk of groundwater depletion for poplar production.

Figure 18 shows the potential water use and the (effective) rainfall in Zhytomyr in North Central Ukraine.

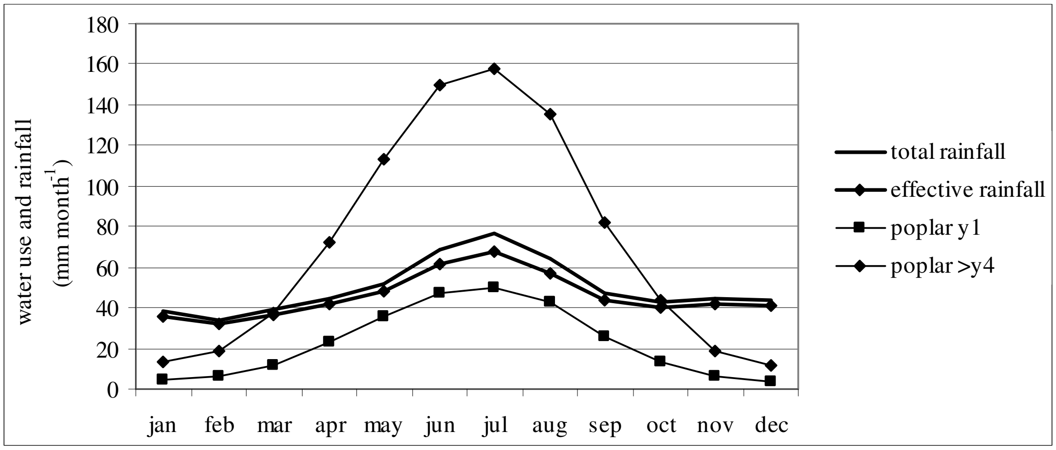


Figure 18. Evapotranspiration of various land use types and effective rainfall in central Ukraine (Zhytomyr) (in mm month^{-1}).

Table 19 shows the total annual evapotranspiration and the (effective rainfall), which gives an indication of the risk of groundwater depletion.

Table 19. Evapotranspiration of eucalyptus plantations in year 1 and year 4 and the total (effective) rainfall (in mm y^{-1}).

	mm y^{-1}
Evapotranspiration polar - year 1	271
Evapotranspiration poplar – year 4 and above	851
Total rainfall	597
Effective rainfall	547

The evapotranspiration is estimated at 217 mm y^{-1} to 851 mm y^{-1}, dependant on the age of the plantation. The data are in line with data reported by Hall (Hall *et al.* 1993). He estimated that plants in general require 30 mm y^{-1} t^{-1} to 100 mm y^{-1} t^{-1} rainfall. This would equal a rainfall requirement of 480 mm y^{-1} to 1600 mm y^{-1}, based on a yield level of 16 odt ha^{-1} y^{-1} or 352 mm y^{-1} to 1175 mm y^{-1}, based on an (unweighed) average yield of 12 odt ha^{-1} y^{-1}.

The data in table 19 shows that the effective rainfall is sufficient to meet the demand for water during the first year and the risk of groundwater depletion is low. The evapotranspiration is estimated at 271 mm y^{-1}, while the effective rainfall is estimated at 547 mm y^{-1}. In full-grown poplar plantations water is a limiting factor for growth during the summer. The rainfall surplus during the winter is insufficient to compensate for the water shortage during the summer: the total evapotranspiration is calculated at 851 mm y^{-1}, while the total rainfall is estimated at 597 mm y^{-1}. Consequently, the risk of groundwater depletion is high. So, additional measures are required to reduce the water use, e.g. by reducing soil disturbance to reduce surface evaporation, by increasing ground cover which avoid runoff and by placing hedges to reduce the wind speed and thereby water use and by optimal species selection that use little water or that have a hortizontal rooting system that does not reach the groundwater table. In addition, the risk of groundwater depletion can also be reduced by an influx of groundwater from areas with a surplus of water to areas with a shortage. After all, only a limited percentage of the total area is planted with SRWC's and the remaining is under other (less water demanding) types of vegetation cover.

Nutrient losses and soil depletion

The *loose set of criteria* requires that soil depletion is avoided through the application of fertilizers. The required input of N, P and K is calculated at 128-160 kg ha^{-1} y^{-1}, 4-10 kg ha^{-1} y^{-1} and 20-50 kg ha^{-1} y^{-1}, respectively. The range refers to the land suitability class. The total fertilizer costs range from 89 € ha^{-1} y^{-1} to 135 € ha^{-1} y^{-1} in mS and VS areas, respectively (numbers in €'s are not discounted).

The *strict set of criteria* requires that the nutrient loss in eucalyptus plantations is reduced as far is reasonably is achievable and at the same time soil depletion is prevented. The nutrient uptake efficiency is 29% to 58% on mS to VS areas, in case of a fertilizer application frequency of twice per rotation cycle (7 years). In case the fertilizer application frequency is increased to once per year, the nutrient uptake efficiency on mS to VS areas increases to 40% to 80%. The value of fertilizers required to prevent soil depletion is decreased to 70 € ha^{-1} y^{-1} to 110 € ha^{-1} y^{-1} in mS and VS areas, respectively. The costs of labour and machinery for fertilizer application is increased by 3 € ha^{-1} y^{-1}. As a result, the average loss of nitrogen ranges is reduced from 23-55 kg ha^{-1} y^{-1} to 68-91 kg ha^{-1} y^{-1} in VS-mS areas. Phosphor and potassium losses are zero, because the nutrient uptake efficiency is 100% (Biewinga and Van der Bijl 1996).

Pollution from agricultural chemicals

The *strict set of criteria* requires that pollution from agricultural chemicals is avoided as far as reasonably is achievable.

Table 11 in section 4.1.5 shows the sustainability scores of the use of agricultural chemicals in various land cover types, including bioenergy crop production. The results show that the toxicity from the use of agricultural chemicals for SRWC production is less than of conventional agricultural crops, but higher than for grassland. In case the use of herbicides is completely replaced by manual and mechanical weeding, than the costs of chemical fertilizer application decrease from an average of 12 € ha^{-1} y^{-1} to zero, while the costs for manual and mechanical weeding increase by a factor 6 to 31 € ha^{-1} y^{-1} (values are in real €, i.e. not converted into Net Present Value).

5. Results and discussion

A prerequisite for the large-scale production of dedicated bioenergy crops and trade of modern bioenergy is that is not only sustainable with respect to the mitigation of greenhouse gas emissions, but also with respect to other aspects. In this study the impact of meeting the requirements of 12 sustainability criteria is analysed and expressed in terms of costs and/or the availability of bioenergy. As a case study we included the production of short rotation woody crops in Ukraine and Brazil, because these regions are identified as promising bioenergy producing regions. Table 20 shows the various criteria included in this study and how these are operationalised.

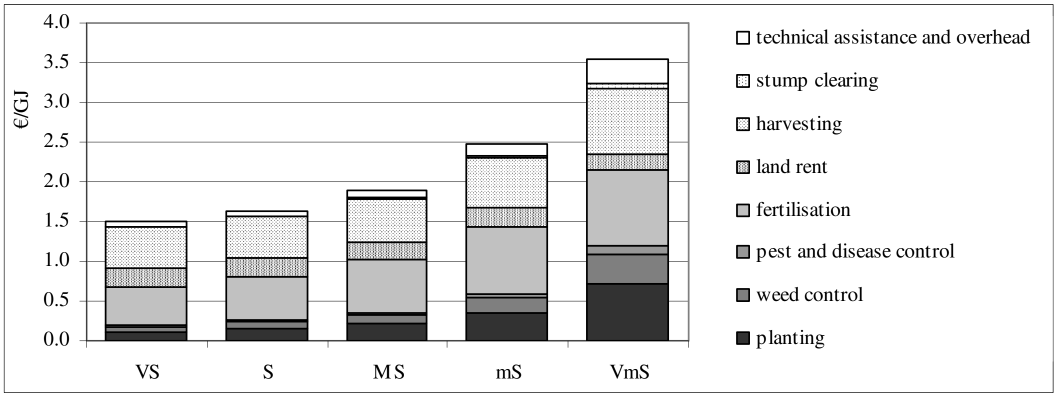


Figure 19a. Cost breakdown in various stage of eucalyptus production and harvesting in Brazil in 2015 for various land suitability classes (€ GJ^{-1}).

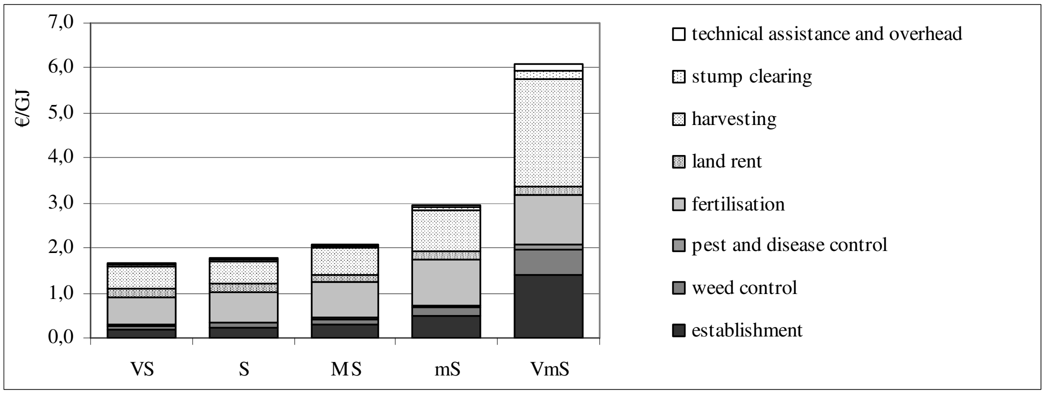


Figure 19b. Cost breakdown in various stage of poplar production and harvesting in Ukraine in 2015 for various land suitability classes (€ GJ^{-1}).

The total costs in Brazil and Ukraine vary roughly between 1.5 € GJ^{-1} to 3.5 € GJ^{-1} and 1.7 € GJ^{-1} to 6.1 € GJ^{-1}, respectively. The costs are higher on low productive areas than in high productive areas, because the fixed costs, such as ploughing and the depreciating of machinery, are divided by a lower yield in the low productive areas compared to the high productive areas. The costs (in € GJ^{-1}) in Brazil are lower than in Ukraine, mainly as a result of the higher yields in Brazil compared to Ukraine.

Table 27. Operationalisation of various areas of concern in the loose and strict set of criteria.

Area of concern	Loose set of criteria	Strict set of criteria
Food supply	The production of bioenergy is not allowed to endanger food supply. The land use required for food production in 2015 is analysed using the methodology described in Smeets (Smeets *et al.* 2004a). Results indicate that technically the efficiency of food production can be increased and large areas surplus land can be generated. Investments to realise these technological potentials may be excluded, because these are considered the responsibility of the government, industry or society as a whole.	The production of bioenergy is not allowed to endanger food supply. The land use required for food production in 2015 is analysed using the methodology described in Smeets (Smeets *et al.* 2004a). Results indicate that technically the efficiency of food production can be increased and large areas surplus land can be generated. Investments to realise these technological potentials may be required and the bioenergy producer should do these. However, no calculations were included due to a lack of suitable methodologies and data.
Deforestation	The production of bioenergy is not allowed to result in deforestation. Forests are excluded as a source of bioenergy and the land under food crop or bioenergy crop production is not allowed to result in deforestation of natural forests, due to an increase of the efficiency of food production. The additional investments to realise these technological potentials are excluded from the costs of bioenergy crop production, because these are considered the responsibility of the government, industry or society as a whole.	The production of bioenergy is not allowed to result in deforestation. Forests are excluded as a source of bioenergy and the land under food crop or bioenergy crop production is not allowed to result in deforestation of natural forests, due to an increase of the efficiency of food production. Investments to realise these technological potentials may be required and the bioenergy producer should do these. However, no calculations were included due to a lack of suitable methodologies and data.
Soil erosion	Soil erosion rates are not allowed to increase compared to conventional agricultural land use. Comparison of soil erosion crop/vegetation management factors for various land use types and crops, shows that soil erosion under bioenergy crop production is likely lower than under conventional crop production and comparable to permanent pastures (Biewinga and Van der Bijl 1996; Ontario 2000; Ma 2001). Therefore, no additional costs are included.	Soil erosion rates are not allowed to increase compared to conventional agricultural land use and must be decreased compared to the natural soil regeneration capacity of 1 t ha^{-1} y^{-1} (OTA 1993). Comparison of soil crop/vegetation management factors for various land use types and crops, shows that soil erosion under bioenergy crop production is likely lower than under conventional crop production and comparable to permanent pastures (Biewinga and Van der Bijl 1996; Ontario 2000; Ma 2001). Soil erosion rates under bioenergy crop production are calculated using the Universal Soil Loss Equation (USLE; (Wischmeier and Smith 1978). Costs to reduce soil erosion are 2.3 € t ha^{-1} y^{-1} based on the average costs of soil erosion prevention measures in the US (Pimentel *et al.* 1995).
Depletion of fresh water resources	Depletion of fresh water resources is not allowed. Evapotranspiration rates are calculated using the CROPWAT software tool of the FAO (FAO 1998a). The evapotranspiration is compared with the (effective) rainfall to indicate the risk of groundwater depletion. Irrigation is not allowed, for ecological and economical reasons; yields are based on rain-fed production. No additional costs to reduce the water use are included, due to a lack of data.	
Nutrient losses and soil nutrient depletion	Soil nutrient depletion is not allowed. Fertilizer requirements are calculated based on the yield level, the nutrient content of the harvested biomass and the nutrient uptake efficiency (Lodhiyal and Lodhiyal in (Biewinga and Van der Bijl 1996; Jorgensen *et al.* 2001; Nario *et al.* 2003; Stape *et al.* 2004).	Soil nutrient depletion is not allowed and nutrient losses must be reduced as far as possible. Fertilizer requirements are calculated based on the yield level, the nutrient content of the harvested biomass and the nutrient uptake efficiency (Lodhiyal and Lodhiyal in (Biewinga and Van der Bijl 1996; Jorgensen and Schelde 2001; Nario *et al.* 2003; Stape *et al.* 2004). The nutrient recovery factor is increased by increase the fertilizer application frequency from one application per rotation cycle to one application per year (Nario *et al.* 2003).

Pollution from chemicals	Pollution from agricultural chemicals must be avoided as far as reasonably is achievable by proper application of chemicals. The pollution from chemicals under various land cover types is estimated (Biewinga and Van der Bijl 1996).	Pollution from agricultural chemicals must be avoided as far as reasonably is achievable. The use of chemicals can be reduced by manual and mechanical weeding, which results in higher labour and machinery costs (McNabb 1994) (IEA 1997).
Employ-ment	The production and trade of bioenergy must contribute to employment. No additional costs are included, because bioenergy crop production always generates direct employment.	The production of bioenergy is not allowed to result in a decrease in employment compared to the baseline situation measured economy-wide. This issue could be further operationalised due to a lack of suitable methodologies and data.
Wages	Wages are based on at least the minimum wages and above the international poverty line (USILA 2002; DB 2003; ILO 2003).	Wages are based on the average wage (ILO 2003).
Child labour	Child labour is not allowed. Costs to prevent child labour are excluded, because these are considered the responsibility of society in general.	Child labour is not allowed and parents are compensated for the loss of family income through higher wages and the costs of education for children. The loss of income from the abolishment of child labour is estimated and added up to the wage of the parents (CR 2004). The costs of education are estimated in the section on education
Education	Education must be available for children. No costs are included, because education is considered the responsibility of the parents, the government or society in general.	Education must be available for children. The average costs for education for an average family are added up to the hourly labour costs (WB 2004a).
Health care	Health care must be available for the workers and their family. Costs for health care are excluded, because health care is the responsibility of society in general.	Health care must be available for the workers and their family. The costs for health care for an average family are added up to the hourly labour costs (WB 2004d)
Bio-diversity	Biodiversity must be protected. 10% of the area is reserved for biodiversity protection, which the lower range of the global area required for biodiversity protection (WBGU 2001).	Biodiversity must be protected. 20% of the area is reserved for biodiversity protection, which the upper range of the minimum area required to protect bioenergy; i.e. 20% of the area is reserved for biodiversity protection (WBGU 2001).

Figure 20a and 20b shows a breakdown of the total costs in the production factors labour, machinery (tractors and harvesters), land rent, and other inputs (chemicals, fertilizers, poles for fencing).

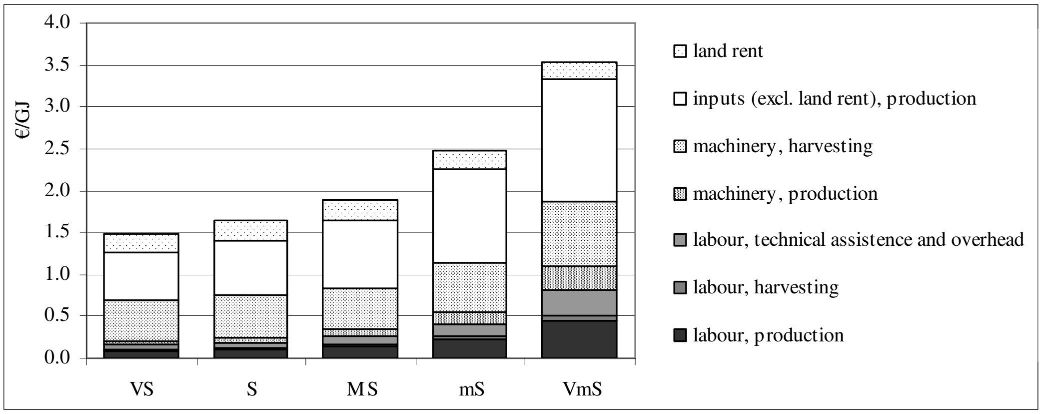


Figure 20a. Cost breakdown in the production factors (labour, machinery, inputs and land rent) of eucalyptus production and harvesting in Brazil in 2015 for various land suitability classes (€ GJ^{-1}).

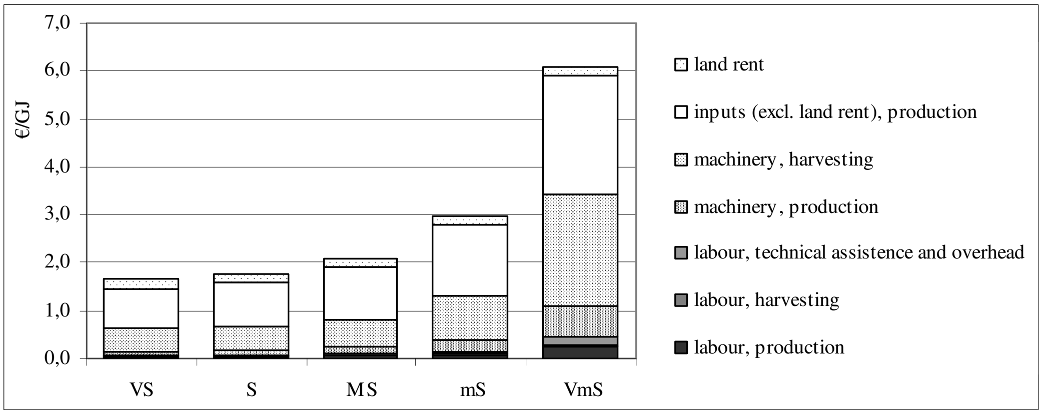


Figure 20b. Cost breakdown in the production factors (labour, machinery, inputs and land rent) of poplar production and harvesting in Ukraine in 2015 for various land suitability classes (€ GJ^{-1}).

The results show that labour, machinery, inputs, and land rent account for some 13%, 33%, 41% and 13% of the total costs in Brazil, respectively. For Ukraine these figures are 5%, 36%, 51% and 9% of the total costs.

Below the impact of the various criteria included in the strict set of criteria on the cost-supply curve are analysed separately, followed an analysis of the total impact on the cost-supply curve.

Health care, education and child labour

The strict set of criteria related to the health care, education and child labour increases the total costs of bioenergy by 6% to 14% on VS to mS areas in Brazil and 4% to 8% on VS to mS areas in Ukraine.

The costs of both health care, education and child labour are added up to the costs of labour. Consequently, the total labour costs per hour increase by half to a factor two in Brazil to roughly one-fourth to two-thrid in Ukraine. However, wages contribute between 10% and 23% of the total bioenergy production costs in Brazil and 4% to 7% of the total bioenergy production costs in Ukraine (the share of labour costs in Brazil is larger than in Ukraine, because wages in Brazil are higher). Consequently, the overall impact of meeting the strict criterion on costs is limited compared to the impact on the labour costs.

The level of costs to meet the strict set of criteria could be an over- or underestimation for multiple reasons. E.g. the costs of health care and education are based on the national average. This approach ignores the quality of the health care and education provided, which may be insufficient and require additional investments.

Wages

The strict set of criteria requires that wages are increased to average wages. For Brazil this implies an increase of the wages (and labour costs) by a factor 2.6 and for Ukraine by a factor 2.0. The final impact on the production costs is much smaller, because wages contribute roughly between a few percent to two-fifth to the total production costs. Consequently, the total increase in costs is limited to ca. one-fourth to half in Brazil and 4% to 7% in Brazil (dependant on the land suitability; present value). We used average wages as a proxy for sustainable level of wages.

In reality wages in agriculture are generally lower than in other sectors of the economy, particularly wages for field labour. This approach may therefore lead to an overestimation of wages. Yet, average wages may also be insufficient to avoid poverty, because in both Ukraine and Brazil poverty is common and average wages may not always be sufficient to avoid poverty. More detailed data based on household surveys in region in which the bioenergy is going to take place are required to accurately estimate wage levels that avoid poverty.

Soil erosion

The reduction of soil erosion rates to the natural rate of soil formation of 1 t ha^{-1} y^{-1} as included in the strict set of criteria results in an increase of the costs of one unit biomass by 6% to 15% in Brazil and 2% to 4% in Ukraine. These data are based on the average costs to prevent soil erosion on slopes with a 6% to 10% slope gradient and an average rainfall profile. The costs in Brazil are higher, because the annual rainfall in Brazil is higher than in Ukraine, which results in a higher risk of soil erosion.

The required reduction in soil erosion rates is the (calculated) soil erosion rate minus the goal of 1 t ha^{-1} y^{-1}. The calculated soil erosion rate could both be over- or underestimated. E.g. the calculations are based on a slope of 100 m length, but in reality this could be longer or shorter, which leads to higher or lower soil erosion rates. The crop/vegetation and management factor (C factor) is calculated based on data found in literature and estimated at 0.05 for eucalyptus and 0.08 for eucalyptus, but this could be overestimated up to a factor ten or underestimated up to a factor seven (see further Appendix D).

The costs to prevent soil erosion are based on the average costs to prevent soil erosion in the U.S.A. Actual costs to prevent soil erosion may be higher or lower. The costs to prevent soil erosion are based on a wide variety of technologies, such as ridge-planting, no-till cultivation, crop rotations, terracing, agroforestry, cover crops and wind breaks. Data on the costs of various technologies were not readily available and vary dependant on the technology. Malik (Malik *et al.* 2000) reports that the use of cover crops in reduced yields in SRWC plantations by 15% to 41%; contour planting in the U.S.A. is reported to increase crop yields by 13% to 25% as a result of increased soil fertility (Pimentel *et al.* 1995). The most advantageous combination of appropriate conservation technologies, soil type, slope gradient, climate and socio-economic circumstances (and consequently costs) requires a more detailed regional approach. In general however, the costs to prevent soil erosion are likely lower than in the U.S.A., because wages are cheaper in Brazil and Ukraine than in the U.SA.

Pollution from agricultural chemicals

The strict set of criteria requires that the use of agricultural chemicals is avoided as far as possible. The use of agricultural chemicals can be limited by replacing chemical treatments by manual operations in combination with optimal selection of tree species and the use of improved (less harmful) pesticides. Figure 21 shows the projected change in cost structure from the replacement of chemical weeding by manual and mechanical weeding.

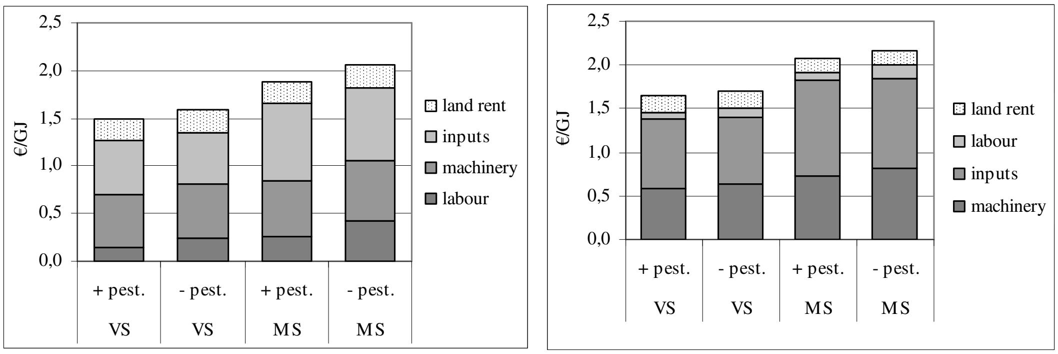


Figure 21. Costs of bioenergy crop production in Brazil (left) and Ukraine (right) with and without the use of pesticides for very suitable (VS) and moderately suitable (MS) areas (€ GJ^{-1}).

Figure 21 shows that in case the use pesticides are replaced by manual and mechanical weeding, the labour and machinery costs increase and the costs required for inputs decreases. Yields are assumed to be the same, because the use of pesticides is largely avoided and replaced by environmentally friendly alternatives. The total costs increase 6% to 16% in Brazil and 3% to 6% in Ukraine.

Note that the costs related to the replacement of herbicides by manual and mechanical weeding are based on the scarce data found in literature. More detailed data based on site-specific conditions, such as tree species, climate, costs of labour and more detailed data on the costs of manual and mechanised weeding are required. Alternatively, one could also use existing data from agriculture as a proxy for the impact on SRWC production costs: yields in organic agricultural are 20% lower than for conventional agriculture, which is the average of a 10% to 30% yield decrease observed in organic agriculture compared to conventional agriculture (FAO 2003b). Further, the production costs decrease, although less than the yield decrease, thus the production costs increase. Note that organic agriculture also includes the abolishment or reduction of the use of fertilizers, which is not specifically included in this section. There are however also examples where a reduction of the use of pesticides and nutrients is both ecologically and economically beneficial (Kartha and Larson 2000).

Nutrient losses

The strict set of criteria requires that soil nutrient depletion is avoided and that nutrient losses are avoided as far as reasonably is achievable. The loss of nutrients is reduced by increasing the uptake (efficiency) of nutrients by the SRWC's by increasing the fertilizer application rate from twice per rotation cycle to 6 times per rotation cycle can reduce nutrient losses. The impact on costs is dual: the costs increase due to the more frequent application (higher labour and machinery costs) and the costs decrease due to the lower demand for fertilizers required avoiding nutrient depletion. Figure 22 shows the total impact on costs.

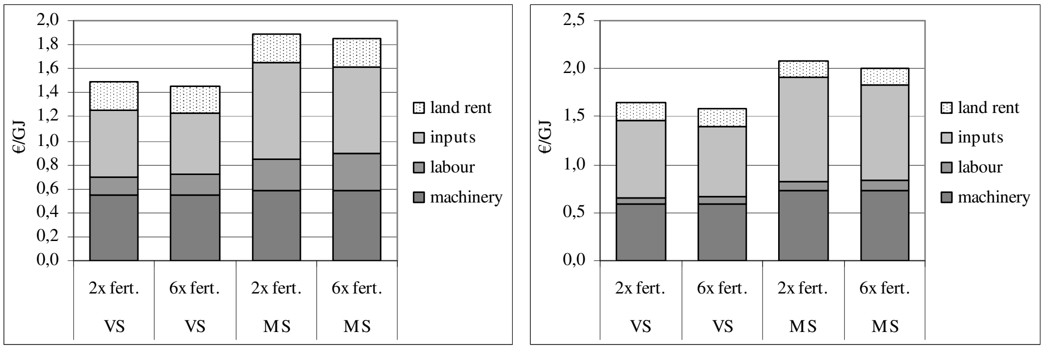


Figure 22. Costs of bioenergy crop production in Brazil (left) and Ukraine (right) based on two fertilizer applications per year (high nutrient losses) and six fertilizer applications per year (low nutrient losses) for very suitable (VS) and moderately suitable (MS) areas (€ GJ^{-1}).

These results in figure 22 indicate that an increase in the fertilizer application rate results in an increase in labour costs, but this increase is compensated by a reduction of the costs of fertilizers. The result is a decrease of the total productions costs of biomass up to 2% in Brazil and up to 4% in Ukraine.

Note that these results are very much dependant on the various (assumptions on) variables, such as the way fertilizers are applied (manually or mechanically), the nutrient content of the harvested biomass, the costs of fertilizers (which vary in time), the costs of labour costs and the fertilizer requirements. E.g. data on the nutrient content of poplar found in literature range roughly by a factor 2; the costs of fertilizer vary by a factor 6 dependant on the type of fertilizer applied (FAO 2003a) and particularly data on the nutrient uptake efficiency seem uncertain, because data found in literature range from roughly 2% to 80%. More detailed data and calculated are required.

Biodiversity

The strict and loose set of criteria result in a decrease of the area available for bioenergy crop production by 10% and 20%, respectively. The areas not used for bioenergy crop production are reserved for bioenergy crop production. We are aware that these percentages are based on an expert judgement of the required protection of representative ecosystems, rather than a biological-physiological assessment of the dynamics of biodiversity in Brazil and Ukraine.

Employment

As explained earlier, bioenergy crop production generates direct employment. In this study the labour requirements are calculated at 17 h ha^{-1} y^{-1}. Estimates in literature range between 0.4 to more than 30 h ha^{-1} y^{-1} (Van den Broek *et al.* 2000a; Berndes *et al.* 2001; Faundez 2003). In this study a relatively labour intensive production system is applied, which is likely due to the low costs of labour in Brazil and Ukraine, although much less labour intensive production systems are also possible.

There are however also various indirect employment effects. Two indirect employment effects are present: first, the effect of the increase in demand for agricultural machinery and other inputs due to bioenergy crop production and the intensification of food production and second the investments in agriculture required to increase the efficiency of food production.

An increase in the food production efficiency (intensification of agricultural production) is in the industrialised regions achieved through mechanisation and further rationalisation and consequently decreasing labour intensity. In case the level of advancement of technology would be increased to a medium level, than some four-fifth of the jobs in agriculture could be lost in 2015 in Brazil and Ukraine compared to the labour intensity estimated from FAO projections on yield levels. The calculations are based on the historic development of labour intensity and productivity observed in industrialised regions during the previous decades. However, an increase in the food production efficiency is not necessarily linked to a decrease in labour intensity in the case of reducing the area agricultural land for bioenergy crop production. The decrease in labour intensity in the industrialised has been the result of various factors, such as the increase labour costs, the decrease in food prices and the advancement of technology. In the case of an increase in the food production efficiency to generate land for bioenergy crop production, the increase in the food production efficiency (above the increase projected to 2015 by the Food Agricultural Organisation) will have to be achieved by means of specifically designed extension programmes, R&D and various other incentives. Increasing labour costs are than not one of the key drivers, which avoid the financial to reduce the labour intensity. Further, the labour intensity of both food and bioenergy production and can be varied by the application of labour intensive, but high yielding, production systems. However, the described above could not be calculated due to a lack of suitable methodologies.

The potential decrease of employment in agriculture is counteracted by the indirect effects from the increase in demand for agricultural machinery and other inputs (e.g. labour, land, chemicals) and additional investments in agriculture to increase the efficiency of food production. The indirect employment effects can be calculated by means of Input-Output (I/O), but this was not possible due to a lack of data.

Land use

A prerequisite for bioenergy crop production in both the strict and the loose set of criteria is that bioenergy crop production is limited to surplus land, i.e. competition with food production and increased deforestation should be prevented. More efficient food production systems result in surplus agricultural land in 2015, but require additional investments in R&D, extension programmes and education of workers in the agricultural sector (other than included in projections of food production efficiency by the Food Agricultural Organisation). The strict set of criteria states that these investments should be at the expense of the bioenergy crop producer.

In Appendix H an approach is presented to calculate the required additional investments to generate surplus agricultural land. The results indicate that the investments are substantial and could double to ten-fold the production costs of SRWC. Note that these calculations are very, very rough and are based on the correlation between crop yield levels and investments in R&D, extension programmes and education of workers in the agricultural sector and are only meant to indicate the impact that this criterion could have. The methodology included in this study ignores any demand-supply interactions, but methods and data to estimate these costs are scarce. More detailed and regional data and research on regional land use dynamics and costs of influencing these dynamics are required.

5.1 Cost-supply curve

Figure 23 gives an overview of the results of the impact on the cost-supply curve of various sustainability criteria. A reference scenario is included, which represents the cost-supply curve of bioenergy crop production in 2015 in case no criteria are included, which is largely similar to the loose set of criteria. Results for the criteria related to employment and land use are excluded and described below.

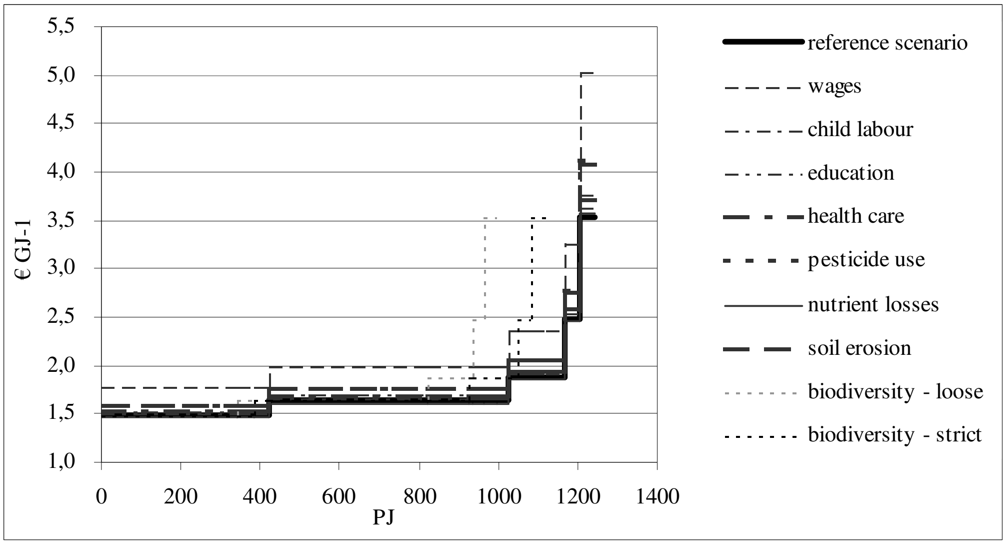


Figure 23a. Cost supply curve for bioenergy crop production is a loose and strict set of criteria in Brazil (Rio Grande do Sul) in 2015 (€ GJ^{-1}).

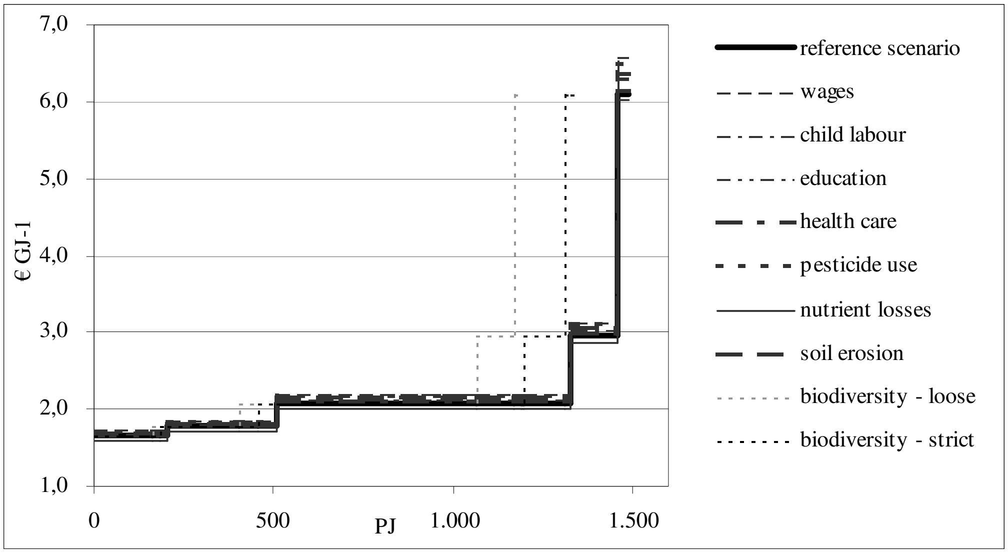


Figure 23b. Cost supply curve for bioenergy crop production is a loose and strict set of criteria in Ukraine in 2015 (€ GJ^{-1}).

As already discussed above, for most criteria the impact on the costs (per unit biomass) is limited to a few percent up to roughly one fourth. The impact of the various sustainability criteria is the largest on the least productive areas (per unit biomass), because the costs to meet the criteria are fixed, while the biomass yield is the lowest on the least productive areas. Note that in reality less intensive management system could be used to optimize profit, but this aspect is not included in this study.

6. Overall discussion and conclusions

Results of previous studies (e.g. (Leemans *et al.* 1996; Fischer *et al.* 2001a; Hoogwijk *et al.* 2004; Smeets *et al.* 2004a, b) have highlighted that various world regions are in theory capable of producing significant amounts of bioenergy crops without endangering food supply or further deforestation.

A prerequisite for *sustainable* large-scale production and trade of biomass (biotrade) is that production and trade is beneficial with respect to the social well being of the people (people), the ecosystem (planet) and the economy (profit).

The goal of this study was to make a first attempt to analyse the impact on the potential (quantity) and the costs (per unit) of bioenergy that the compliance with various sustainability criteria brings along. This nature of this work is exploratory, because of the broad set of issues covered very little work has been published on which we could build. Ukraine and Brazil are used as case studies, because both regions are identified as promising bioenergy producers (Smeets *et al.* 2004b).

This study is part of the FAIRBiotrade project, which is aimed to identify and quantify the impact of sustainability criteria on the potential of bioenergy. Previous work includes an identification of sustainability criteria relevant for bioenergy (Lewandowski and Faaij 2004), an assessment of the environmental and economic costs of long distance biotrade (Hamelinck *et al.* 2003) and an assessment of bioenergy production potentials in 2050 in various world regions (Smeets *et al.* 2004c). This work is funded by NOVEM (Netherlands Organisation for Energy and the Environment) and the Dutch electricity company Essent N.V.

Poplar production in Ukraine and eucalyptus production in Brazil are used as case studies, because both regions are identified as promising bioenergy producers (Smeets *et al.* 2004b). For both regions cost calculations are included for a representative intensive commercial short rotation forestry management system. The year 2015 was chosen as a target, because this allows a 10-year period required to implement changes in land-use, establish plantations and develop a framework to implement criteria.

A list of 127 criteria relevant for sustainable biomass production and trade is composed based on an extensive analysis of existing certification systems on e.g. forestry and agriculture (Lewandowski *et al.* 2004). To be able to analyse the impact of these criteria on the cost and potential of bioenergy, the various criteria needed to be translated into a set of concrete (measurable) criteria and indicators that have an impact on the management system (costs) or the land availability (quantity). 12 key criteria are included in this study: competition with food production and deforestation, child labour, wages, employment, soil erosion, water use, nutrient losses, pollution from chemicals, biodiversity, education and health care. This is a reasonable basis, since many criteria cannot be translated into practically measurable indicators and/or measures and many criteria are related and/or overlap.

To account for differences in the perception of sustainability, a strict and loose set of criteria are identified. The impact of various sustainability is expressed in the costs or potential of bioenergy crop production (excluding monitoring, certification costs and other costs related to the certification itself).

Figure 24 shows the production costs of bioenergy in the reference scenario (including already a loose set of criteria!) and the additional costs resulting from meeting the criteria included in the strict set based on VS and mS areas. Compliance with the loose set of criteria as defined in this study does not result in an increase of costs compared to the reference scenario. Therefore, the costs of the reference scenario are the same as in the loose set of criteria; the only difference is that in the potential for bioenergy crop production is decreased to meet the criteria related to biodiversity protection.

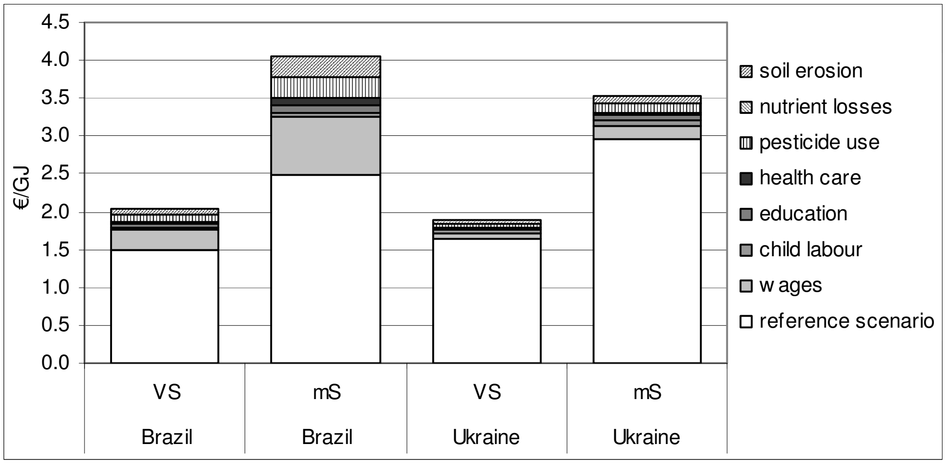


Figure 24. The costs of bioenergy production in the reference scenario (loose set of criteria) and the costs of various sustainability criteria included in the strict set of criteria. VS = very suitable areas, mS = marginally suitable areas.

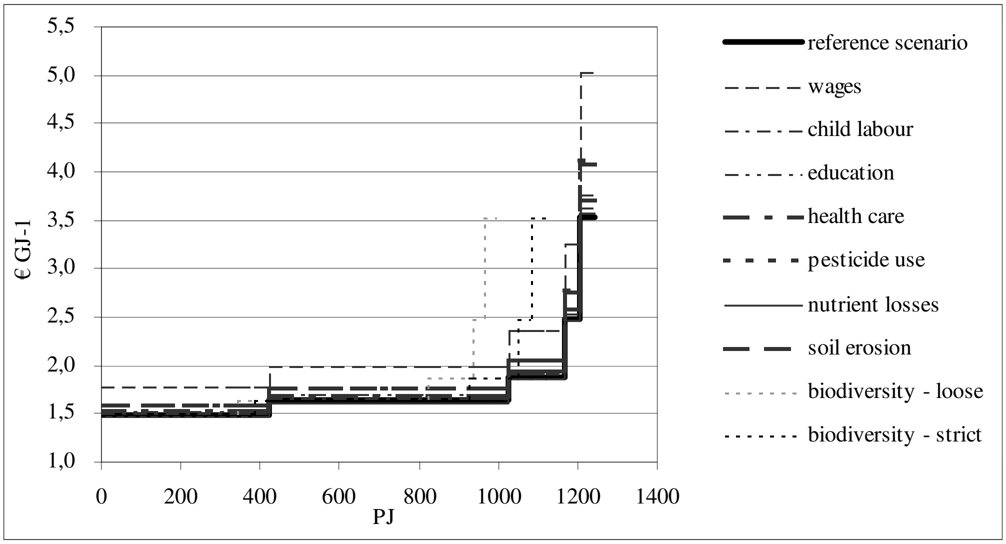
Figure 24 shows that the overall impact on costs is estimated at 35% up to 88% in Brazil for marginally suitable lands and 10% to 26% in case of the Ukraine. In general, the difference in impact of various criteria between Brazil and Ukraine is caused by the difference in wages in Brazil and Ukraine, which are higher in Brazil than in Ukraine.

Figure 25 shows the impact of the various criteria on the cost-supply curves for the study regions. A reference scenario is included that represents the situation in which no criteria are included, which is largely similar to the loose set of criteria. Results for the criteria related to employment and land use are excluded and described below. Note that the largest part of the potential is represented by better quality soils.

The total costs for bioenergy crop production in Brazil and Ukraine are calculated at 1.5 € GJ^{-1} to 3.5 € GJ^{-1} and 1.7 € GJ^{-1} to 6.1 € GJ^{-1} dependant on the land suitability class (and respective yields), including the impact of basic levels for the various sustainability criteria. The criteria are grouped into three clusters:

Land use patterns
Land use patterns include criteria related to the avoidance of deforestation, competition with food production and protection of natural habitats. The theoretical potential to generate surplus agricultural land in 2015 was estimated, following the methodology of Smeets (2004a). This methodology includes, among other variables, population growth, income growth and the efficiency of food production. Results indicate that (in theory) large areas surplus agricultural land could be generated without further

deforestation or endangering the food supply. However, additional investments in agricultural intensification may be required to realise these technical potentials.



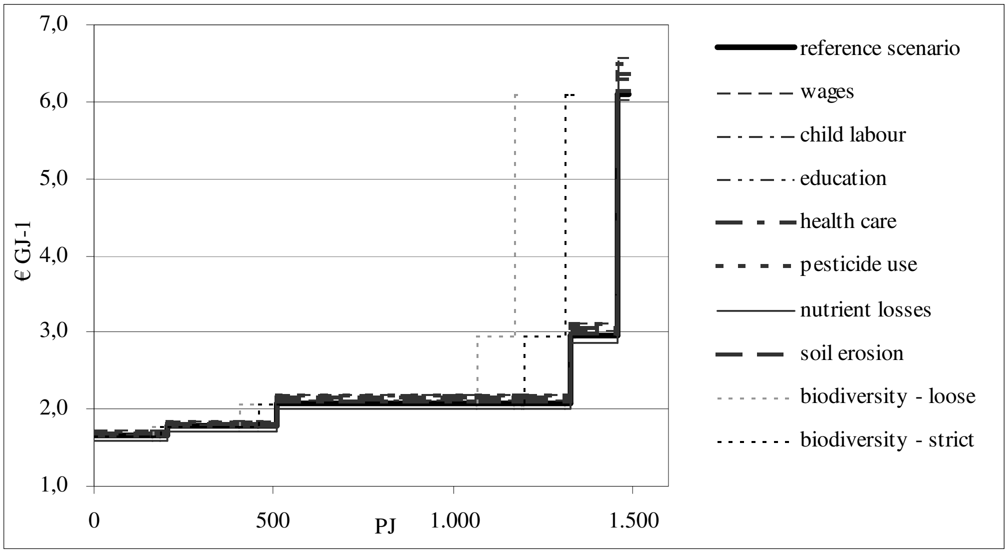


Figure 1. Cost supply curve for bioenergy crop production is a loose and strict set of criteria in Brazil (Rio Grande do Sul; top figure) and Ukraine (bottom figure) in 2015 (€ GJ^{-1}).

Socio-economic criteria

Socio-economic criteria include criteria related to e.g. child labour, (minimum) wages, employment, health care and education. Compliance with the various criteria results in additional (non) wage labour costs, which are a separate cost item in the calculation of the production costs of biomass. The loose set of criteria does not influence the costs or quantity of bioenergy crop production. The strict criteria related to child labour, health care and education has a very limited impact on the costs of bioenergy crop production, between up to 8% in Ukraine and up to 14% in Brazil. The impact of the strict criterion related to wages is larger, which results in an increase of the costs of bioenergy crop production of up to 8% in Ukraine to up to 42% in Brazil. In general, the impact of the strict set of criteria is limited, because labour costs account for maximum two-fifth of the total production costs.

Another key socio-economic issue is the generation of direct and indirect employment. The direct impact of bioenergy crop production on employment is calculated based on the labour requirement for the various management activities. The indirect impact of bioenergy crop production consists of two aspects. First, the employment effect of the increase in demand for agricultural machinery and other inputs due to bioenergy crop production and the intensification of food production. Second, the investments in agriculture require increasing the efficiency of food production, which may lead to more mechanisation and a loss of employment. Indirect (employment) effects of increased agricultural productivity and additional biomass production are very likely to be positive though. Due to a lack of data and suitable methodologies the indirect employment effects could not be calculated in the framework of this study, but these indirect effects could be significant and require further study.

Environmental criteria

Environmental criteria include criteria related to e.g. soil erosion, fresh water use, pollution from the use of fertilizers and agricultural chemicals. Compliance with various environmental criteria requires an adaptation of the bioenergy crop management system, e.g. an increase in mechanical and manual weeding to avoid the use of agricultural chemicals. For the loose set of criteria no additional costs were required. The impact of the strict criteria related to soil erosion is limited to 15% and 4% maximum in Brazil and Ukraine, respectively. The impact of the strict set of criteria related to pollution from chemicals is up to 16% in Brazil and up to 6% in Ukraine. The strict set of criteria related to nutrient leaching and soil depletion results in a cost decrease of up to –2% in Brazil and up to –4% in Ukraine, which is the combined effect of increasing labour and machinery costs and decreasing fertilizer costs. For the protection of biodiversity protection, 10 to 20% of the surplus agricultural land could be set aside, although we acknowledge that this may be insufficient for the protection of biodiversity and that additional or other requirements for the plantation management may be required. Due to a lack of data and suitable methodologies, indirect effects from the intensification of agriculture were not included, but these are potentially significant. A logical consequence would be that similar criteria should be in please for conventional agriculture as for biomass production.

The total costs increase by 35% to 88% in Brazil and 10% to 26% in Ukraine, dependant on the land suitability class (yield). The highest impact on costs (in € odt^{-1}) can be found on the lowest productive areas, because a large share of the costs are fixed, while the yield level depends on the land suitability class. For many of the areas of concern included in this study, data and methods used to quantify the impact of sustainability criteria on costs or potential are crude and therefore uncertain. The ecological criteria require a more site-specific analysis with specific attention for e.g. soil type, slope gradient and rainfall. The social oriented criteria require more reliable and detailed data e.g. at a household level data and better methodologies to analyse indirect effects. Further research in this area is needed to provide more accurate estimates of the impact that various sustainability criteria may have on the costs and potential of bioenergy crop production.

Overall, the results of this study indicate that:

- In several key world regions biomass production potentials can be very significant on foreseeable term (10-20 years from now). Feasible efficiency improvements in conventional agricultural management (up to moderate intensity in the case regions studied) can allow for production of large volumes of biomass for energy, without competing with food production, forest or nature conservation. The key pre-condition for such a development are improvements in the efficiency of agricultural management.
- it seems feasible to produce biomass for energy purposes at reasonable cost levels and meeting strict sustainability criteria at the same time. Setting, strict, criteria that generally demand that socio-economic and ecological impacts should ***improve*** compared to the current situation will make biomass production more expensive and will limit potential production levels (both crop yield and land surface) compared to a situation that no criteria are set. However, the estimated impact on biomass production costs and potential is far from prohibitive. For the case studied (SE Brazil and Ukraine) estimated biomass production costs under strict conditions are still attractive and in the range of 2 Euro/GJ for the largest part of the identified potentials.
- It should be noted that such improvements, when achieved, also represent an economic value, which could be considerable (e.g value of jobs, improvement of soil quality, etc.). Such ‘co-benefits’ could especially be relevant for the less productive, marginal lands. Such a valuation has however not been part of this study.
- The results are indicative, based on a desktop approach (and not on field research) and pay limited attention to macro-effects as indirect employment and both potential negative and positive impacts on conventional agriculture. More work to verify and refine the methodological framework developed is therefore needed, preferably involving specific regional studies and including regional/national stakeholders.

The approach proposed does however provide an original and quantitative framework that can be used as a basis for designing sustainable biomass production systems and monitoring existing ones. Besides more detailed and refined approaches, the framework may also be developed into a more simplified quickscan method to identify and monitor biomass production regions. It is recommended to develop and deploy such a quantitative framework for future biomass production projects in different settings.

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Appendix A. Criteria with relevance for sustainable biomass trade

Table 1: Criteria with relevance for sustainable biomass trade (+ = included, - =excluded).

Criteria number				Loose version	Strict version
Social criteria					
Labour conditions	1	Freedom of Association and collective bargaining	-		
	2	Prohibition of forced labour	-		
	3	Prohibition of discrimination and equal pay for equal work	-		
	4	Least minimum wages	+	At least minimum wages are required.	See the loose set of criteria and in addition at least average wages are included.
	5	No illegal overtime	-		
	6	Equal pay for equal work	-		
	7	Regulations are in place to protect the rights of pregnant women and breastfeeding mothers	-		
Protection of human safety and health	8	Protection and promotion of human health	+	Not the responsibility of the bioenergy producer	The costs of health care are included in the labour costs.
	9	Farmers, workers etc. are not unnecessarily exposed to hazardous substances or risk of injury	+	Not the responsibility of the bioenergy producer	The use of agricultural chemicals is avoided as far as reasonably is achievable.
	10	A safe and healthy work environment, with aspects such as machine and body protection, sufficient lighting, adequate indoor temperature and fire drills.	+	Included in overhead and non-wage labour costs.	Included in overhead and non-wage labour costs.
	11	Availability of document routines and instructions on how to prevent and handle possible near-accidents and accidents.	+	Included in overhead and non wage labour costs	Included in overhead and non wage labour costs
	12	Training of all co-workers is performed and documented; training ensures that all co-workers are able to perform their tasks according to the requirements formulated on health protection and environmental benign management or resources.	+	Included in overhead and non wage labour costs	Included in overhead and non wage labour costs
Rights of children, women, indigenous people and discrimination.	13	Elimination of child labour: a minimum age and a prohibition of the worst form of child labour	+	The minimum age for the employment of children is 15 year.	Same as loose and in addition the wages of the parents are increased by the loss of income from child labour and the average costs of education.
	14	Children have access to schools, work does not jeopardize schooling	+	Not the responsibility of the bioenergy producer	Same as loose and in addition the wages of the parents are increased by the loss of income from child labour and the average costs of education.
	15	Indigenous people's and tribe's rights have to be respected	-		
	16	Recognizing and strengthening the role of indigenous people and their communities	-		
	17	Women should not be discriminated and their rights have to be respected	-		
	18	Spouses have the right to search work outside the entity where the husband works	-		
Access to resources ensuring adequate quality of life	19	Farmers are content with their social situation	-		

	20	Access to potable water, sanitary facilities, adequate housing, education and training, transportation, and health services	+	Partially in included in 4 and 8 to 12.	Partially in included in 4 and 8 to 12
	21	Promoting of education, public awareness and training	+	Included in 12, 20	Included in 12, 20
	22	Market access for small farmers and producers	-		
	23	Equitable access to forest/farm certification among all forms of forest/farm users and tenure holders	-		
	24	Establishment of a communication systems that facilitates the exchange of information	+	Including in 10 to 12 and in costs for technical assistance.	Including in 10 to 12 and in costs for technical assistance.
Food and energy supply and safety	25	Enough food of sufficient quality is available.	+	An assessment of the impact of bioenergy production on the local supply of food and energy supply is carried out. Bioenergy production is only allowed on previously agricultural land. The surplus is dependant on the yield level, which is determined by the level of agricultural technology applied. No additional costs are included.	An assessment of the impact of bioenergy production on the local supply of food and energy supply is carried out. Bioenergy production is only allowed on previously agricultural land. The surplus is dependant on the yield level, which is determined by the level of agricultural technology applied. To make efficiency gains possible, investments in infrastructure, training and R&D are required
	26	Biomass production should not lead to severe competition with food production and the shortage of local food supply	+	Included in 25	Included in 25
	27	Energy supply in the region of biomass production should not suffer from biomass trading activities	+	Included in 25	Included in 25
Capacity building	28	Local organizations, institutions or companies should be involved in the process, e.g. control and certification	-		Excluded
	29	Marginalized social groups should play and equitable role in certification processes	-		Excluded
	30	Jobs should be generated	+	The number of jobs generated (directly and indirectly) as a result of bioenergy production should be higher than a situation without bioenergy crop production.	The number of jobs generated (directly and indirectly) as a result of bioenergy production should be higher than a situation without bioenergy crop production.
	31	Trade-related skills development and social justice oriented capacity building are facilitated through learning exchanges between trading partners	-		
	32	Building and use of local labour and skills	+	Included in costs for technical assistance.	Included in costs for technical assistance.
Combating Poverty	33	The activity should contribute to poverty reduction	+	Included in 4, 8, 12, 13, 14, 20, 21	Included in 4, 8, 12, 13, 14, 20, 21
Democratic participation	34	Stakeholder involvement in the decisions that concern them	-		
Land ownership	35	Avoidance of land tenure conflicts	-		
	36	Land ownership should be equitable	-		
	37	Tenure and use rights shall be clearly defined, documented and legally established	-		
	38	Projects should not exclude poor people from the land in order to avoid leakage effects	+	Included in 30.	Included in 30.
Community (institutional) well-being	39	Farms must be "good neighbours" to nearby communities and a part of the economic and social development	-		
	40	A basis is created for strengthening the mutual confidence between business and the society in which they are active	-		
	41	Involvement of communities into management planning, monitoring and implementation	-		

Fair trade conditions	42	Transparency and Accountability of Negotiations	-		
	43	Direct and long-term trading relationships	-		
	44	Fair and equal remuneration – All supply chain partners are able to cover costs and receive fair remuneration for their efforts through prices that reflect the true value of the product. Risk sharing mechanisms are actively encouraged	-		
	45	Communication and Information flow – Supply chain partners communicate openly with each other showing a willingness to share information	-		
Acceptance	46	Acceptance of the production methods by producer and consumer	-		
	47	The activities do not lead to disadvantages for the local population like losses of jobs or food shortage	+	Included in 25, 26, 27, 30.	Included in 25, 26, 27, 30.
	48	The activity carries advantages for the local population	-		
Economic criteria					
Viability of the business infrastructure development, acquisition of machines and to meet day-to-day running of the operation	49	The business has to be economically viable	+	A calculation is made of the price of bioenergy. The cost price of bioenergy production and trade can be used as an indicator to what extend bioenergy production is economically attractive compared to other GHG mitigation options.	A calculation is made of the price of bioenergy. The cost price of bioenergy production and trade can be used as an indicator to what extend bioenergy production is economically attractive compared to other GHG mitigation options
	50	Minimization of costs to ensure competitiveness	+	Included in 49	Included in 49
	51	There is sustained and adequate funding for running the operation, i.e. the liquidity of cash flow to support	-		
Long term perspective	52	Long-term commitments, contracts and management plans	-		
Strength and diversification of local economy	53	The activity should contribute to strengthening and diversifying the local economy	-		
	54	Local labour and skills should be usable	+	Included in 30.	Included in 30.
	55	Professional and dedicated human resources are enhanced	+	Included in 32	Included in 32
Reliability of resources	56	Minimization of supply disruptions	-		
	57	Supply security for the biomass consumer	-		
	58	No over dependencies on a limited set of suppliers should be created	-		
Yields	59	Sustainable rate of harvesting - Forest should only be harvested at the rate that they regrow	-		
	60	Agricultural yields should be maintained on an economic viable and stable level	+	Various level of advancement of agricultural technology are included which are based on long-term stable yields. The various levels of agricultural technology result in different price levels that can be used to assess the economic viability.	Various level of advancement of agricultural technology are included which are based on long-term stable yields. The various levels of agricultural technology result in different price levels that can be used to assess the economic viability.
	61	A management plan that describes the operational details of production is in place	-		
	62	A comprehensive development and research program for new technologies and production processes is in place	+	Partially included in technical assistance.	Partially included in technical assistance.

No blocking of other desirable developments	63	The activity should not block other desirable developments	-		
Ecological criteria					
Protection of the atmosphere	64	Reduction and minimization of greenhouse gas emissions	-		
	65	Efficient use of energy	-		
	66	Use of renewable resources	-		
	67	Low nitrogen emissions to the air	-		
	68	No use of persistent organic pollutants (POPs) and substances that deplete the ozone layer	-		
Preservation of existing sensitive ecosystems	69	Avoidance of pollution of natural ecosystems neighbouring the fields	-		
	70	Prevention of nutrient leaching	-		
	71	Plantations should not replace forests	+	An analysis of various land use scenarios is carried out in which forests are excluded from bioenergy production.	An analysis of various land use scenarios is carried out in which forests are excluded from bioenergy production.
	72	Maintenance of high conservation value forests	+	Included in 71.	Included in 71.
Conservation of biodiversity	73	No use of GMOs	+	Various levels of agricultural technology are included to project bioenergy plantation yields, but GMO's are not allowed.	Various levels of agricultural technology are included to project bioenergy plantation yields, but GMO's are not allowed
	74	Careful/no use of exotic species, their monitoring and control	-		
	75	Prevention of spreading of diseases	-		
	76	Environmentally sound management of biotechnology	-		
	77	Consideration of the needs of nature and species protection	+	An assessment is made of the impact of bioenergy production systems on the biodiversity of large species (e.g. birds) compared to a reference vegetation cover.	Same as loose.
	78	The development and adoption of environmentally friendly non-chemical methods of pest management should be promoted and it should be strived to avoid the use of chemical pesticides	+	Not included.	The use of chemicals is avoided as far as reasonably is achievable.
	79	Preservation of habitats	+	Included in 72, 77, 78	Same as loose.
Conservation and improvement of soil fertility – avoidance of soil erosion	80	No impoverishment of the soil; nutrient balances should remain in equilibrium	-		
	81	Optimized utilization of the soil's organic nitrogen pool	-		
	82	Measures to prevent soil erosion are applied and described in a management plan	+	A soil erosion assessment is carried out. Soil erosion rates of bioenergy crops can be compared to conventional crops and/or acceptable soil erosion levels. Conversion of land use types into land use types with higher erosion susceptibility is allowed.	Same as loose version, but including the criteria that the absolute level of soil erosion is not allowed being above sustainable levels.
	83	No accumulation of heavy metals in soil	-		
	84	No irreversible soil compaction; measures to prevent soil compaction are taken and described in a management plan	-		
	85	No pesticide residues in the soil	+	Included in 78.	Included in 78.

Conservation of ground and surface water	86	No depletion of ground and surface water resources	+	A simple water balance is composed, based on which the water use of bioenergy crops can be compared to various other types of land use and compared to natural rainfall.	A simple water balance is composed, based on which the water use of bioenergy crops can be compared to various other types of land use and compared to natural rainfall.
	87	Protection of the quality and supply of freshwater resources	+	Included in 86	Included in 86
	88	Avoidance of pollution of ground and surface water	+	Included in 78.	Included in 78.
	89	No eutrophication of surface water by phosphorus emissions	+	Included in 78.	Included in 78.
	90	No pesticide residues in the water	+	Included in 78.	Included in 78.
Combating of deforestation	91	Plantations should not replace forests	+	Included in 71.	Included in 71.
	92	Sustainable harvest rates – harvest at the rate the forest regrows	-		
	93	Limitations for the size of the harvested areas	+	Bioenergy production is only allowed on surplus areas as analysed in 25 and 26.	Same as loose.
	94	No logging activities in protected forests	+	Included in 71.	Included in 71.
Combating desertification and drought	95	Measure to comate desertification and drought are taken and described in a management plan	+	Included in 86.	Included in 86.
Landscape view	96	Increase and improvement of the variation of the landscape	-		
	97	Conservation of typical landscape elements	-		
Conservation of non-renewable resources	98	Efficiency in the use of natural resources, including energy	-		
	99	Positive energy balance	+	Included in 64.	Included in 64.
	100	Minimization of the use of raw material, resources and land	-		
	101	Focus on increased efficiency by increasing filling rates, decreasing fuel consumption and by using transport modes that release less greenhouse gases	-		
	102	Minimization of phosphorus extraction from non-renewable deposits	+	Various types of agricultural management are included that vary with respect to e.g. fertilizer use.	
Waste management	103	Minimization of wastes	-		
	104	Sorting of wastes	-		
	105	Proper handling and disposal of waste	-		
	106	Recycling of waste where possible	-		
	107	Recycling of ashes from biomass combustion	-		
	108	Environmental training of employees, to facilitate waste sorting and initiate energy saving.	-		
	109	Environmental checklist on waste management, training of employees etc.	-		
Environmental additionally	110	Projects have to be environmental additional by improving the environmental situation against a baseline (status quo)	+	Included in 64-102.	Included in 64-102.
General criteria					
Compliance with laws and international agreements	111	Activities have to comply with national laws and international agreements	-		
	112	All applicable and legally prescribed fees, royalties, taxes and other charges shall be paid	-		

	113	In signatory countries, the provisions of all binding agreements such as CITES, ILO Conventions shall be respected.	-		
Traceability	114	Biomass has to be traceable	-		
	115	Biomass from non-certified resources can not enter the trade chain	-		
	116	A chain-of-custody control system is in place	-		
Avoidance of leakage effects	117	(Negative) leakage effects should be avoided	-		
	118	People should not involuntarily be driven from their land	-		
	119	The biotrade activity provides local people with income opportunities that are at least equivalent in quality and quantity to the baseline situation (i.e. situation without biomass trade activity)	-		
Strengthening the role of non-governmental organisations	120	The role of non-governmental organizations should be strengthened	-		
Improvement of conditions at local level	121	Generation of jobs	+	Included in 30.	Included in 30.
	122	Generation of education opportunities	+	Included in 20, 21, and 24.	Included in 20, 21, and 24.
	123	Capacity building	-		
	124	Support of infrastructure development	+	Included in 20.	Included in 20.
	125	Enhancement of democratic development	-		
	126	Increase of (farmers) income	+	Included in 4.	Included in 4.
	127	Improvement of environmental management at local level	-		

Appendix B. Key cost data for eucalyptus and poplar production.

Table 2. Key cost and labour data for eucalyptus and poplar production (€ are in € of 2002).

	Eucalyptus					Poplar			
	Cost description	**value**	**unit**	**source**		**Cost description**	**value**	**unit**	**source**
1.0	General data				1.0	General data			
1.1	Wages				1.1	Wages			
	Field worker	2.30	€/h	calculated		Field worker	0.78	€/h	idem
	Supervisor	5.78	€/h	calculated		Supervisor	1.65	€/h	idem
1.2	Machinery				1.2	Machinery			
	Tractor	9.38	€/h	(WSRG 1994)		Tractor	9.38	€/h	idem
1.3	interest rate	7	%	same as (WSRG 1994) and	1.3	interest rate	7	%	idem
2.0	Soil preparation				2.0	Soil preparation			
	tractor, ploughing	0.72	h/ha	(Van den Broek *et al.* 2000a)		tractor, ploughing	0.72	h/ha	idem
	tractor, deep ploughing	1.8	h/ha	(Van den Broek *et al.* 2000a)		tractor, deep ploughing	1.8	h/ha	idem
	labour, ploughing	0.72	h/ha	same as tractor hours		labour, ploughing	0.72	h/ha	idem
	labour, deep ploughing	1.8	h/ha	same as tractor hours		labour, deep ploughing	1.8	h/ha	idem
3.0	Fencing				3.0	Fencing			
	labour	20	h/ha	(Faundez 2003)		labour	20	h/ha	idem
	material and machinery	314	€/ha	(Faundez 2003)		material and machinery	314	€/ha	idem
4.0	Planting				4.0	Planting			
4.1	plants	2100	plants/ha	(Faundez 2003)	4.1	plants	2750	plants/ha	idem
	plant costs	0.05	€/plant	estimated based on range found in literature		plant costs	0.05	€/plant	assumed same as eucalyptus
4.2	planting				4.2	Manual planting			
	labour	28	h/ha	(Van den Broek *et al.* 2000a)		labour, fieldworkers	36	h/ha	idem
	labour, supervisor	0.31	h/ha	(Van den Broek *et al.* 2000a)		labour, supervisor	0.31	h/ha	idem
	labour, transport of plants	1.7	h/ha	(Van den Broek *et al.* 2000a)		labour, transport of plants	1.7	h/ha	idem
	tractor, transport of plants	1.7	h/ha	(Van den Broek *et al.* 2000a)		tractor, transport of plants	1.7	h/ha	idem
	labour, transport of personnel	1.4	h/ha	(Van den Broek *et al.* 2000a)		labour, transport of personnel	1.4	h/ha	idem
	tractor, transport of personnel	1.4	h/ha	(Van den Broek *et al.* 2000a)		tractor, transport of personnel	1.4	h/ha	idem
5.0	Weed control				5.0	Weed control			
5.1	Weeding, natural, manual				5.1	Weeding, manual			
	labour	23	h/ha	(Van den Broek *et al.* 2000a)		labour	23	h/ha	idem
5.2	Mechanical weeding				5.2	Weeding, mechanical			
	tractor	2.4	h/ha	(Van den Broek *et al.* 2000a)		tractor	2.4	h/ha	idem
	labour	2.4	h/ha	(Van den Broek *et al.* 2000a)		labour	2.4	h/ha	idem
5.3	Chemical weeding				5.3	Weed control, chemical			
	tractor	1.2	h/ha	(Faundez 2003)		tractor	1.2	h/ha	idem
	labour	1.2	h/ha	same as tractor		labour	1.2	h/ha	idem
	chemical	90	€/ha	(Faundez 2003)		chemical	90	€/ha	idem
6	Fertilisation				6	Fertilisation			
	labour	12	h/ha	(Faundez 2003)		labour	12	h/ha	idem
	fertilizers, VS areas	68	€/ha	various, own calculations		fertilizers, VS areas	52	€/ha	idem
	fertilizers, mS areas	39	€/ha	various, own calculations		fertilizers, mS areas	36	€/ha	idem
7	Pest and disease control				7	Pest and disease control			
7.1	Pesticides				7.1	Pesticides			
	labour	8	h/ha	(Faundez 2003)		labour	8	h/ha	idem
	pomp	2	€/ha	assumption		pomp	2	€/ha	idem
	chemicals	4	€/ha	(Faundez 2003)		chemicals	4	€/ha	idem
7.2	Fungicides				7.2	Fungicides			
	labour	8	h/ha	Faundez		labour	8	h/ha	idem
	pump	2	€/ha	assumption		pump	2	€/ha	idem
	chemicals	1	€/ha	(Faundez 2003)		chemicals	1	€/ha	idem
8	Land rent				8	Land rent			
	land rent, VS areas	104	€/ha	(FAO 1998b), own calc.		land rent, VS areas	48	€/ha	idem
	land rent, mS areas	35	€/ha	(FAO 1998b), own calc.		land rent, mS areas	16	€/ha	idem
9	Harvesting				9	Harvesting			
	Claas harvester	230	k€/#	(Gigler *et al.* 1999)		Claas harvester	230	k€/#	idem
	tractor	81	k€/#	(Gigler *et al.* 1999)		tractor	81	k€/#	idem
	trailer	16	k€/#	(Gigler *et al.* 1999)		trailer	16	k€/#	idem
	harvesting speed, VS areas	1.9	h/ha	(Gigler *et al.* 1999), own calc.		harvesting speed, VS areas	1.9	h/ha	idem
	harvesting speed, mS areas	0.5	h/ha	(Gigler *et al.* 1999), own calc.		harvesting speed, mS areas	0.5	h/ha	idem
	labour, VS areas	7.7	h/ha	(Gigler *et al.* 1999), own calc.		labour, VS areas	7.7	h/ha	idem
	labour, mS areas	2.0	h/ha	(Gigler *et al.* 1999), own calc.		labour, mS areas	2.0	h/ha	idem
10	Stump removal				10	Stump removal			
	tractor and other machinery	210	€/ha	(Hartsough *et al.* 1994), own calc.		tractor and other machinery	210	€/ha	idem
	labour	5.9	h/ha	(Hartsough and Richter 1994), own calc.		labour	5.9	h/ha	idem

Note that data on the costs of SRWC production are difficult to compare, because of:

- Regional differences resulting from differences in management systems, which on their turn are dependant on climate, soil suitability, the costs of the various production factors (labour, machinery, input land rent).
- Fluctuations in exchange rates. Both in Brazil and Ukraine the national currency is depreciated considerably compared to the euro over the last decade. The base year used in this study is 2002. Conversion of historic figures of production costs, either expressed in reais or US $ can be converted into 2002 euro's in two ways. First, by converting from e.g. 1998 reais to euros using the 1998 exchange rate data and than by converting 1998 euros to 2002 euros based on the euro GDP deflator. Second, by converting from 1998 reais to 2002 reais based on the reais GDP deflator and than by converting the reais to euro based on the exchange rate in 2002. These two methods do not necessarily give the same result. There is also no good or wrong methodology. In this study the first method is used, because the calculated cost price of bioenergy in Brazil is similar to the present price of bioenergy.

Site preparation

Site preparation is a crucial part of plantation management, because it reduces weed competition, which is crucial during the establishment phase. Site preparation includes (deep) ploughing and fencing. Data on the input of labour, machinery and other materials are and the costs of these items are derived from various sources as shown in table 2.

Planting

The cost of planting is calculated using the formula

$$C = d * c + l * w + p * m$$

C = costs of planting (euro ha^{-1})

d = planting density (ha^{-1}). Planting densities depend on various conditions, e.g. soil type, climate, species, purpose of the plantation, and quality of the planting material. The yield data used in this study for poplar production in Ukraine are based on a crop growth model operated by the IIASA which states that the planting density is 2500 plants ha^{-1} (Fischer *et al.* 2005). Note that typical planting densities in commercial poplar plantations are significantly higher, some 15000 plants ha^{-1} (DEFRA 2002), because higher planting densities in general give higher yields. Eucalyptus planting densities in Brazil range from 1600 stems ha^{-1} (for pulp and paper fibre production) to 2100 stems ha^{-1} (for charcoal production) (IEA 1997). Considering the purpose of wood production (fuelwood) we use the planting density of 2100 plants ha^{-1} for charcoal wood production

c = cost per seedling/cutting (euro). Prices for seedlings/cutting range dependant on e.g. size, species and the nursery. For eucalyptus cuttings prices found in literature range roughly between 0.02 € per plant in Nicaragua (Van den Broek *et al.* 2000b) to some 0.2 € in Argentina and Australia (ANU 1998). Prices for poplar cuttings range between 0.08 € per cutting in the Czech Republic (Roman, 2004 in (Van Dam *et al.* 2003) to 0.65 € per cutting in the US (CSF 2003). Prices of commercially grown cutting were found to vary dependant on the size of the cutting and the quantity ordered. In this study we use a price of 0.10 € per cutting.

l = labour required for planting of one hectare (h ha^{-1}). Manual planting rates for poplar are 1.2 hectare $person^{-1}$ day^{-1}, mechanical planting rates are 2.7 hectare $person^{-1}$ day^{-1} (Tuskan 2000). For eucalyptus manual and mechanised planting rates are 0.5 and 0.8 hectare $person^{-1}$ day^{-1} respectively (IEA 1997). Considering the relatively low costs of labour in Ukraine and Brazil manual planting rates are included in this study.

w = wage as calculated in section 3.2 (euro h^{-1}).

p = machinery required for planting of one hectare (h ha^{-1}). Tractors are required for the transportation of plants and personnel; data on required hours are derived from Van den Broek (Van den Broek *et al.* 2000a).

m = costs of machinery (euro h^{-1}). Data on the costs of one hour tractor use are derived from the Coppice Harvest Decision Support System (WSRG 1994). The hourly costs are estimated at 9.38 €, based on the default values.

Fertilizers

Fertilizers are required to promote growth (shorten rotation age) and avoid soil nutrient depletion. The costs of fertilizers are derived from the net amount of nutrients removed from the field and the price of fertilizers, using a nutrient mass balance.

$F_{NPK} = f * m * a * p$

F_{NPK} = fertilizer costs of N, P_2O_5 and K_2O fertilizer (euro ha^{-1} y^{-1})

f = annual required nutrient inputs to compensate the loss of nutrients N, P and K (kg ha^{-1} y^{-1}) as a result of biomass harvesting, ammonia voltalisation and nutrient leaching.

m = mol weight conversion factor (dimensionless). The N, P and K content of fertilizers is usually indicated by the percentage N, P_2O_5 and K_2O. A multiplication factor of 1, 2.3 and 1.3 respectively is included to account for the differences in mol weight.

a = fertilizer concentration (dimensionless). Fertilizers content is usually depicted by three numbers (e.g. 11-52-0) depicting the content N, P_2O_5 and K_2O respectively. For practical reasons, we assume that N, P and K fertilizer are used separately with an N, P_2O_5 and K_2O content of 46% (46-0-0 fertilizer or urea), 46% (0-46-0 fertilizer or superphosphate) and 62% (0-0-62 fertilizer), respectively.

p = price of fertilizer (euro kg^{-1}). For the prices of 46-0-0, 0-46-0 and 0-0-62 fertilizer we data on fertilizer prices from FAO statistics, data of the U.S.A. are used to avoid problems when converting from local currencies to euro.

Weed and pest control

Weed control is crucial for plantation productivity. Weed control is particularly required during the first period after planting, once canopy closure is complete weed control is no longer necessary. Three types of weed control can be applied: manual, mechanical and chemical. Chemical weed control is standard practice in eucalyptus and poplar plantations; manual and mechanical weed control is sometimes also used, although chemical weeding is generally the cheapest option (IEA 1997). Data on the frequency of the application of weed control measures vary widely, dependant on the specific plantation characteristics such as planting density, terrain and soil type, climate and weed species. For both poplar and eucalyptus one application of manual, mechanical and chemical weed control is included in the calculations. Pest and diseases are sometimes applied. In general, pests and diseases are a very limited problem, but this may increase when large-scale bioenergy plantations are established. To avoid an underestimation of the costs of bioenergy crop production, one application of pesticides and fungicides is included. The costs of weed and pest control is based on the following formula:

$C = i * c + l * w + p * m$

C = costs of weed or pest control (euro ha^{-1})

i = input of chemicals (pesticides, herbicides or fungicides; l ha^{-1}). Data on the required input of chemicals are based on eucalyptus plantations (Faundez 2003). For poplar plantations no data were readily available so we used the expenses of eucalyptus plantations as a proxy.

c = cost per litre chemical (euro l^{-1}). Data on costs per litre chemical are based on data for Chile and are derived from Faundez (Faundez 2003).

l = labour required for the weed or pest control activity (h ha^{-1}). Data on manual and mechanical weeding are based on Van den Broek (Van den Broek *et al.* 2002); data on the labour requirements for chemical weeding are based on Faundez (Faundez 2003).

w = wage, as calculated in section 3.2 (euro h^{-1}).

p = tractor hours for weed or pest control (h ha^{-1}). Data on the tractor input for mechanical weeding and chemical weeding are derived from Van den Broek (Van den Broek *et al.* 2000a) and Faundez (Faundez 2003), respectively.

m = costs of machinery (euro h^{-1}). Data on the costs of one hour tractor use are derived from the Coppice Harvest Decision Support System (WSRG 1994). Data on manual pump system are based on Faundez (Faundez 2003).

Land rent

In general, land prices are dependant on the local circumstances such as the quality of the soil, the vicinity of infrastructure and the demand for land.

In this study data from the Zimmermann are used (Zimmermann *et al.* 2002). Data for Brazil are based on land rent data for arable land costs in centre south Brazil. Data for Ukraine are based on land rent data for arable land for Poland, because no data for Ukraine are available. In this study, the value of arable land is taken as a function of the productivity of land. The value of very suitable, moderately suitable, marginally suitable, marginally suitable and very marginally suitable land is determined on the difference in the maximum constraint free yield (MCFY) as defined in 2.2.1. The resulting annual land rent costs are shown in table 3.

Table 3. Annual land rent costs in Ukraine and Brazil per suitability class (€ ha^{-1} y^{-1}).

	VS	S	MS	mS	VmS	NS
Brazil	138	107	77	46	20	5
Ukraine	48	38	27	16	7	3

Harvesting

Trees are cut and chipped by a Claas harvester, which is basically a forage or maize chopper with a special header that cuts the stems from the stools. Data on performance and costs are derived from Gigler et al. (Gigler *et al.* 1999) and corrected for Brazilian and Ukrainian labour costs. The costs include chipping and transportation by tractor and trailer to a waiting truck on the headland or farm. Harvesting costs per unit biomass increase in lower productive areas. The impact of various yield levels on harvesting costs is estimated based on data from the Coppice Harvesting Decision Support System (CHDSS, (WSRG 1994). The CHDSS is a software tool that includes data on costs and labour input on various self-propelling harvesting machines. It allows the user to specify the characteristics of the plantation (e.g. yield level, planting density, row spacing), harvesting system (e.g. type of machine, place of storage, chipping locations) and the price of various cost items (e.g. labour, fuel) (WSRG 1994).

Costs per production phase

Establishment

The total establishment costs for eucalyptus plantations in Brazil are calculated at 600 € ha^{-1}, For Ukraine establishment costs of poplar plantations are estimated at 553 € ha^{-1}. The range is the result of differences in the land suitability and consequently land rent costs (costs include land rent, soil preparation, fencing, cutting production, planting, weeding, fertilisation and the use of pesticides). These data are broadly in line with figures found in literature. Larson (Larson *et al.* 1995) reports that the total establishment costs for Eucalyptus in Brazil range between ca. 1600 € ha^{-1} to 500 € ha^{-1} (including land rent, sapling production, land preparation, planting, fertilizers and herbicides; based on data collected early 1980's). These values are higher than our values, but the authors specifically state that new tillage practices may lower these values. Marrison (Marrison *et al.* 1995) reports that establishment costs in Brazil are 448 € ha^{-1} (including land rent, ground clearing, marking and survey of the site, establishment of roads, first and second ploughing, ant killing, seedling production, planting of seedlings, replacing, fertilizers and administration). Damen reports a value of 1200 € ha^{-1} (including planting, weeding and the application of fertilizer and insecticides during the first growing year (Daemen 2001). Azar *et al.* (Azar *et al.* 2000) use a figure of 819 € ha^{-1} (excluding land rent) as an average for Brazil, based on figures derived from literature. Establishment costs in the US are estimated at ca. 540 € ha^{-1} (Perland and Wright in (Perlack *et al.* 1995). Note that various factors may increase the costs of plantation establishment. E.g. in case of degraded, low productive areas or land under grass cover, establishment can be more intensive: pits and terrace construction may be required to prevent soil erosion, additional fertilizers may be required, extensive land clearing is required in case of permanent pastures to allow planting and/or extensive road building may be required in remote building.

Maintenance

Maintenance includes fertilisation and weed and pest control. The average annual costs of maintenance are calculated at 142 € ha^{-1} y^{-1} to 223 € ha^{-1} y^{-1} in Brazil and 112 € ha^{-1} y^{-1} to 158 € ha^{-1} y^{-1} in Ukraine (undiscounted euros; including first year weed control). These figures are somewhat higher than data found in literature. Marrison and Larson (Marrison and Larson 1995) reports a value of ca. 85 € ha^{-1} y^{-1} for Brazil. Couto et al (1993, in (Perlack *et al.* 1995) report a value between 19 € ha^{-1} y^{-1} to 120 € ha^{-1} y^{-1}. Regional differences in climate, soil type, tree species and type of management result are responsible for the differences in maintenance costs. Carpentieri et al., 1993 in (Azar and Larson 2000) reported a value of 28 € ha^{-1} y^{-1}. In this study the requirement for fertilisation is based on the annual loss of nutrient from the field from leaching and harvesting. This results in higher fertilization rates than found in literature, because in reality the application of fertilizer aims for an economic optimisation rather than the prevention of nutrient depletion or nutrient losses. The relative low fertilisation application rates found in literature may therefore lead to nutrient depletion on the long-term, although various other factors such as soil structure, atmospheric deposition, climate and the tree species may also reduce fertilizer requirements compared to the calculations in this study.

Appendix C. Land use classification

The land use classification used in this study is a modified version of the one used in the FAOSTAT database (FAO 2003a):

- *Permanent pastures*: land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).
- *Forests*: land under natural or planted stands of trees (excluding plantations), whether productive or not. This category includes land from which forests have been cleared but that will be reforested in the foreseeable future, but excludes woodland or forest used only for recreation purposes.
- *Permanent crops:* land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber.
- *Arable land:* land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years).
- *Agricultural land:* sum of permanent crops, arable land and permanent pastures.
- *Other land*: total land area minus the areas given by the FAO for permanent pastures, forests and woodland incl. plantations, arable land and permanent crops. Other land includes e.g. barren land and build-up land. Build-up is land used for housing and infrastructure.

Appendix D. Indirect employment

The production of bioenergy crops is less labour intensive than the production of conventional agricultural crops: soil preparation is done only once, planting and harvesting is done once per rotation cycle, while for conventional annual agricultural crops these activities are required every year. Biewinga estimated the labour requirement of various agricultural crops between 10 to 36 h ha^{-1} y^{-1}; the labour requirements of poplar production in the Netherlands is estimated at 6 h ha^{-1} y^{-1} (Biewinga and Van der Bijl 1996). No data were available for the labour requirement for permanent pastures, which are the bulk of the surplus agricultural areas available for bioenergy crop production. Note that in this study the labour requirement for bioenergy crop production ranges between ca. 30 to 40 h ha^{-1} y^{-1}. Differences are caused by differences in the type of production system (data from Biewinga are based on highly mechanised, high input production systems common in the Netherlands), differences in the system boundaries (data on bioenergy crop production include harvesting and transport) and differences in data on labour requirement for various activities.

We assume that the relative between agricultural crops and bioenergy production is the same in less intensive production systems used in Brazil and Ukraine. These data show that the conversion of arable land to bioenergy crop plantation is likely to have a negative impact on the direct employment. However, this comparison is based on the replacement of food crop production by bioenergy crop production. To avoid competition between bioenergy crop production and food production, the productivity of conventional agriculture must be increased to generate surplus agricultural areas. In that case there is no replacement of agricultural production, rather an intensification of agricultural production. This intensification will likely result in a decrease in the labour intensity, because of the increase of inputs such as fertilizers, pesticides and agricultural machinery.

First, the employment in agriculture in 2015 is estimated based. Two scenarios are composed. One scenario is based on projections from the United Nations Population Division (UNPD 2003) and the International Labour Organisation (ILO 2003) and is the baseline scenario. This scenario represents the employment in agriculture as projected by the FAO (FAO 2003b). The second scenario is based on the employment in agriculture in 2015 including the intensification of agriculture required to generate surplus agricultural land.

Second, the impact on employment is estimated based on the correlation between the cereal yield between 1961-2000 and the average labour intensity in the industrialised countries (the number of agricultural workers divided by the area arable land). Data on cereal yields and arable land were obtained from the FAOSTAT database (FAO 2003b). Data on the number of agricultural workers is derived from the LABORSTA database (ILO 2003). For both Brazil and Ukraine national data are used for the industrialised regions, because national data are biased by e.g. agricultural policies, economic and political changes. Between 1961 and 2000 the average cereal yield increased roughly by a factor 2 (FAO 2003a), while the average number of economically active persons in agriculture per hectare arable land and permanent crops decreased by a factor 5 (FAO 2003a; ILO 2003).

The third step involves an assessment of the direct employment (employment directly related to farm operations) as a result of the introduction of bioenergy crop production. This is calculated based on the cost equation in section 3.1. For each of the cost items data are included on labour costs, inputs (chemicals, fertilizers, fencing) and machinery (tractors and harvesters) as summarized in Appendix B.

Brazil

Data on the employment in agriculture from 1960 to 2000 are derived from the LABOURSTAT database (ILO 2003). Analysis of the employment in agriculture shows that the percentage of the economically active population in agriculture and the percentage of the total population in rural areas follow a very similar (decreasing) trend, from roughly two-third in 1950 to one-fifth in 2000. The employment in agriculture to 2015 is assumed to follow the same trend as the total rural population: a continued decrease of the share to 12% in 2015 (UNPD 2003). The total employment is assumed to increase proportional to the medium population growth scenario as projected by the United Nations (UNPD 2003). All data are translated from national aggregated data to data for Rio Grande do Sul based on the share of the population of Rio Grande do Sul in 2000. The population of Rio Grande do Sul is 10 million in 2000. If we assume the relative population trend as in table 4, the economically active population in agriculture in 2015 is 0.69 million people. Results are shown in table 4.

The impact on employment of an increase in yields resulting from the implementation of an intermediate technological level of technology in agriculture is estimated based on historic data for the industrialised countries. Yields increase by a factor 2.2, which corresponds to a decrease of the labour intensity of a factor 5.6. This equals a decrease of the population in agriculture by 0.59 million, from 0.69 to 0.10 million jobs. The direct employment from bioenergy plantations is estimated at ca. 22 thousand jobs. The overall impact on employment of bioenergy crop production and increasing the efficiency of agriculture is negative: 0.5 million people. The costs to compensate for the loss of jobs are considerable: more than 2.2 billion €.

Table 4. Economically active population (EAP) in agriculture in Rio Grande do Sul in 2000 and 2015. Source: (ILO 2003; UNPD 2003).

In million	2000	2015
EAP in agriculture, excluding bioenergy production	1.12	0.69
EAP in agriculture, incl. yield increase, excl. bioenergy crop production	1.12	0.10
EAP in bioenergy crop production	0.00	0.02
Net EAP effect	0.00	-0.61

Ukraine

Data on the employment in agriculture from 1950 to 2000 in Ukraine are derived from the LABOURSTAT database (ILO 2003): the percentage of the employed population working in the agricultural sector decreased from 59% in 1950 to 17% in 2000. This percentage decreased slowly from 20% in 1990, to 18% in 1995 to 17% in 2000. For the year 2015 we estimated that 14% of the total employed population is employed in agriculture. The total employed population is assumed to decrease at the same rate as the total population to 2015, as projected by the United Nations (UNPD 2003). The employment effects related to the intensification in agriculture are calculated based on the relative decreased in the industrialised countries in combination with the projected agricultural labour force in 2015 in a baseline scenario. Results are shown in table 5.

Table 5. Employment and population in agriculture in Ukraine in 2000 and 2015. Source: (ILO 2003; UNPD 2003).

In million	2000	2015
EAP in agriculture, excluding bioenergy production	1.17	0.88
EAP in agriculture, incl. yield increase, excl. bioenergy crop production	1.17	0.19
EAP in bioenergy crop production	0.00	0.05
Net EAP effect	0.00	-0.64

The data show that in case the agricultural production efficiency is increased strongly to generate surplus agricultural land, than a considerable loss of jobs in agriculture can be expected. Some 50 thousand jobs are directly generated, while some 690 thousand jobs are lost due to the intensification of agriculture resulting in a total net reduction of some 640 thousand jobs. The costs to compensate for the total loss of jobs are estimated at 0.7 billion €.

Appendix E. Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is:

A = R * K * LS * C * P

A = soil loss (t ha^{-1} y^{-1}).

R = rainfall erosion index (MJ mm ha^{-1} h^{-1} $year^{-1}$). R factor is a summation of the various properties of rainfall including intensity, duration, size etc. It is generally computed from the kinetic energy of rainfall and the maximum intensity of rain in 30 minutes. Due to the high data demand, various alternative procedures have been developed over the years to estimate R based on annual and monthly data (see e.g. (Sun *et al.* 2002) for a comparison of 10 different equations). In this study, we use a coarse approximation of R based on the equation proposed by Renard and Freimund (Renard *et al.* 1994):

$$R = (0.04830\ A^{1.610})\ 0.1$$

A = annual rainfall (mm y^{-1}). Data on annual rainfall are based on an annual rainfall map from UNEP (Deichmann *et al.* 1991). The rainfall data and R-values included are shown in table 6.

Table 6. Annual rainfall (mm y^{-1}) and rainfall erosion index (MJ mm ha^{-1} h^{-1} y^{-1}) used in this study for the regions under investigation. Values marked with a * occur only very limited in the regions under investigation. N/a = not applicable.

Brazil		Ukraine	
Rainfall (mm y^{-1})	R factor (MJ mm ha^{-1} h^{-1} y^{-1})	rainfall (mm y^{-1})	R factor (MJ mm ha^{-1} h^{-1} y^{-1})
1000	327	400	75
1250	468	600	143
1500	627	800*	228
1750	804	1000*	327
2000	997	n/a	n/a

K = soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}) represents the cohesive, or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow. The K factor is (empirically) estimated from four soil texture properties: organic-matter content, soil structure, and permeability data. Coarse textured soils, such as sandy soils, have low K values, to 0.25, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have a moderate K values, about 0.25 to 0.5, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having high silt content are most sensitive for soil erosion of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.5.

A global soil texture map was used to identify soil textures in Brazil and Ukraine (FAO 2002d). In this map, soil textures are classified as fine, medium and coarse. Coarse textured soils are almost not existent in the regions under investigation and are therefore not included. No information was available on various soil characteristics of the different soil texture classes. K values for the three types of soil texture are estimated as show in table 7.

Table 7. Soil texture classification and soil erodibility (K) factor (t ha h ha^{-1} MJ^{-1} mm^{-1}).

Soil texture class	K factor
Fine texture	0.13
Medium texture	0.38
Coarse texture	0.63

LS = slope length and slope gradient factor (dimensionless). The slope gradient is the more important of the two. A high(er) slope gradient results in a high(er) erosion sensitivity. The LS factor can be calculated using the formula

$$LS = (x/22.13)^n \, (0.065+0.045s+0.065s^2)$$

x = slope length (m)
s = slope gradient (%)
n = 0.5 for slope >5%, =0.4 for slope 3.5 to 5%, = 0.3 for slope 1 to 3.5% and = 0.2 for slope less than 1%

A slope gradient map is used to estimate slope gradients (FAO 2000), see figure * and *. Soil erosion through water depends on the slope gradient.

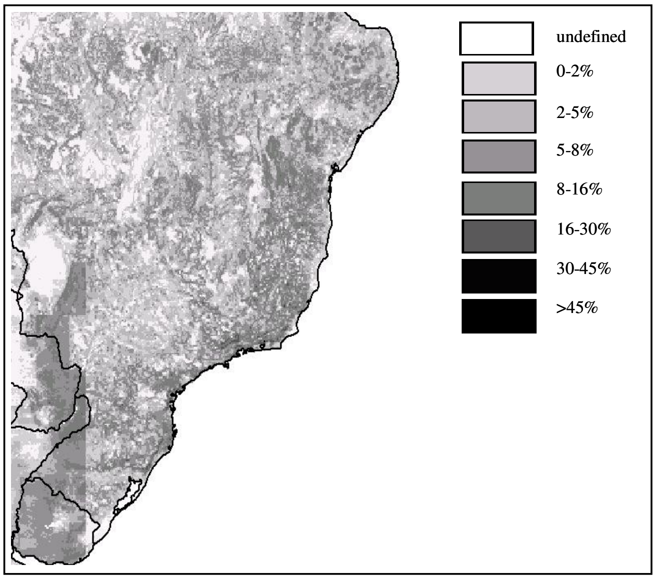

Figure 1. Medium slope gradient in Brazil (%). Source: (FAO 2000).

The vertical abrupt change in gradients shown in the Southern part and Western of Brazil is the result of the combination of different tiles of satellite data that have been combined into one dataset. This also indicates the relative unreliability of this dataset.

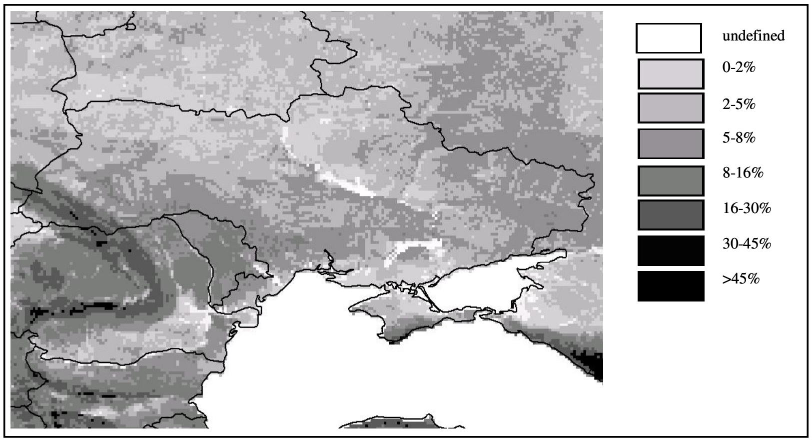

Figure 2. Medium slope gradient in Ukraine (%).Source: (FAO 2000).

Slope gradients in both regions are as steep as 16%, although these values are exceptional. In this study we only consider slopes with a gradient of maximum 10% suitable for bioenergy production. LS values range between 0.1 and 2.5 for a 100 m long slope (the default slope length included in this study) with 2 and 10% gradient respectively.

C = crop/vegetation and management factor (dimensionless; C factor) is defined as the ratio soil loss from land cropped under specified conditions to the loss under tilled, continuous follow conditions. The C factor combines plant cover and the associated cropping techniques. The value of the C factor varies from 1 on bare soil to 1/1000 for areas under dense forest, see table 8. Typical values for well-protected land are 0.005 to 0.1.

Table 8. Crop/vegetation and management factor (C factor) for various land cover types[26]. Source: (Biewinga and Van der Bijl 1996; Ontario 2000; Ma 2001).

Land cover type	C factor
Roads and other bare areas	1
Fresh clean-tilled seedbed	0.8
Grain corn	0.4
Silage corn, beans & canola	0.5
Cereals (spring & winter)	0.35
Seasonal horticultural crops	0.5
Orchards/nurseries	0.5
Pasture/hay	0.020-0.050
Grassland	0.05
Water/wet areas	0
Urban, low density	0.03
Urban, high density	0
Deciduous forest	0.009
Evergreen/coniferous forest	0.004
Mixed forest	0.007
Forest/woody wetland	0.003
Short rotation forestry plantations (no winter leaf fall)	0.05
Short rotation forestry plantations (winter leaf fall)	0.08

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[26] For annual crops the C factors represents average annual values.

Soil erosion rates of land under SRWC production are 7 to 70 times lower than in wheat cultivations (Pimentel and Kummel, 1987 in (Borjesson 1999). The C value of wheat cultivation is 0.35, thus the C value for SRWC's is 0.05 to 0.005. To avoid an underestimation of the soil erosion sensitivity of SRWC's, we use a factor 0.05. Because it was not known if the data reported by Pimental and Kummel include leaf fall or not and we did not want to underestimate the soil erosion rates, the C value of 0.05 is assumed to represent an all year round tree cover (winter leaf fall results in a high(er) susceptibility for soil erosion compared to a year round leaf cover). The ratio between the value of the C factor of poplar production in Germany (including winter leaf fall) and eucalyptus production in Portugal (no winter leaf fall) is used to calculate the C factor of SRWC's with winter leaf fall. This ratio is 1.6 (Biewinga and Van der Bijl 1996), thus the value of the C factor of SRWC's with winter leaf fall is 0.08.

Biewinga and Van der Bijl report a value of 0.2 to 0.5 for the early growth phase and full crow cover phase, respectively, in both eucalyptus and poplar (Biewinga and Van der Bijl 1996), but these figures seem unrealistically high compared to estimates found in literature and are therefore excluded from this study. E.g. the US Congress Office of Technology Assessment estimates that SRWC's generally will have lower level of erosion than conventional row crops and similar levels as well-maintained pastures (OTA 1993).

P = agricultural practice factor (dimensionless; P factor). A large variety of measures can be applied to reduce the slope length, increase ground cover, increase soil permeability or increase soil particle bonding. Table 9 shows values for the P factor for various erosion control practices used in conventional crop production, but we assume that these values are also valid for conventional crop production.

The value of the P factor ranges between 0 to 1: 0 means a reduction of the rate of soil erosion by 100% and 1 means no reduction of the rate of soil erosion. Data for other measures such as the use of residues for an increasing ground cover or the use of sediment basins are not available.

Various tillage and support practice methods can be combined, which means that the P factors of the support practices, tillage and cover crop can be multiplied. The data show that various support practices can significantly reduce the erosion rates. In the calculations a P factor of 1.0 is used, because we want to calculate the soil erosion rate in case no soil erosion reduction factors are used. In case the calculated soil erosion rates are above the acceptable soil erosion losses, appropriate soil erosion prevention measures must be applied of which the costs are included in the costs of bioenergy crop production.

Table 9. P factor for various activities. Source: (Malik *et al.* 2000; Ontario 2000).

	P factor
Support Practice	
Up & down slope cropping (planting with the slope)	1.00
Cross slope cropping (planting across the slope)	0.75
Contour farming (planting across the slope, parallel with the altitude line)	0.50
Strip cropping, cross slope (alternate crops, planting across the slope)	0.37
Strip cropping, contour (alternate crops, planting parallel with the slope)	0.25
Tillage Method	
Fall ploughing	1.00
Spring ploughing	0.90
Mulch tillage	0.60
Ridge tillage	0.35
Zone tillage	0.25
No-till	0.25
Cover crop	
Average of 4 cover crops	0.37-0.64

Appendix F. Nutrient balance

The total loss of nutrients (L_{NPK}) is used as an indicator for the emissions to ground and surface water, see the following equation:

L_{NPK} = f x (1-c_d)

L_{NPK} = loss of N, P or K (kg ha^{-1} y^{-1}).

f = fertilizers input (kg ha^{-1} y^{-1}). The input of fertilizers is based on an input level that avoids soil nutrient depletion, which is considered unsustainable. Nutrient depletion may trigger a downward spiral of reduced tree growth, lower ground leaf cover and loss of soil organic matter, higher rates of erosion, loss of fertile topsoil and reduced tree growth. The calculated demand for fertilizers is also included in the calculation of the costs as described below. The required amount of fertilizer input is based on the equation:

f = yld x C_{NPK} /c_y

yld = average yield of (bioenergy) crops (ton dry weight ha^{-1} y^{-1}). The yield levels of common agricultural crops are based on country specific data from the IIASA GAEZ crop growth model (FAO 2002c). Crop yield data are based on a high input agricultural system and are based the complete removal of the above ground plant biomass. No demand for nutrients required for below ground growth is included, because we assume that sufficient nutrients are available in the soil to allow root development and these nutrients are left in the ground after harvesting.

C_{NPK} = mineral concentration (kg ton^{-1} dry weight). For practical reasons we focus on these three main nutrients: nitrogen (N), phosphor (P) and potassium (K). Literature values for the mineral concentration in poplar and eucalyptus biomass vary significantly.

Table 10 shows an overview of values for poplar and eucalyptus found in a short literature scan and for some common agricultural crops.

Values on mineral composition may vary significantly as a results of a variety of potential factors, such as natural variation in nutrient content, plantation age, type of biomass included (foliage), differences in management (application of fertilizer or irrigation), differences in soil structure. We use data reported by Lodhiyal and Lodhiyal in (Jorgensen and Schelde 2001), because these data fall within in the range given by Jug et al., 1999 in (Jorgensen and Schelde 2001) and are specifically for above ground harvested biomass for bioenergy production. For other crops we use data reported by Biewinga (Biewinga and Van der Bijl 1996).

Table 10. Mineral composition of poplar, eucalyptus and some annual agricultural crops (kg ton^{-1} dry weight). a.g.h.w. = above ground harvested weight; n.s. = not specified for which part of the plant the data are given.

kg ton^{-1} dry weight	N	P	K	Source
poplar (a.g.h.w.)	2.7-6.9	0.5-1.0	2.7-3.9	Jug et al., 1999 in (Jorgensen and Schelde 2001)
willow & poplar (a.g.h.w.)	3.7-9.3	0.5-1.2	1.4-5.1	Adegbidi et al., 2001 in (Jorgensen and Schelde 2001)
poplar (a.g.h.w.)*	5.7	0.6	3.1	Lodhiyal and Lodhiyal in (Jorgensen and Schelde 2001)
poplar (a.g.h.w.)	5.9	0.7	3.1	Lodhiyal and Lodhiyal in (Jorgensen and Schelde 2001)
poplar (n.s.)	4.7	0.9	2.5	(Biewinga and Van der Bijl 1996)
poplar (n.s.)	6.0	0.5	2.3	(Kaltschmitt *et al.* 1997)
eucalyptus 8 y (a.g.h.w.)*	4.6	0.3	2.3	Lodhiyal and Lodhiyal in (Jorgensen and Schelde 2001)
eucalyptus (n.s.)	0.8	0.1	0.5	(Biewinga and Van der Bijl 1996)
eucalyptus 3 y (stemwood)	1.4	0.5	2.5	(Pereira 1999)
eucalyptus 10-12 y (wood)	0.8	0.2	0.7	(Pereira 1999)
eucalyptus 10-12 y (bark)	1.9	0.1	1.2	(Pereira 1999)
eucalyptus 10-12 y (topwood)	1.2	0.1	1.3	(Pereira 1999)
eucalyptus 10-12 y (branches)	2.8	0.1	3.6	(Pereira 1999)
eucalyptus 10-12 y (foliage)	11.4	0.5	5.3	(Pereira 1999)
maize	13	2.2	14.9	(Biewinga and Van der Bijl 1996)
sugar beet	6.5	1.7	8.3	(Biewinga and Van der Bijl 1996)
sugar cane	0.8	0.2	2.1	(USDA, 2004)
sorghum	8.8	1.5	12.2	(Biewinga and Van der Bijl 1996)
wheat[27]	23.5	4.4	4.9	(Biewinga and Van der Bijl 1996)
grass fallow	3.0	0.4	3.0	(Biewinga and Van der Bijl 1996)

c_y = nutrient recovery coefficient (dimensionless). Only a part of the fertilizer applied is available for plants, the remaining is lost through runoff, chemical conversion or leaching. Recovery factors for common agricultural crops are well researched and can be differentiated based on climate and soil data. Therefore we use one crop nutrient recovery factor as reported by Biewinga (Biewinga and Van der Bijl 1996). For maize and wheat the nitrogen recovery coefficient is 0.72 and 0.76. P and K recovery coefficients are 1.00 for all crops. The nitrogen recovery coefficient of poplar and eucalyptus plantations is 0.80 and 0.84. These values are used to compare the nutrient losses of bioenergy crops and conventional agricultural crops. For the calculation of the costs related to avoidance of nutrient leaching, a more detailed set of data is used. The N recovery factor is found to vary with the soil suitability class and the management system. Stape (Stape *et al.* 2004) reports a relative difference in nitrogen uptake efficiency of a factor two between a low and high productive areas. Nario (Nario *et al.* 2003) reports that the nutrient uptake in peach tree orchards in Chile increases 38% in case fertilizer application is split in a summer and spring application instead of one application in spring. Biewinga reports that the attainable nutrient recovery coefficient is 0.84 for eucalyptus and 0.80 for poplar. This figure is used for the nutrient recovery coefficient in VS areas in combination with an annual fertilizer application rate. The nutrient recovery coefficient in the mS areas is set at half of the efficiency in VS areas based on data from Stape (Stape *et al.* 2004) as

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[27] Based on the values for winter wheat (Biewinga and Van der Bijl 1996).

described above. In case the rate of fertilizer application is increased from the default of two times per rotation cycle to once per year, the nutrient recovery coefficient decreases by 38% based on data from Nario (Nario *et al.* 2003) as described above. The resulting nutrient recovery values are shown in table 11.

Table 11. Nitrogen recovery coefficient (%) per land suitability class and for two fertilizer application frequencies.

Bioenergy crop	Fertilizer application frequency	VS	S	MS	mS
Eucalyptus	Once per year	84	70	56	42
Eucalyptus	Twice per rotation cycle	60	50	40	30
Poplar	Once per year	80	67	54	40
Poplar	Twice per rotation cycle	58	48	39	29

The nutrient recovery coefficient varies between four-fifth to one-third, dependant on the land suitability class and fertilizer application frequency. By changing the fertilizer application rate nutrient losses can be reduced. In the loose set of criteria one fertilizer application is allowed; in the strict set of criteria one fertilizer application per year cycle is required. The costs for the application of fertilizers are included in the cost of bioenergy production. In addition, nutrient losses from run-off are prevented by means of soil erosion prevention measures, of which the costs are included in the criteria related to soil erosion.

Note that the nutrient recovery coefficients represent to the overall long-term recovery coefficients. Nutrients from litter are recycled and nutrients not absorbed during the first year may be absorbed during the following years, which reduces the need for fertilizers and increases the nutrient recovery coefficient in time. Reported nutrient recovery efficiencies found in literature are therefore often much lower. E.g. Conçalves (Gonçalves *et al.* 2003) reports a nutrient recovery coefficient of 50%, which is in line with the data in table 11. Data on the nutrient recovery efficiency in trees are however much lower: Miller (Miller, 1991 in (IEA 1997) reports that trees only absorb some 20% of the nutrients applied and (McLaughlin *et al.* 1987) reports an N uptake efficiency in poplar plantation of 2% to 13%, dependant on the type of biomass. On the longer term however, nutrients recycling and various chemical processes are likely to result in an increased nitrogen uptake in line with the data in table 12 (Rogner 2000; Lewandowski 2004).

Appendix G. Land suitability for rain-fed crop production

Figure 1 and 2 show the suitability of Brazil and Ukraine for rain-fed crop production.

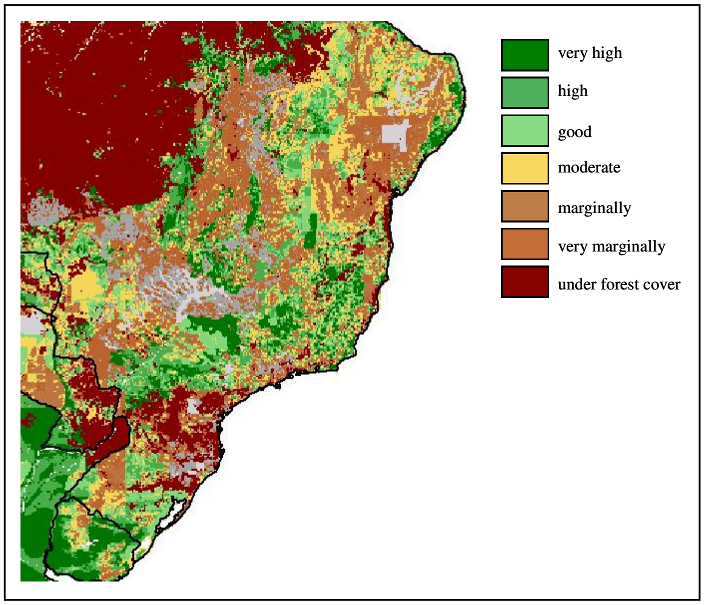

Figure 1. Suitability of land for rain-fed crop production excluding areas under forest cover in Brazil. Source: (FAO 2000).

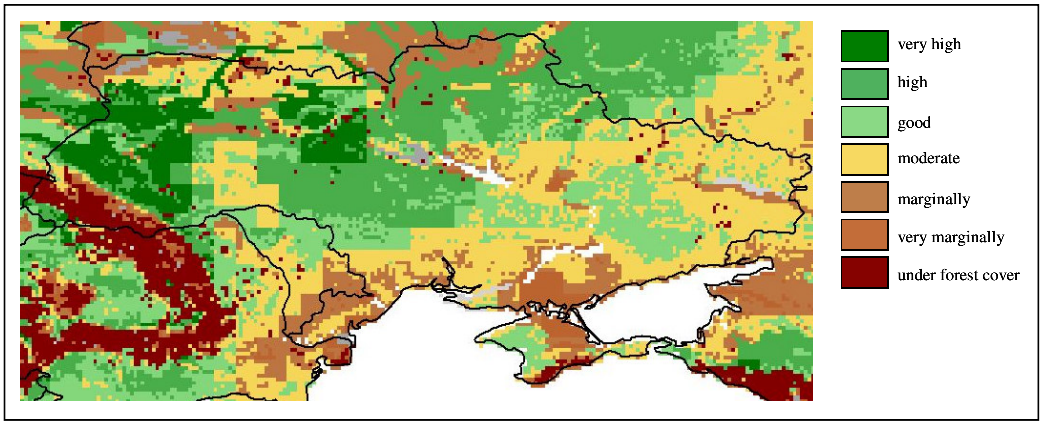

Figure 2. Suitability for rain-fed crop production of areas not under forest cover in Ukraine. Source: (FAO 2000).

Appendix H. Water balance

The following formula is used to calculate water shortages or surpluses:

WS = $(ET_0 \times K_c) - P$

WS = water shortage (or surplus if negative; mm month^{-1}). In case of a water (precipitation) shortage, crop growth is hampered.

ET_0 = reference evapotranspiration (mm month^{-1}) is the process of evaporation and transpiration. The ET_0 is dependant on climate factors only, excluding the impact of the soil factors.

K_c = crop evapotranspiration coefficient (dimensionless). A standardised set of K_c values for agricultural crops is included in the CROPWAT software tool. K_c values for eucalyptus and poplar are estimated using the sparse data we found in literature. The average K_c values are calculated based on a 7-year rotation period. Higher values are also reported for particular cases, e.g. up to >1.5 for Eucalyptus (Greenwood et al., 1985 in (Worledge *et al.* 1998) and Morris and Wehner, 1987 in (Worledge *et al.* 1998).

A comparison of the K_c values for conventional agricultural crops and bioenergy crops is used as a proxy to the relative changes in water demand in case of a replacement of conventional agricultural crops with bioenergy crops. Table 13 shows K_c values for a selection of (bioenergy) crops for various crop development stages (initial, middle, end) and average for a growth cycle.

The data show that the average annual water use of woody bioenergy crops is dependant on the plantation age. During the first years after planting, the annual average K_c factor is generally lower than the annual average K_c factor of most agricultural crops. Once full-grown however, the water use is higher than in most crops, because: (1) full canopy cover is reached earlier in the growing stage and (2) perennial tree roots exploit a deeper and larger portion of the soil profile and extract more water compared in spring and early summer when row crop root systems are still developing. Note that the specific characteristics of bioenergy crops such as crown cover, root structure and litter fall that result in the reduction of soil erosion rates are also responsible for the increase in water use compared to conventional agricultural crops.

The K_c values for poplar and eucalyptus are annual average values. Consequently, evapotranspiration is underestimated when the crop coefficient is maximal at the end of the annual growing season, when leaf cover is maximum and overestimates evapotranspiration when the crop coefficient is low early spring when crown cover is developing. This means that evapotranspiration in the summer is underestimated and evapotranspiration in the winter is overestimated. A second complicating factor is that no distinction is made between the water use of poplar growth under various land suitability classes and corresponding growth speed and yield levels.

Table 13. K_c factors for various crop types and development stages (K_c ini is the K_c in the initial growth fase (before crown cover is complete), Kc end is the K_c at the end growth fase, and Kc average is the average K_c over the entire growth period. Values marked with a * are estimated. Sources: (FAO 1998a, 2000; NMCC 2001).

Crop		K_c mid	K_c ini	K_c end	K_c average
Cereals (e.g. wheat, millet, excl. rice)		1.15	0.30	0.40	0.84
Roots and tubers (e.g. cassava, potatoes, sugar beets)		1.10	0.50	0.95	0.85
Legumes (leguminosae; e.g. beans, peas, soybeans)		1.15	0.40	0.55	0.85
Small vegetables (e.g. broccoli, carrots, onions)		1.05	0.70	0.95	
Oil crops (e.g. rapeseed, safflower, sesame, sunflower)		1.15	0.35	0.35	0.82
Sugar cane		1.25	0.40	0.75	
Forages					
Alfalfa hay	Averaged cutting effects	0.95	0.40	0.90	
Grazing pasture	Rotated grazing	0.85-1.05	0.40	0.85	0.95*
Grazing pasture	Extensive grazing	0.75	0.30	0.75	0.75*
Tropical fruits and trees					
Banana	1st year	1.10	0.50	1.00	
Banana	2nd year	1.20	1.00	1.10	
Coffee	Bare ground cover	0.95			
Coffee	With weeds	1.10			
Special					
Open water, < 2 m depth or in sub humid climates or tropics		1.05			
Open water, > 5 m depth, clear of turbidity, temperate climate		0.65			
Bioenergy crops					
Eucalyptus year 1					0.55
Eucalyptus year 2					0.85
Eucalyptus year 3					1.15
Eucalyptus >year 4					1.30
Eucalyptus average					1.11
Poplar year 1					0.35
Poplar year 2					0.65
Poplar year 3					0.95
Poplar >year 4					1.10
Poplar average					0.91

P = the effective precipitation (mm month^{-1}). Data on precipitation for Brazil are taken from the CLIMWAT database (FAO 1994). Climate data for the Ukraine are based on IPCC data (IPCC-DCC 2004) and Sperling's climate database (Sperling 2004). Only a part of the precipitation is available for plant growth, some of the precipitation is loss through deep percolation to groundwater and through runoff. The effective rainfall (rainfall not lost through deep percolation or runoff) is estimated using the United States Soil Conservation Service Method as included in the CROPWAT model.

Table 14 shows climate data and calculated reference evapotranspiration for Passo Fundo (Brazil) and Zhytomyr (Ukraine).

Table 14. Climate data and calculated reference evapotranspiration for Passo Fundo (Brazil) and Zhytomyr (Ukraine).

Zhytomyr Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rainfall (mm/month)
January	1.7	-4.4	77	120	2	3.3	0.38	38	35.7
February	1.7	-3.9	75	130	2.7	5.5	0.6	34	32.2
March	6.1	0	72	120	3.3	8.7	1.1	39	36.6
April	12.8	5.6	63	120	5.1	13.8	2.19	45	41.8
May	19.4	10.6	59	104	6.6	18	3.32	52	47.7
June	23.9	15	56	104	10	23.3	4.53	69	61.4
July	26.1	16.7	52	95	10	22.8	4.62	77	67.5
August	26.1	16.1	49	95	9.2	19.5	3.96	64	57.4
September	21.1	11.7	53	95	6.7	13.3	2.48	47	43.5
October	14.4	6.7	63	104	4.8	8	1.27	43	40
November	7.8	1.7	73	104	2	3.7	0.56	45	41.8
December	3.3	-2.2	79	120	1.7	2.6	0.33	44	40.9
Average	16.9	8.9	64.3	109.3	5.3	11.9	2.23		
Total								597	546.5

Passo Fundo Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rainfall (mm/month)
January	28.6	17.3	75	199	8	23.4	5.14	144	110.8
February	27.9	17.1	77	121	7.3	21.2	4.36	147	112.4
March	26.3	15.9	77	199	7.3	19.1	3.97	120	97
April	22.6	12.5	80	156	6.3	14.8	2.68	129	102.4
May	20.1	10.7	81	112	5.6	11.4	1.8	140	108.6
June	18.5	9.3	82	181	5.2	9.9	1.64	149	113.5
July	19	8.4	81	190	5.8	10.9	1.86	132	104.1
August	19.8	9.3	75	181	5.9	13.2	2.42	132	104.1
September	21.6	10.7	78	181	5.5	15.3	2.93	160	119
October	24.1	12.5	78	164	6.5	19.1	3.73	162	120
November	25.7	14.1	72	130	7.9	22.8	4.52	111	91.3
December	28.3	16.1	71	199	8.5	24.4	5.39	133	104.7
Average	23.5	12.8	77.3	167.8	6.7	17.1	3.37		
Total								1659	1287.9

Appendix I. Costs to increase the agricultural productivity

Additional investments, on top of expected baseline developments, may be required to increase the efficiency of the agricultural production system. Increases of the agricultural efficiency through technological progress are the outcome of process in which numerous variables and actors are involved; as a result the costs to increase the efficiency of agricultural production are very difficult to estimate.

The loose set of criteria is limited to the site of production. As a result, the efficiency of the agricultural production sector is regarded as the responsibility of the national government, the agro-industry and various (international) organisations. Therefore, no costs are included. In case the efficiency of the agricultural production system are insufficient to generate surplus agricultural areas, additional investments to increase the agricultural efficiency are required.

The other extreme is that the total costs to increase the efficiency of the agricultural production from the baseline projections of the FAO (FAO 2003b) to the technological potential required to general surplus agricultural areas. The efficiency increase included in the baseline projections of the FAO is based on a scenario without bioenergy production. Therefore, no costs are allocated for the yield increase included in the FAO scenarios. The costs to increase the agricultural productivity are however difficult to estimate. The process through which efficiencies gains can be realised is a complex process involving many actors.

In this study the process of achieving efficiency improvements is simplified and aggregated into two variables: innovation capital and imitation capital (Avila *et al.* 2004).

The amount of innovation capital is used to describe the capacity of a region to invent new technology and to innovate or commercialise that technology. For innovation capital two indicators are included: the number of scientists per hectare arable land and the expenses on industrial R&D as percentage of the Gross Domestic Product (GDP). Imitation capital is used to describe the capacity of a region to master technology produced outside the region our country. For imitation capital two other indicators are used: the number of years of schooling of the working population and the number of extension workers per hectare arable land. For both innovation and imitation five classes are defined. Comparison of the innovation and imitation class and the average cereals yield levels, reveals that yield levels increase with a higher innovation and imitation capital class, see table 15.

Some developing countries in the various innovation capital classes: Cambodia, Morocco, Yemen, Mali, Sudan (class 2), Nepal, Tunesia, Vietnam, Senegal, Ghana (class 3), Indonesia, Peru, Thailand, Turkey (class 4) and Argentinea, India, China, Brazil (class 5 and 6). Some countries in the various imitation capital classes: Mozambique, Sudan, Angola, Namibia (class 2), Ghana, Senegal, Egypt, Iran (class 3), Thailand, Turkey, Mexico, Indonesia (class 4) and Philippines, China, South Africa (class 5 and 6).

Table 15. Innovation and imitation capital class and average yield levels. Source: (Avila and Evenson 2004).

Innovation capital class	Cereal yield (t ha^{-1} y^{-1})	Number of scientists per hectare arable land (number ha^{-1})*	Industrial R&D expenditures (% of GDP)*
2	0.9	0.020	0.003
3	1.9	0.025	0.0035
4	2.5	0.02-0.04	0.003-0.005
5-6	3.2	≥0.04	≥0.005
Imitation capital class	Cereal yield (t ha^{-1} y^{-1})	Schooling of the worker (years)*	Extension worker per hectare arable land (number ha^{-1})*
2	0.8	4.0	0.06
3	1.7	4.5	0.145
4	2.0	5.0	0.23
5-6	3.5	6.0	≥0.4

* The relative contribution of the two parameters in the innovation and imitation capital class is set at 50% to calculate the average values of each parameter.

The relative difference in yields between capital class 2 and 5-6 and the difference in the various parameter values is used to quantify the correlation between yield levels and investments in schooling, training and public and private R&D. I.e. going from innovation capital class 2 to 5-6 yields increase a factor 3.6. This requires an increase of the number of scientists by one person per hectare and an increase in industrial R&D investments of 0.002% of the GDP. The same calculations are done for the schooling of the workers and the number of extension workers. I.e. from imitation capital class 2 to class 5-6 yields increase a factor 4.1 and the schooling per workers increases by 2 year and the number of extension workers increases by one person per three hectares. For each of these items costs are calculated based on the agricultural land use in 2015. The ratio of the yield increase in Brazil and Ukraine to 2015 and the yield increase between the various classes is calculated. The costs are calculated by multiplying this ratio by the required investments in schooling, training and public and private R&D as described above.

Note that these calculations are extremely crude and we would like to stress that the calculations are only intended to indicate the order of magnitude. In general, we consider the calculated costs rather an underestimation than an overestimation, because of two reasons. First, the calculated costs are only based on the difference between the least developed developing countries and the most developed developing countries. This difference includes the large efficiency improvements resulting from the Green Revolution, which have not (yet) been realised in the least developed countries. Brazil and particularly Ukraine have already experienced these transitions. Further efficiency gains are likely to require more investments per percentage efficiency increase, because of decreasing marginal returns on investments. Second, only four variables are included in the calculations. In reality, many more variable are relevant, such as the availability of infrastructure for transportation, the availability of communication facilities, the availability of knowledge networks, the absence of corruption. The costs related to these variables are excluded. We are also aware that this approach is somewhat inconsistent with the technological potential included in this study, because the technological potentials are based on existing technologies used in the industrialised regions, which implies that R&D is not needed. Ideally, the costs of the implementation of these technologies are analysed, but such an exercise was not possible due to a lack of data. However, in reality R&D is a powerful way of increasing the agricultural production efficiency. Note that R&D contributes significantly to the (economic) efficiency considering the high rates of return, e.g. 40% in case agricultural research and development expenditures in Latin America.