BIOENERGY FEEDSTOCK PRODUCTION ON GRASSLANDS AND PASTURES: BRAZILIAN EXPERIENCES AND GLOBAL OUTLOOK

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Bioenergy Feedstock Production on Grasslands and Pastures: Brazilian Experiences and Global Outlook

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ACRONYMS AND ABBREVIATIONS

27% ethanol blend (E27)

Capital expenditure (CAPEX)

Emissions Trading Scheme (ETS)

EU-Renewable Energy Directive (EU-RED)

European Union (EU)

Exajoule (EJ)

Flexible fuel vehicles (ffvs)

Gigajoule (GJ)

Gigawatt (GW)

Gigawatt hours (gwh)

Greenhouse gas (GHG)

Indirect land use change (iluc)

Land use change (LUC)

Light-duty vehicles (LDV)

Million grams (Mg)

Million tons (Mt)

Million hectares (Mha)

Non-governmental organization (NGO)

Operational expenditure (OPEX)

Parts per million (ppm)

Tons Carbon (tc)

United States of America (USA)

U.S. Environmental Protection Agency (EPA)

World Energy Outlook (WEO)

1 BACKGROUND AND SUMMARY

This report is part of a broader IEA Bioenergy InterTask Project 'Mobilising sustainable bioenergy supply chains'. In this project, prospects for large-scale mobilization of major bioenergy resources were analysed through five case studies that determine the factors critical to their sustainable mobilization. The following bioenergy resources were analyzed, with special focus on selected countries and regions that cover different conditions:

- forest biomass in temperate and boreal ecosystems, including a broad range of countries and conditions;
- agricultural crop residues focusing on supply chains in Denmark, the United States of America and Canada;
- biogas production from municipal solid and liquid waste, oil palm residues, and co-digestion of agricultural crops and residues and animal wastes;
- lignocellulosic crops in agricultural landscapes, with special attention to their place in sustainable landscape management and design; and
- bioenergy feedstock cultivation on pastures and grasslands, with special focus on sugarcane ethanol in Brazil

This report concerns the bioenergy feedstock cultivation on pastures and grasslands. It describes sugarcane ethanol production conditions and prospects for expansion, governance, and factors affecting market demand for Brazilian ethanol, including the interaction between the sugar and ethanol markets. Lignocellulosic and other feedstocks are also briefly discussed, especially palm oil biodiesel that has received increased attention in Brazil in recent years. The influences of water resource availability and use is given special attention because of their strong influence on the prospects for bioenergy feedstock production on grasslands and pastures in Brazil and around the world.

Grasslands and pastures represent a very large resource base on a global level. In Brazil, large-scale mobilization of bioenergy supply chains in Brazil is very possible. Few techno-economic barriers exist and legal conditions for production are settled throughout the country; production systems are mature; and there is technology and capacity to rapidly increase production in response to increasing demand. Progressive infrastructure investments further strengthen capacity, notably in export routes via the Amazon River basin.

Brazilian agricultural production can grow without extensive conversion of forests and other native vegetation. Large areas of extensively used pastures are suitable for cultivation of sugarcane and other bioenergy feedstocks, and land productivity improvements in meat and dairy production can accommodate a large expansion of such cultivation. More widespread use of water-efficient irrigation could boost Brazilian agriculture output significantly. The following factors must be understood clearly to enable such mobilization to occur and therefore justify taking action.

- As for other bioenergy options, mobilization can be hampered by uncertainty concerning future markets and evolving regulations. Specifically for the Brazilian sugarcane case, low margins for sugar and ethanol are magnifying the importance of surplus electricity sales to the grid but several barriers inhibit development for electricity co-generation in ethanol mills. Clear and consistent policy definitions and targets providing stable market conditions are required. Policies can either guarantee markets or increase fossil fuels prices sufficiently to make bioenergy options competitive. More favorable conditions for power generators and resource planning integrating bioelectricity with other renewable electricity resources can stimulate development.

- The governance situation in Brazil is illustrative of possible challenges for sustainable mobilization around the world: incentives and alternative regulation (e.g., licences and conditional credits) may be needed to complement governmental command and control to protect native vegetation and promote land use productivity. While consumer demand for sustainable products is increasing, sourcing can be challenging due to diverging views on sustainability aspects, the variety of issues to be considered, and the many suggested indicators for representing these issues. A polarized debate about the priorities of agriculture production versus environmental protection may in itself be a barrier against progress and sensible balancing of these objectives, since debate and conflict contributes to uncertainty about future markets, including sustainability standards and regulations imposed on producers.
- Sustainably increasing food, biomaterials, and bioenergy production on grasslands and pastures requires structural shifts and incentives rewarding higher productivity. This is especially important in cattle production where, historically, ample supply of new land in frontier regions has fostered a culture among cattle producers and associated actors where management options to increase land- use efficiency are less important.
- The analyses showed that productivity improvements in meat and dairy production could release very large grassland and pasture areas for other uses. Illustrative calculations on the global level show that several hundred EJ per year could be produced. Brazilian ethanol production could be many times larger than today. Best management practices for cultivating low productivity pastures will be important since much of the land that can become available through intensification is currently used for extensive grazing. Criteria, data and methods are needed to distinguish highly biodiverse grassland from other land and to address hydrological aspects of grassland and pasture cultivation.

2 INTRODUCTION

Grasslands and pastures cover a large part of the global land area, and significant areas are suitable for bioenergy feedstock production. The use of grasslands and pastures for this purpose has attracted increased attention because (i) land productivity improvements free up large grassland and pasture areas for other uses, and (ii) the greenhouse gas (GHG) emissions associated with establishing bioenergy plantations on such lands are lower than when forests are converted. At the same time, there are several challenges associated with the use of grasslands and pastures, including the risk of biodiversity losses, water resource competition, and deforestation due to indirect land use change (iLUC). It is therefore essential to learn from experiences in locations where large grassland and pasture areas have been converted to bioenergy plantations.

This report summarizes outcomes of an IEA Bioenergy inter-Task project involving collaborators from Tasks 37 (Energy from Biogas), 38 (Climate Change Effects of Biomass and Bioenergy Systems), 39 (Commercialising Conventional and Advanced Liquid Biofuels from Biomass), 40 (Sustainable International Bioenergy Trade: Securing Supply and Demand), 42 (Biorefining: Sustainable Processing of Biomass into a Spectrum of Marketable Bio-based Products and Bioenergy), and 43 (Biomass Feedstocks for Energy Markets). The purpose of the collaboration has been to analyze prospects for large-scale mobilization of major bioenergy resources through five case studies that determine the factors critical to their sustainable mobilization.

The focus of this report is bioenergy involving feedstock cultivation on pastures and grasslands, with special focus on sugarcane ethanol in Brazil. The sugarcane ethanol system could be promoted in many countries around the world and the report therefore has broad relevance. Further, many of the aspects discussed are relevant also for other bioenergy systems. The report treats production conditions and prospects for expansion, governance aspects and factors affecting market demand for Brazilian ethanol, and the interaction between the sugar and ethanol markets. Lignocellulosic and other feedstocks are briefly discussed, especially palm oil biodiesel, which has received increased attention in Brazil in recent years. A section is dedicated to water resource availability and use since it has strong influence on the prospects for bioenergy feedstock production around the world.

3 SUGARCANE ETHANOL IN BRAZIL: A BRIEF OVERVIEW

The production of ethanol and sugar from sugarcane in Brazil has been linked since the 1920s, when ethanol was first considered to be a feasible co-product from frequent surpluses of sugarcane (Walter et al. 2014), leading to the first mandate for a 5% ethanol blend in Brazilian gasoline in 1931. In 1975, motivated by the negative impacts of oil imports on Brazil's balance of payments after the 1973 oil crisis, the National Alcohol Program (Proalcool) was launched with a target to replace 20% of the gasoline consumed in the country with ethanol. From 1975/1976, ethanol production increased more than 20-fold, reaching almost 12 $x10^9$ liters in the 1985/1986 season (MAPA 2013). The sharp decline in oil prices combined with the increase in national oil production led to a period of stagnation for Proalcool that lasted until 2002/2003, when escalating oil prices renewed interest in ethanol fuel. The market launch of Flex Fuel Vehicles (FFV) in 2003 motivated consumers to return using ethanol, which had become very cost-competitive with gasoline despite the absence of subsidies. Production more than doubled from 2002/2003 to 2008/2009, when the economic crisis, low gasoline prices to Brazilian consumers despite high oil prices, and a series of extreme weather events, along with poor field management, contributed to the end of this period of growth. Ethanol production costs increased, mainly because of low sugarcane yields and higher fertilizer and fuel costs. At the same time, the government had kept the gasoline prices constant at the pump since 2005 aiming to hold down inflation (Jank 2013), in spite of escalating oil and gasoline prices in the international markets.

During these periods of growth and stagnation of ethanol production and consumption, the economic competitiveness of Brazilian sugar production improved due to reductions in feedstock cost. The deregulation of the sugar/ethanol sector in the 1990s spurred the rapid growth of sugar exports, as shown in Table 1. Thus, in parallel with the enormous growth of ethanol production since 1975/1976, sugar production increased six times and sugar exports went from near zero to 24.9 million tonnes (Mt), nearly half of the international market. Brazil became not only the largest sugarcane ethanol producer, but also the main sugar producer and exporter, so that in the medium to long term the ethanol and sugar markets acted independently.

Table 1. Evolution in sugarcane, sugar, and ethanol production (MAPA 2013)

Harvest season*	1975/76	1985/86	2002/03	2008/09	2011/12
Sugarcane production (Mt)	68.3	223.2	316.1	572.7	560.5
Ethanol production (million liters)	556	11,932	12,485	27,681	22,701
Sugar production (Mt)	5.9	7.8	22.4	31.5	36.0
Sugar exports (Mt)	<1	-	13.5	20.8	24.9

* From April 1 to March 31 the following year.

With the deregulation of the power sector in the 1990s, the industry was able to increase resource efficiency and afford the premium for more efficient equipment required to generate electricity as an additional product with guaranteed revenues. The electricity for export doubled between 2006 and 2012 to 30 x10^3 GWh, primarily during the seasons of low hydropower production in North Brazil (Chum et al. 2015).

Lately it appears that, because of the importance of Brazil in the international sugar market and of ethanol in the domestic market, a strong linkage was created between the prices of raw sugar in the New York Mercantile Exchange and the hydrous ethanol parity prices (price of ethanol converted in sugar equivalent) in Brazil's Center-South Region (LMC 2015). The anhydrous ethanol prices are indirectly connected with these two markets because the distilleries can normally vary the production ratio of hydrous to anhydrous. Yet product demand is affected by the blending rate (kept in the range of 18 to 27% for anhydrous ethanol by government controls), and the hydrous ethanol pump price is capped by the gasoline pump prices and is also affected by the raw sugar prices in the New York Mercantile Exchange. These complex supply–demand relationships can be used to adjust the production profile of the three products to maximize profits (or minimize losses). This is aided by the fact that around two-thirds of the sugarcane is processed in mills that produce both ethanol and sugar and have the flexibility to change the production profile by plus/minus 20% of either product (CONAB 2013). One serious external and uncontrolled cause of strong impacts on the performance and volumes of the three product markets is international sugar prices, which are normally affected by climate variations in important producing countries, and the instability of Asian producers' demand–supply equilibrium (LMC 2015).

Public policies and legal frameworks directly impact the three products of sugarcane and their relationships with markets. Policy-driven biofuel demand, such as in the USA and EU, can stimulate investments, but uncertainties about future biofuel markets impact on investment interest. Domestic ethanol demand is becoming difficult to predict due to lack of government mandates clarifying the role of ethanol in the Brazilian light-duty vehicle (LDV) fuel matrix. This is further complicated by the fact that the participation of flexible fuel vehicles (FFVs) in the LDV fleet has reached 60% and is increasing, creating direct competition between gasoline and hydrous ethanol in the filling stations. The equivalence ratio between hydrous ethanol and gasoline (E27) is estimated to be close to 0.70, meaning that when the ethanol price is above 70% of the price of gasoline, the consumer will tend to choose the fossil option to fill the FFV tank. The government projection of 2023 transport fuel demand indicates a gap equivalent of 26 $x10^9$ liters of gasoline equivalent, to be filled by gasoline, ethanol (predicted ethanol demand: 39 $x10^9$ liters), or a combination of both (MME 2015). Yet there exist capacity constraints in today's oil refineries and there are also limitations in the gasoline supply infrastructure (e.g., port terminals, storage tanks, and pipelines). The ethanol sector does not seem inclined to invest in expansion of production capacity to meet the projected demand due to the uncertainty in the future market and evolving regulations.

In Brazil, the internal and external sugar markets are totally deregulated and steered by free market forces; the growth on the internal market is relatively easy to predict, but the international market has several players in different regions of the world and is subject to rules and conditions (such as weather) that make market prediction a challenge. Nevertheless, the international market represents close to 70% of Brazilian sugar sales and has a strong economic impact. Finally, the interaction of the sugar and ethanol markets and its dependence on gasoline prices demonstrates the need to reduce ethanol production costs to the levels of the recent past. This would require significant additional investment that can only occur if public policies provide market stability as they did in the past. The situation is becoming even more complex because the low margins for sugar and ethanol are magnifying the importance of surplus electricity sales to the grid. The increasing scale of new mills improves conditions for electricity cogeneration, and delayed hydropower projects open opportunities for other renewable energy development, mainly wind and biomass. Several barriers (e.g., the requirement that power generators assume the full cost of grid connection) inhibit development, but experience shows that resource planning integrating biopower with other power resources benefits both power producers and Brazilian people (Chum et al. 2015). In spite of these challenges, the installed capacity at bioenergy mills recently passed the 10 GW mark, with a significant part of that capacity being available for sale.

4 PROSPECTS FOR BIOENERGY EXPANSION IN BRAZIL

The recent revision of the Brazilian Forest Act, the main legal framework for protection of native vegetation on private land, has changed the context for mobilizing bioenergy supply chains in Brazil by altering the relative importance of public and private governance systems addressing nature conservation and agricultural production. The Forest Act revision resulted in less protection of native vegetation, and less stringent requirements for restoration planting and assisted regeneration of natural ecosystems on agricultural land. The legislation also includes a comprehensive Environmental Rural Registry that facilitates monitoring and surveillance by government and civil society. Whether conversion of natural ecosystems will take place depends on how public and private governance together balance the purposes of protecting natural ecosystems and agricultural production (further discussed below).

Figure 1 shows how land suitability for biomass production (right) and protection of native vegetation (left) vary across Brazil. The greater the ratio of protected vegetation to total native vegetation, the greater share of native vegetation is protected under legal command and control regulatory frameworks on private or public land. It can be expected that conversion of native vegetation into biomass cultivation will be more prevalent where a high proportion of land suitability overlaps with a lower degree of protection of native vegetation (i.e., low ratio on left map), unless protection is enhanced by incentives and other regulations that complement governmental directives.

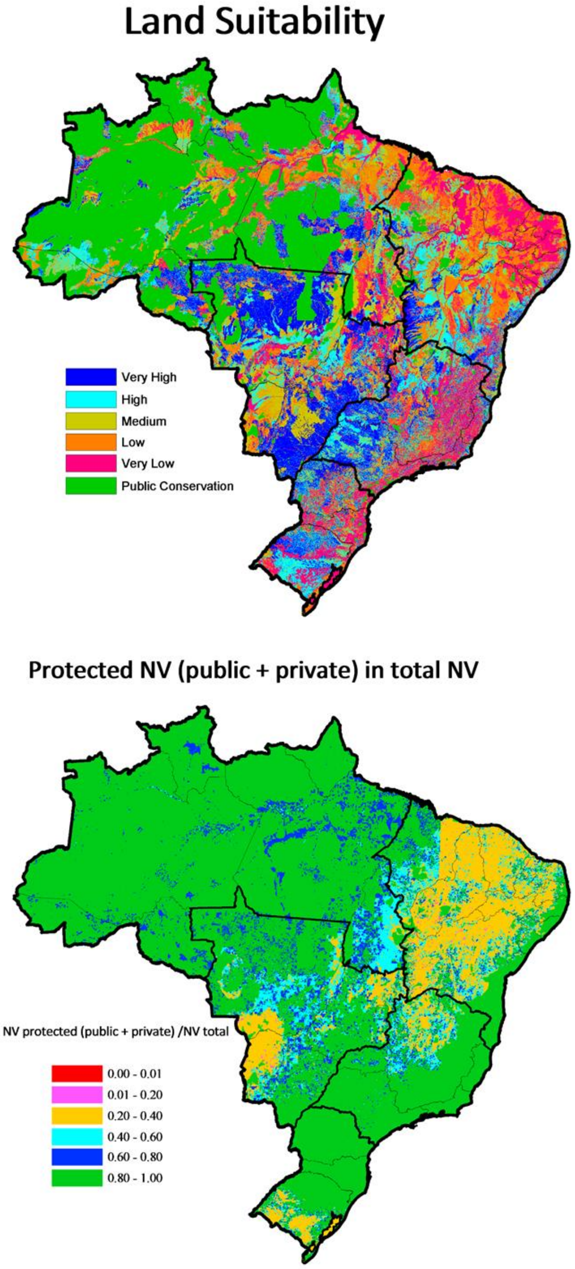

Figure 1. Ratio of protected native vegetation to total native vegetation (left), and land suitability classes and public conservation (right). (Sparovek et al. 2015a)

Figure 2 shows results of three scenarios for allocation of legally available land to cropland, pasture, and native vegetation (see Figure 7), one prioritizing conservation objectives, one prioritizing production objectives, and one that is neutral between those objectives. The assessment of available land used a spatially explicit land-use modelling framework for Brazilian agricultural production and nature conservation that considers: (i) the Atlantic Forest Law, (ii) the revision of the Forest Act, (iii) the Amazonian land-titling initiative "Terra Legal," (iv) the spatial distribution of agricultural land suitability, (v) technological and management options, and (vi) the effects of market driven regulations. Information about the considered laws and initiatives is given in Sparovek et al. (2015a). The land allocation is guided by criteria commonly considered in frameworks for agro-ecological and economic zoning, which are frequently used[1] to fulfil legal demands and meet requirements set by the Brazilian Ministry of Environment at the state level.

In the ***Conservation scenario***, marginal lands are set aside for restoration of native vegetation, in line with the Brazilian experience of abandoning such agricultural land after the consolidation period; high yielding cropping systems expand on very high suitability lands currently under native vegetation and pastures; and beef production increases through productivity improvements on pastures situated on high and medium suitability lands. Native vegetation prevails in the entire Legal Amazon region, Pantanal, steep areas along the Atlantic Forest biome, and climatically marginal areas of the northeastern and southeast semi-arid regions. The remaining pasture area occupies larger parts of Rondônia and Roraima, south of Acre, a larger extension north of Tocantins, Maranhão and Pará, and moving south, a more patchy distribution on the lower suitability classes associated with steep slopes. Crops dominate on legally available lands in most of the Cerrado biome and northwest of Rio Grande do Sul. In total under this scenario, native vegetation increases by about 30%, cropland increases 1.5 times, and pasture land decreases more than 40%.

In the ***Production scenario***, there is no restoration of native vegetation; pasture expands on native vegetation land, and pasture production is intensified even on lower suitability land, and native vegetation and pastures on higher suitability lands are converted to improved croplands. Native vegetation prevails on available land in the semi-arid northeastern Caatinga biome and steep slopes or extremely poor soils of the Cerrado biome and Pampas, but is replaced by pasture or cropland in the other areas. Crops dominate landscapes, while pastures show a more patchy distribution occupying the lower suitability areas surrounded by crops. Agronomic intensification on lower suitability lands potentially increases impacts associated with soil erosion and environmental pollution. In total, more than two-thirds of native vegetation on legally available lands is converted to agriculture; cropland increases 2.7 times, and pasture lands decreases about 30%.

In the ***Neutral scenario***, conversion of native vegetation to improved cropland and pasture is partly balanced by restoration of native vegetation on pastures situated on very low suitability lands. Native vegetation expands on available land, only excluding areas in some states with continuous prevalence of very high and high suitability land where crops occupy larger portions of the rural landscape. Pastures expand over the medium and low suitability land throughout Brazil, seldom dominating the landscape but rather introducing variation in landscapes dominated by either cropland or native vegetation. In total, native vegetation is reduced by 17%, cropland increases 2.1 times, and pasture land decreases by about 40%, with roughly 70% of the remaining pasture land placed under intensified use.

[1] Users include investment agencies such as the Brazilian development bank for sugarcane investments, governmental agencies engaged with policy design, and organizations engaged with sustainability certification (Sparovek et al. 2015a).

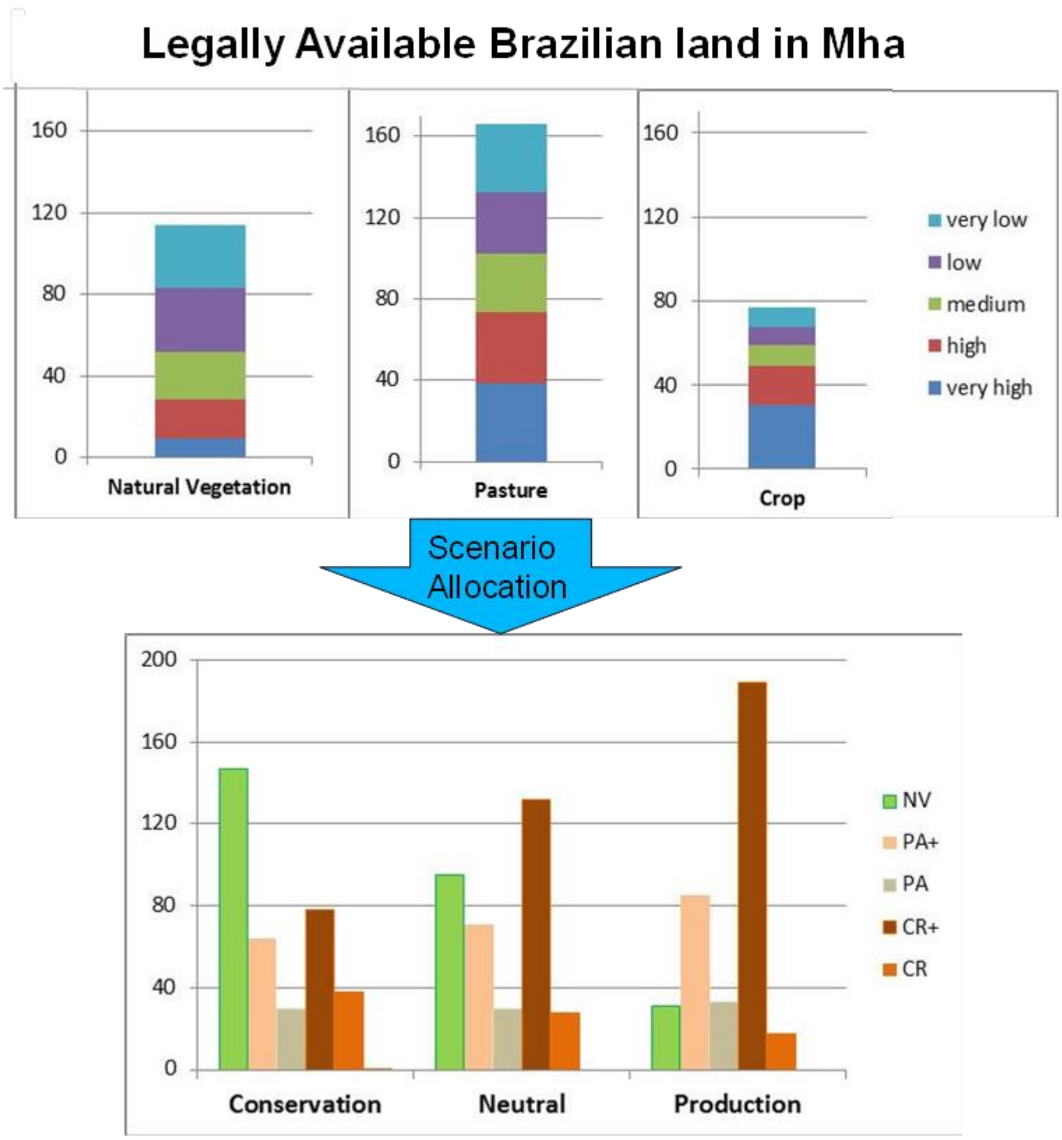

Figure 2. Land allocation on legally available land for the three scenarios (+ denotes application of productivity enhancing measures in favorable locations). See Sparovek et al. (2015a) for details about the land allocation rules applied. NV = Natural Vegetation, PA = Pasture, CR = Crop, + = great potential for increasing current productivity.

One important finding of the above scenario analysis is that Brazilian agricultural production can grow without extensive conversion of forests and other native vegetation. To illustrate, municipal level analyses made across the whole of Brazil showed that relatively modest productivity improvements[2] would allow a doubling of the current crop output (excluding sugarcane) and maintaining — or even increasing by 20% — beef production, while leaving enough suitable and legally available land for sugarcane production to support an ethanol industry five to seven times

[2] Average cattle productivity increases 50 and 100% on low and high suitability pastures, respectively, and crop yields increase on average 20 and 50% on low and high suitability lands, respectively.

its current size, corresponding to an ethanol output at some 135–190 x10^9 liters[3]. About 20 Mha would be used for sugarcane production in this scenario (Figure 3). For comparison, 63.5 Mha was mapped as suitable by the Brazilian government, after taking into account the need to protect the Amazon, conserve biodiversity, and avoid conflict with food production (Souza et al. 2015). Much of this mapped land consists of pasture, largely in the Cerrado region, with low stocking density. Planting sugarcane on these lands without indirectly causing extensive conversion of native vegetation elsewhere would require improvement of the remaining pasture to support an increase in the number of head per hectare.

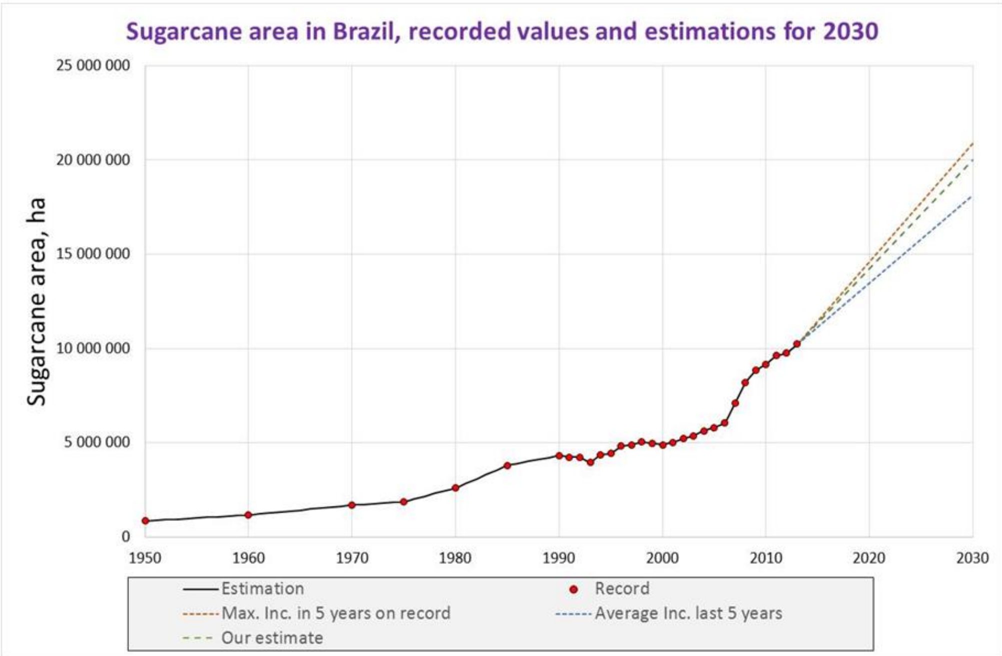

Figure 3. Historical expansion of sugarcane area in Brazil and a comparison of the average and maximum historical expansion rates (measured over five years) with the implied expansion rate in our illustrative calculation above.

As a second illustration, analyses show that palm oil production on some 40–60 Mha of suitable land can support biodiesel production corresponding to approximately 10% of the current global diesel demand without impinging on protected areas or causing direct LUC emissions (i.e., carbon stock would increase or be roughly unaffected where oil palm is planted). Almost all of this area is currently in agriculture, with roughly three-quarters in pasture (15–25% of all pasture in Brazil) and one quarter in cropland (10–15% of all cropland). Thus, oil palm expansion would certainly

[3] Assuming ethanol output at 80 and 120 liters per Mg of sugarcane (only first- and combining first and second-generation technologies, respectively).

affect food production and the outcome depends on how an expanding palm oil production integrates with existing agriculture production — and agriculture producers — and how existing production responds to the increasing land claim for oil palm. It can be expected that the present land-use patterns would change (e.g., extensive cattle production would likely decrease) and that agricultural land use would become more intensive in areas where land prices rise. Again, productivity gains as illustrated in the above scenario analysis can support production increases that avoid conversion of native vegetation. However, a combination of incentives and effective protection of native vegetation is likely required to achieve productivity gains that moderate area expansion. The pressure on remaining native vegetation can be expected to increase in areas where palm oil production capacity and associated infrastructure become established.

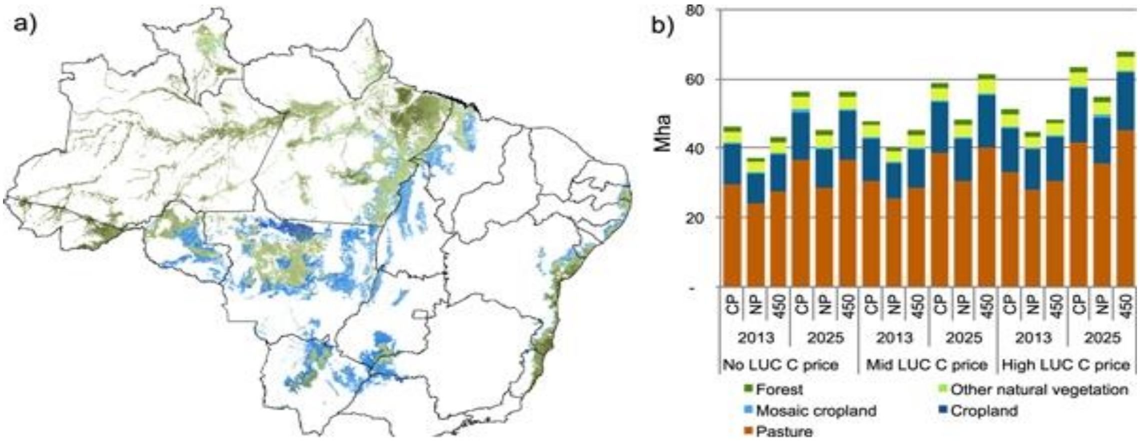

Figure 4. Areas where establishing new oil palm plantations would (1) be profitable for producers; (2) increase carbon stock; and (3) not impinge on land protected by law. Thus, no deforestation or conversion of tropical forest causing high LUC emissions. The map shows the spatial distribution of such areas in 2 out of 18 scenarios: those with the lowest potential (green) and highest potential (green + blue). Darker colors indicate higher yields. The diagram shows quantified results for all scenarios divided into six land-use/cover classes. The scenarios combined the three 2012 World Energy Outlook (WEO) scenarios - providing variations in oil, coal and carbon price developments that affect the willingness to pay for biodiesel and palm oil residues - Current policies (CP), New policies (NP), and 450 ppm, with three different levels for LUC carbon price development[4] to form nine scenarios. Two different establishment years (2013 and 2025) were used for each of these nine scenarios to analyze how the results differ over time, given the price projections for oil, coal, and carbon in the WEO scenarios. Source: Englund et al. (2015).

5 ECONOMIC COMPETITIVENESS

The Brazilian sugarcane ethanol supply chain represents a mature system that is already competitive in some markets having policy and regulatory support, e.g., in Brazil, the EU, and the USA. Revenues from co-products (energy, food, feed) and technology advances in conversion (second-generation ethanol) can further improve cost competitiveness. The competitiveness also

[4] The LUC carbon levels used for year 2013 correspond to the average carbon price on voluntary carbon markets ($22/t C: “mid”) and the modelled carbon price on the EU Emissions Trading Scheme (ETS) market as presented in the WEO ($64/t C: “high”). Carbon price levels diverge over time and are assumed to grow faster in the scenarios with more stringent climate policy (i.e., 450 ppm). By 2025, in the 450 ppm scenario, the highest carbon price used was $249/t C. Oil palm cultivation is found to be unprofitable on 80–90% of the Brazilian forest area at $125/t C.

depends on international sugar prices, e.g., in 2010–2011 a combination of factors[5] resulted in nearly double the estimated average production cost, making Brazilian ethanol roughly 30% costlier to produce than corn ethanol in the USA. Modelling indicates that Brazilian sugarcane and sugar costs are influenced by ethanol production to a higher degree than US corn cost (Chum et al. 2014), in part because of lower utilization of capital investments. The utilization of existing capacity could be increased by processing complementary crops, such as sweet sorghum, outside the sugarcane-harvesting season.

Brazil is currently a minor producer of palm oil, but large areas are suitable for oil palm cultivation, and Brazil has launched several initiatives seeking to promote and regulate expansion of oil palm involving technical assistance to farmers, agricultural and industrial incentives and credits, sustainability monitoring and evaluation, land titling, protection of traditional peoples, and social inclusion (Villela et al. 2014). To illustrate the competitiveness of biodiesel from palm oil, the range of fossil fuel prices in the 2012 IEA WEO scenarios (IEA 2012) would allow profitable oil palm cultivation over very large areas, including areas where it displaces forests and other native vegetation and causes LUC emissions. In the absence of governance preventing high LUC emissions, profitable biodiesel production at the scale of present global diesel demand is possible, but the associated LUC emissions would correspond to almost half of the US cumulative emissions from fossil fuels since preindustrial times (Englund et al. 2015).

However, as was shown above, the economic potential is large also when high LUC emissions are avoided, since there are large areas of suitable land outside forests. The map in Figure 4 shows the locations where palm oil biodiesel production would be profitable in a situation where high carbon prices discourage high LUC emissions. As noted above, much of these lands is already under agriculture and the net GHG savings that can be obtained by planting on agricultural areas depend on whether such planting indirectly leads to LUC causing GHG emissions elsewhere (Berndes et al. 2013).

6 SUPPLY CHAIN TECHNOLOGY AND SYSTEM INTEGRATION

Some modifications in Brazilian sugarcane production and processing have resulted from the requirement to phase out cane burning prior to harvest in several important sugarcane cropping states, including São Paulo. A shift from manual to mechanical harvesting and planting is underway, which has brought both benefits and challenges. Soil compaction, ratoon damage, and increases in sugarcane impurity levels reduce crop yields and sugar losses, as well as increase maintenance costs in the mills. Continuous improvement in the mechanization technology is mitigating the negatives impacts, but the technology is not yet optimized for the more complex feedstock. On the positive side, air pollution and GHG emissions are reduced and extra biomass becomes available in the form of residues left on the ground after the harvest, which can bring benefits such as increased soil organic matter, reduced erosion, carbon sequestration, and nutrient recycling.

[5] Including global weather-related problems affecting the production of sugar, low sugar stocks, and a rise in the sugarcane feedstock price caused by record-high sugar prices (Chum et al. 2014).

Sugarcane yields in new production regions in Brazil have been lower than the national average due to less fertile soil, longer periods of water deficit, and limited availability of cane varieties suited to the local conditions. The technology development in improved management practices to increase soil fertility includes adequate soil acidity correction and fertilizer use combined with pre-cropping the area with nitrogen-fixing crops such as soybeans, sun-hemp, or peanuts, and incorporating the crop residues into the soil to increase organic matter content. So-called supplementary or "salvation" irrigation to improve yields in areas with greater water deficits were adopted when necessary. New sugarcane varieties are being developed for the new production environments, and several new breeding stations were created.

In the processing plants, the main change in technology is the use of high-pressure, state-of-the-art power generation systems (boiler/turbine generator) made more economical by the expanding number of green field projects and the increase in scale. The average capacity of existing mills is 1.5 million tons of cane processed each harvesting season, only half the capacity of most of the new mills. This reduces the capital expenditure (CAPEX) and operational expenditure (OPEX) in the sugar, the cost of ethanol, and electricity generation costs, and significantly increases competitiveness. Harvest trash recovery is being tried by several mills to increase surplus power generation by the use of a supplementary biofuel from bagasse, to extend power generation into the off-season, and to improve the capacity factor of existing facilities. These are mature technologies with low risk and guaranteed cost reduction if well maintained and operated properly to avoid problems with boiler slagging and fouling. Capacity building became key because the high rate of growth in sugar and ethanol production in 2007–2012 outpaced the ability to train the new plant operators, maintenance staff, and management staff.

In addition to producing sugar, integration of sugar cane production with food production occurs through crop cultivation (mainly soy and peanut) during renewal of the sugarcane ratoons. Some process by-products[6] are also used as animal feed. The by-products suit a wide range of livestock production systems but, on a commercial scale, mostly apply to ruminants for beef or milk production in feedlots operating close to the mills. These feedlots were common in the 1980s and 1990s, but their numbers have declined because of the high demand for bagasse for energy cogeneration.

7 LOGISTICS

Transport costs and the rapid loss of free sugars after harvest requires sugarcane to be sourced from areas close to the ethanol production plants. For instance, ethanol mills built in State of São Paulo before 2006 obtain basically all their sugarcane from plantations located within 40 km of the mill. The need for relatively short distances from source to mill limits the capacity to guide ethanol and associated sugarcane expansion exclusively into use-specific land types, such as extensively used pastures. In fact, payment for sugarcane is based on sugar content on arrival at the mill. In Sao Paulo, which had about 60% of the Brazilian sugarcane production in 2012, almost all of the sugarcane expansion in 2004–2008 took place on roughly equal shares of cropland and pasture land (Rudorff et al. 2010). An assessment of land cover and land use surrounding existing operating mills and 21 approved mill projects in the State of Sao Paulo (Figure 5) indicates that

[6] The most common by-products used to feed animals are hydrolyzed bagasse (steam-treated bagasse), raw bagasse, liquid yeast, dry yeast, molasses, cane straw, filter cake, vinasse, and cane tops.

most new sugarcane needs to be planted on cropland unless it is sourced from longer distances than has typically been the case (Egeskog et al. 2014).

Thus, scientific studies confirm that sugarcane expansion does not cause much direct deforestation, but it is less clear whether direct competition for prime cropland is generally avoided by planting sugarcane on extensively used pasture lands. On the other hand, crops other than sugarcane can be cultivated on pastures, and the promotion of increased land productivity in meat and dairy production can consequently reduce the risk of sugarcane expansion causing indirect conversion of forests or other native vegetation land by making pasture land available for either sugarcane plantations or other crop cultivation if displaced by sugarcane.

Longer post-harvest storage times and transport distances are economically feasible for some other bioenergy feedstock alternatives, such as eucalyptus and soy. These feedstock alternatives will benefit more from the current infrastructure expansion into northern Brazil since they can be cultivated there. Sugarcane's climatic requirements limit its expansion to the north of Brazil, and mills are primarily located in well-consolidated agricultural areas with favorable logistics.

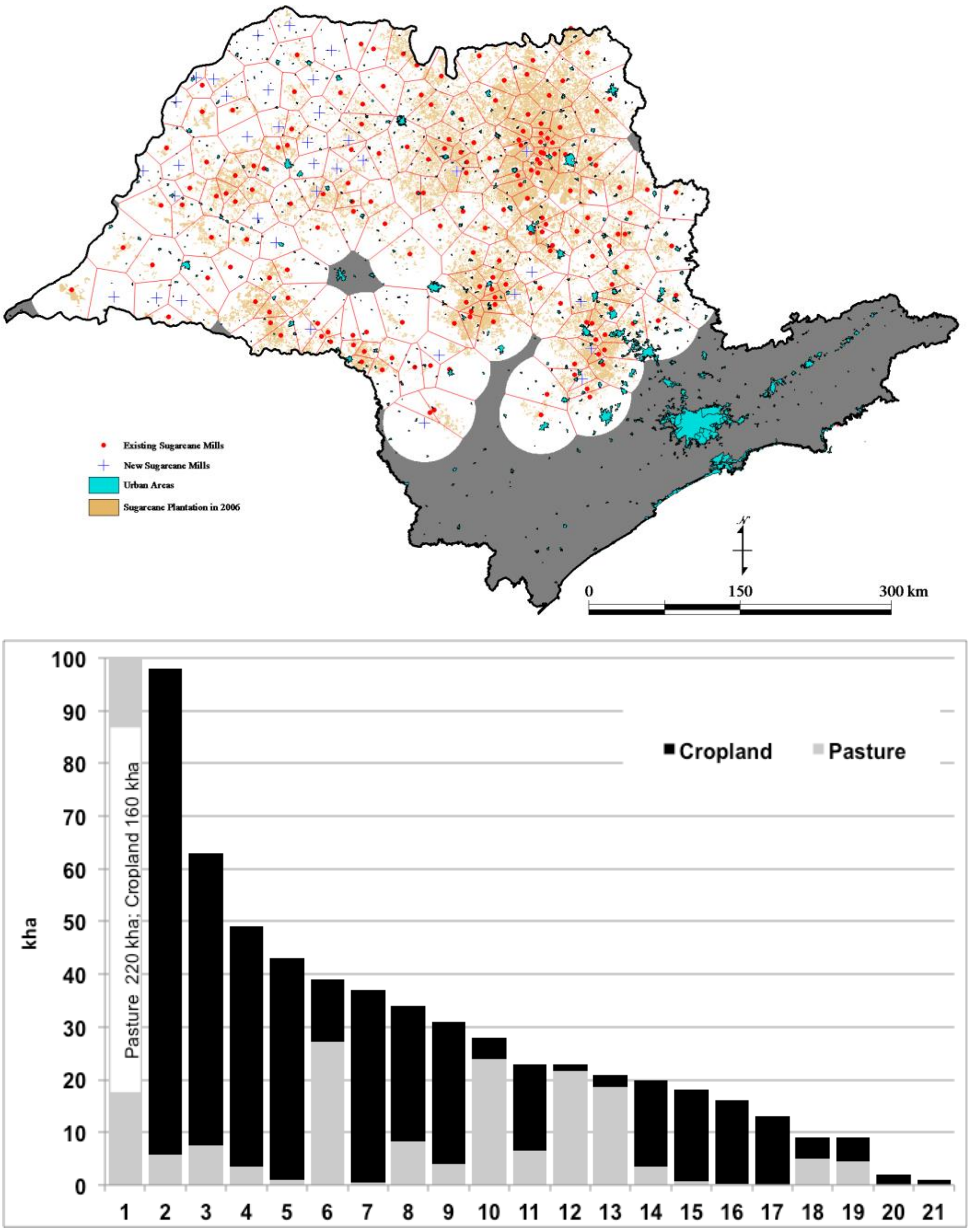

Figure 5. Top: Voronoi diagram relating to existing and 21 approved mills in the state of São Paulo. A Voronoi cell associated with a mill consists of all points closer to this particular mill than to any other mill. Some 34,000 ha of plantation land (including necessary roads) is needed to service an average size mill, assuming capacity corresponding to 2.3 Mt cane processed per season and yield at 85 t cane/ha/yr. Based on experience, Voronoi cell size was here defined by setting the maximum distance from mills to 40 km. The red dots represent locations of mills built before 2008; the + symbols represent locations of the 21 mill projects that were approved at the time of data collection. The light brown areas show where existing sugarcane plantations are located and the grey areas are either more than 40 km away from a mill or protected. Bottom: Existing pasture and cropland area within Voronoi cells surrounding the 21 mills. Each bar represents one approved mill. Source: Egeskog et al. (2014).

8 FEEDSTOCK AVAILABILITY

When bioenergy feedstocks are derived from dedicated cultivation systems, availability depends on how the feedstock cultivation interacts with cultivation for food, feed, and biomaterials. When the bioenergy sector uses the same feedstock as other sectors (e.g., sugarcane for ethanol or sugar, corn for food, feed, or biofuels) availability is a matter of: (i) payment capacity in the bioenergy sector versus other sectors and (ii) capacity in the agriculture sector to ramp up production in response to the total growth in demand. Some of the crops that are suitable for cultivation on lands that are currently grassland and pastures, are cultivated primarily for other purposes, and the bioenergy feedstock is a by-product. The availability of bioenergy feedstock is then limited by the market for the main products and by the ramp-up capacity in the agriculture sector. One example is soy, which is cultivated to produce animal feed and produces oil suitable for biodiesel production as a by-product (soybeans consists of approximately 20% oil).

As described above, many sugarcane mills in Brazil can produce both sugar and ethanol and can change output products (within a limited range) based on price expectations. However, while the competitiveness of the ethanol system is sensitive to developments in the sugar market, the total ethanol output is not restricted by the size of the sugar market. If demand for ethanol grows more rapidly than demand for sugar, sugarcane ethanol production can be ramped up based on constructing sugarcane mills that are dedicated to only ethanol production (and by-products such as electricity) and that can use sugarcane varieties that are optimized for ethanol production.

Few techno-economic barriers exist against large-scale cultivation on grasslands and pasture lands in Brazil: legal conditions for production are settled, production systems for several feedstock alternatives are mature, and there is technology and capacity to rapidly increase production in response to increasing demand. Progressive infrastructure investments further strengthen capacity, with significant investment in export routes via the Amazon River basin to support exports of soy, grain, cotton, etc. New investments aim at consolidating the north trade route by establishing new docks, barge fleets, and terminals along the Amazon River and tributaries, and improving capacity of ports in Belem, Itaituba, Santarem, and Santana, for example. It can be expected that increased agriculture production will be achieved based on both land expansion and improved land productivity, with possible LUC depending on how governance systems shape development. Among the options for boosting productivity, irrigation stands out because its expansion rate is difficult to project and because it can have such a strong effect on annual outputs by facilitating multiple cropping schemes (e.g., soy with corn or cotton) on the same land area.

Some feedstock options are in development stage and will not respond as quickly to rising bioenergy demand because they are not integrated with well-established agricultural supply chains, or require specialty equipment. This includes several of the lignocellulosic grasses and short rotation woody crops that commonly are proposed as major feedstock supply systems in the longer term. However, countries that have extensive areas with tree plantations that provide wood for pulp and paper as well as sawn-wood products would have the capacity to ramp up production to meet growing demand for lignocellulosic biomass as bioenergy feedstock (Chum et al. 2015, Goh et al. 2013).

Feedstock availability may be restricted by policies in some markets; the decision to cap the contribution of first generation biofuels in the EU-Renewable Energy Directive (EU-RED) is one example of such restrictions. Further, barriers against mobilization may exist in the sense that markets are associated with sustainability requirements, which can limit the rate at which feedstocks become available in several ways. Depending on how sustainability requirements and governance systems are shaped to guide bioenergy growth, the rate at which feedstock availability can grow will be affected by the pace of structural shifts and incentives rewarding higher productivity in agriculture. Availability of grasslands and pastures can be a critical determinant of possible mobilization rates for feedstocks supporting the production of "low-indirect-land-use-change" (low-iLUC) biofuels, because conceptual approaches for providing such biofuels often target marginal and/or "degraded" lands, which are commonly used for grazing. The large areas of grasslands and extensively used pastures in Brazil represent an important mobilization opportunity, but there are also challenges because, historically, ample supply of new land in frontier regions has fostered a culture among cattle producers and associated actors where management options to increase land-use efficiency are less important (Sparovek et al. 2015b). This is another area in which government policy can foster recovery of degraded pastures, where productivity would initially be low but then rise over time and enable both bioenergy and food crop expansion if needed.

9 GHG BALANCES AND OTHER SUSTAINABILITY ASPECTS

The sugarcane ethanol supply chain performs favorably and can improve further on critical aspects such as GHG savings and resource use efficiency. There is still significant progress to be made in power production with more efficient turbines and integrated systems. Analyses of GHG emissions and savings support the view that expansion of sugarcane ethanol in Brazil will bring about substantial GHG savings if LUC emissions are avoided (Figure 6). Sugarcane ethanol in Brazil also presents lower impacts than gasoline in terms of fossil fuel depletion and ozone layer depletion, but higher impacts in terms of acidification, eutrophication, and photochemical oxidation. Human health toxicity values are similar to those of gasoline (Cavalett et al. 2013). Ethanol from sugarcane refineries that use mechanical harvesting of unburned cane and configure the process to efficiently generate power qualify for the U.S. Environmental Protection Agency (EPA) Advanced Biofuel category (meeting the 50% threshold level) and receive a 50% reduction in the EU-RED system (Figure 6). Caldeira-Pires et al. (2013) also stress further improvements in agricultural management to decrease fuel, fertilizer, and herbicide consumption.

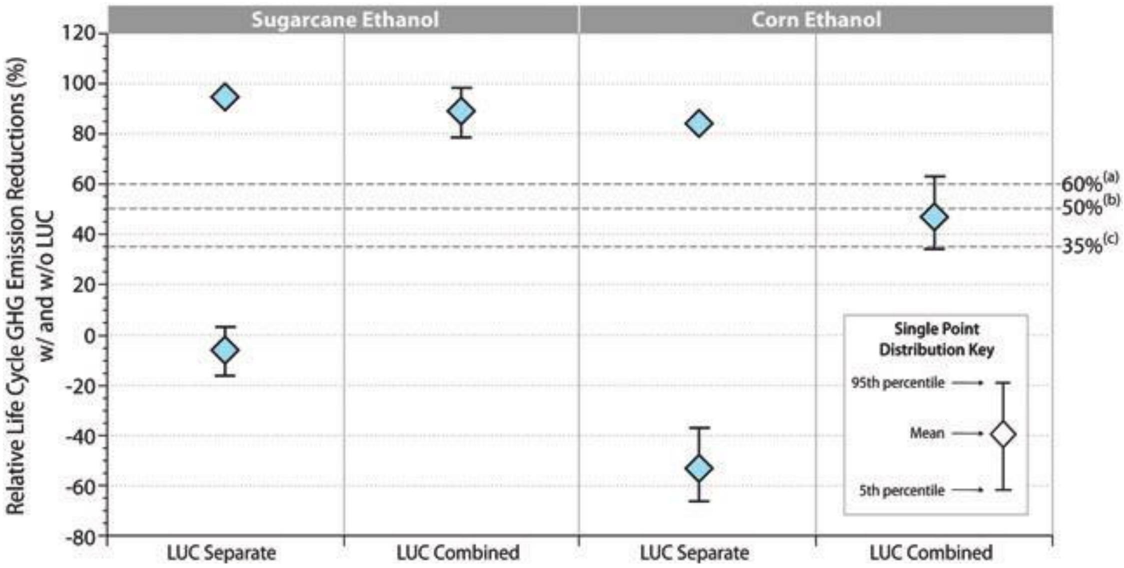

Figure 6. Relative life cycle GHG emissions reductions for Brazilian sugarcane ethanol and US corn ethanol, with and without LUC-induced GHG emissions separated from supply-chain GHG emissions. The highest points in the "LUC separate" fields correspond to the relative GHG reductions when excluding LUC and considering only the well-to-tank life cycle GHG emissions. The lowest points in the "LUC separate" fields (that include uncertainty ranges) correspond to the Monte Carlo distributions of LUC emissions. These LUC emissions are combined with well-to-tank life cycle GHG emissions to obtain the relative reduction when including LUC, shown in "LUC combined" fields. Legislated reduction: (a) 60% US EPA-classified cellulosic biofuel; (b) 50% US EPA-classified advanced biofuel; (c) EU-RED (Chum et al. 2014).

Oil palm, tree plantations, and soybeans can also support bioenergy and provide GHG savings, although soybean crops are less area efficient and are a less ideal use of land above the scale defined by animal feed markets. Other environmental impacts depend on the production location. Sugarcane and oil palm cultivation on grasslands and pastures causes relatively small carbon emissions or carbon sequestration, i.e., corresponding to GHG savings from displacing gasoline/diesel with biofuels during a few years (Mello et al. 2014, Souza et al. 2015). Carbon emissions are generally larger for annual crops, although no-till production reduces soil carbon losses under annual crops. If sugarcane or oil palm displaces annual crops to grasslands or pastures where their cultivation causes soil carbon losses, the fact that soil carbon simultaneously increases when the previous croplands are used for sugarcane or oil palm should also be considered. Land preparation and planting of trees can induce soil carbon losses, which are balanced by subsequent soil carbon gains depending on plantation management (Smith et al. 2014).

As described throughout this chapter, the opportunity to cultivate grasslands and pastures cannot be investigated based on analysing bioenergy options in isolation from other land uses, because cultivation of grasslands and pastures is attractive also to producers of other crops. This also means that availability of grasslands and pastures can accommodate expansion of cultivation systems that become displaced if bioenergy feedstock production expands on croplands. Thus, LUC, with its associated impacts, is not a concern for the bioenergy sector alone: a key question for Brazilian production of food, biofuels, and bioproducts is how the growing agriculture production affects the environment as well as social and economic development. The overall impacts need to be analysed together for the specific landscape, watershed, and biomass types for all their uses, and consider spatial and temporal dimensions (e.g., multiple cropping).

While information is lacking concerning bioenergy feedstock expansion on grasslands and pastures globally, it has been shown by Souza et al. (2015) that the net cropland area claimed for biofuels is so far relatively small; an analysis of the 34 largest biofuel producing countries, which accounted for more than 90% of global biofuel production in 2010, indicates that the increase in biofuel production from 2000 to 2010 resulted in a gross land demand of 25 Mha out of a total of 471 Mha arable land. However, nearly half the gross biofuel land area was associated with commercial co-products (primarily animal feeds), leaving a net direct biofuel land demand of 13.5 Mha, or 2.4% of arable land area. Despite this increased land demand for biofuel feedstock production, total agricultural land area decreased by 9 Mha in the evaluated countries as a result of increasing cropping intensity. See also Langeveld et al. (2013).

If land productivity growth continues to outpace growth in demand, so that the increase in production volume is decoupled from area expansion, environmental impacts will, to a greater degree, arise because of the agricultural management used to achieve the intensification, i.e., nutrient and pesticide leaching, soil erosion, etc. Implementation of best management practices will consequently be crucial for mitigation of environmental impacts. In Brazil, best management practices for cultivating low productivity pastures will be especially important since much of the land that can become available through intensification is currently used for extensive grazing.

Irrigation, currently occurring on 6 out of nearly 70 Mha of cropland in Brazil, could expand the agricultural frontier by adding areas unsuitable for rain-fed agriculture but suitable for cropping under irrigation. About 27 Mha of such land is located in areas where no important competition for water is foreseen, and no additional conversion of natural systems is needed to support the irrigation expansion. Most of these areas are also located in poor regions, neighboring the main important areas of agricultural production in the center and south of Brazil and in the recently consolidated region of crop production called "MAPITOBA" located in transitional areas between Cerrado and Caatinga biomes (FEALQ/IICA/MI, 2015). Since these areas are coincident to regions with significant amounts of unprotected native vegetation, governance systems balancing nature conservation and agricultural production will be important.

Some marginal lands (including grasslands) support relatively high levels of biodiversity and widespread use of marginal lands might therefore impact biodiversity (Chum et al. 2011). WBGU (2009) indicates that biodiversity considerations can have a larger impact on technical biomass potential than either irrigation or climate change. However, more current studies indicate that available land resources exceed the projected needs for biodiversity conservation in terms of the Convention on Biological Diversity’s target for protected area systems to expand to 17% of the global terrestrial area (Joly et al. 2015). It has also been shown that to some extent crops grown on degraded or abandoned land, such as degraded cropland and grassland, could have positive impacts on biodiversity by restoring or conserving soils, habitats, and ecosystem functions (Firbank 2008, Danielsen et al. 2009, Joly et al. 2015).

As for food and feed crop production, bioenergy feedstock production can occur in monoculture systems that use large amounts of synthetic fertilizers, pesticides and other inputs. Such systems are often criticized due to impacts on the environment, public health, and rural communities. More holistic approaches to land use have been called for that can better address issues associated with the complexity of food and other production systems in different ecologies, locations and cultures (see, e.g., IAASTD 2008). It should be noted that there are many ecosystems where monocultures develop naturally in forest and grassland biomes at both stand and landscape scales. The sustainability criterion of interest is most appropriately monitored at landscape to regional scales since the full range of micro- and meso-habitats will be sampled and inform the analysis. Nevertheless, the promotion of holistic approaches and a stronger link between agriculture and ecology is essential since a narrow focus on biomass production can reduce the value of biomass plantings with regard to the provision of other ecosystem services.

10 GOVERNANCE

10.1 Brazil

Figure 7 illustrates the current land governance structure in Brazil, including areas under several types of ownership and regulation. The trend in Brazilian agriculture is toward greater legal compliance and standardization. The Brazilian Forest Act is the most important legal framework for regulating conservation and restoration on private land, covering all natural vegetation; i.e., not only forests but also the non-forest biomes. The approval in 2012 and current implementation of the revised Forest Act changed the rules to facilitate legal compliance by reducing the requirements for land set-asides and/or restoration of native vegetation on productively used farmland. The revised Forest Act also includes a comprehensive environmental rural registry that facilitates monitoring and surveillance by government and civil society.

Amazonian deforestation rates have drastically declined since 2004 and the deforestation rate in 2014 was roughly 75% below the average for 1996 to 2005. Explanatory factors include effective surveillance and articulated networking of civil society and governmental agencies, as well as actions among important stakeholders in the agriculture sector (e.g., the soy moratoria) recognizing that businesses are negatively impacted by association with environmental degradation, especially in the Amazon (Nepstad et al. 2014). Analyses indicate that the focus on command and control measures on larger properties in deforestation hotspots may be increasingly limited in their effectiveness, and that further reductions in deforestation are likely to require actor-tailored approaches, including better monitoring to detect small-scale deforestation and more incentives-based conservation policies (Godar et al. 2014).

Consumer demand for certified agricultural products is increasing and an increasing share of Brazilian agriculture is adopting certification schemes. Governmental land entitlement initiatives reduce the degree of informality and legal noncompliance in the land-use sector. Global corporations are increasing their share in agricultural businesses, and these corporations are more sensitive to public image issues than individual farmers are, and less permissive with respect to legal nonconformity. Stakeholders' commitments have also grown more ambitious. These trends towards increased compliance and adoption of voluntary control standards reflect underlying and long-term external and endogenous drivers.

Governance of land use in Brazil is complicated by the fact that opposing sides in stakeholder disputes have ignored progress in balancing agricultural production and nature conservation, especially related to expansion in frontier regions (Sparovek et al. 2015b). The common ground perspective that agricultural and conservation interests can be compatible is challenged by old and deeply rooted mutually *exclusive* conceptions and positions of opposing sides. Mutually exclusive agendas may be favored over compatible agendas if they are strategically and tactically advantageous in processes shaping the governance of land use in Brazil. The polarizing positions expressed during the Forest Act discussions, and repeated on other occasions, indicate that stakeholders have indeed judged that debate and conflict will bring the most beneficial outcome. As a consequence, much of public opinion — and in turn government decision-making concerning Brazilian agriculture and conservation — appear to be shaped by a perceived conflict between these objectives and a debate that has become, at least to some extent, an end in itself.

10.2 Global

Assessment and certification schemes differ in degree of protection of environmental values and economic, social, and other implementation criteria. Diverging views on sustainability aspects and indicators around the world may reduce the effectiveness of sustainability certification systems, many voluntary, intended to support mobilization of sustainable bioenergy supply chains — sustainability being defined according to the particular principles and indicators chosen for evaluating the supply chain (Stupak et al. 2015). Thus, while biofuel producers and global trade companies create pressure towards legal regulation and engagement in certified production among feedstock producers, leakage effects may reduce the effectiveness of governance mechanisms.

Conversion of grasslands and pastures to bioenergy plantations will be affected in various ways by policies and regulations intended to protect biodiversity. One example of such regulation is found in the EU-RED where it is stated that biofuels and bioliquids shall not be made from raw material from "... land with high biodiversity value, e.g., areas designated for nature protection purposes, primary forest and highly biodiverse grassland" (European Parliament and Council 2009). Within the EU there has been a process to define the criteria and geographic ranges of highly biodiverse grassland (see e.g., European Commission 2014), and this process might continue in the future for solid biomass as well.

Schueler et al. (2013) estimated that 90% of a theoretical global and regional biomass potential is affected by the EU-RED sustainability criteria. They also indicate that about 60% of this biomass supply potential is subject to biodiversity considerations. Böttcher et al. (2013) report that about 8 and 5% of global grassland and natural vegetation, respectively, are considered to be highly biodiverse. Until now, few studies allow for quantification of how consideration of highly biodiverse grassland influences the biomass mobilization potential. Besides data and methods to distinguish highly biodiverse grassland from other land, there is a need for studies of the supply potential of biodiverse grassland that require management with biomass extraction to maintain its biodiversity status. Uncertainties will be reduced as schemes for demonstrating compliance with biodiversity requirements contribute to the establishment of criteria and geographic ranges of highly biodiverse grasslands.

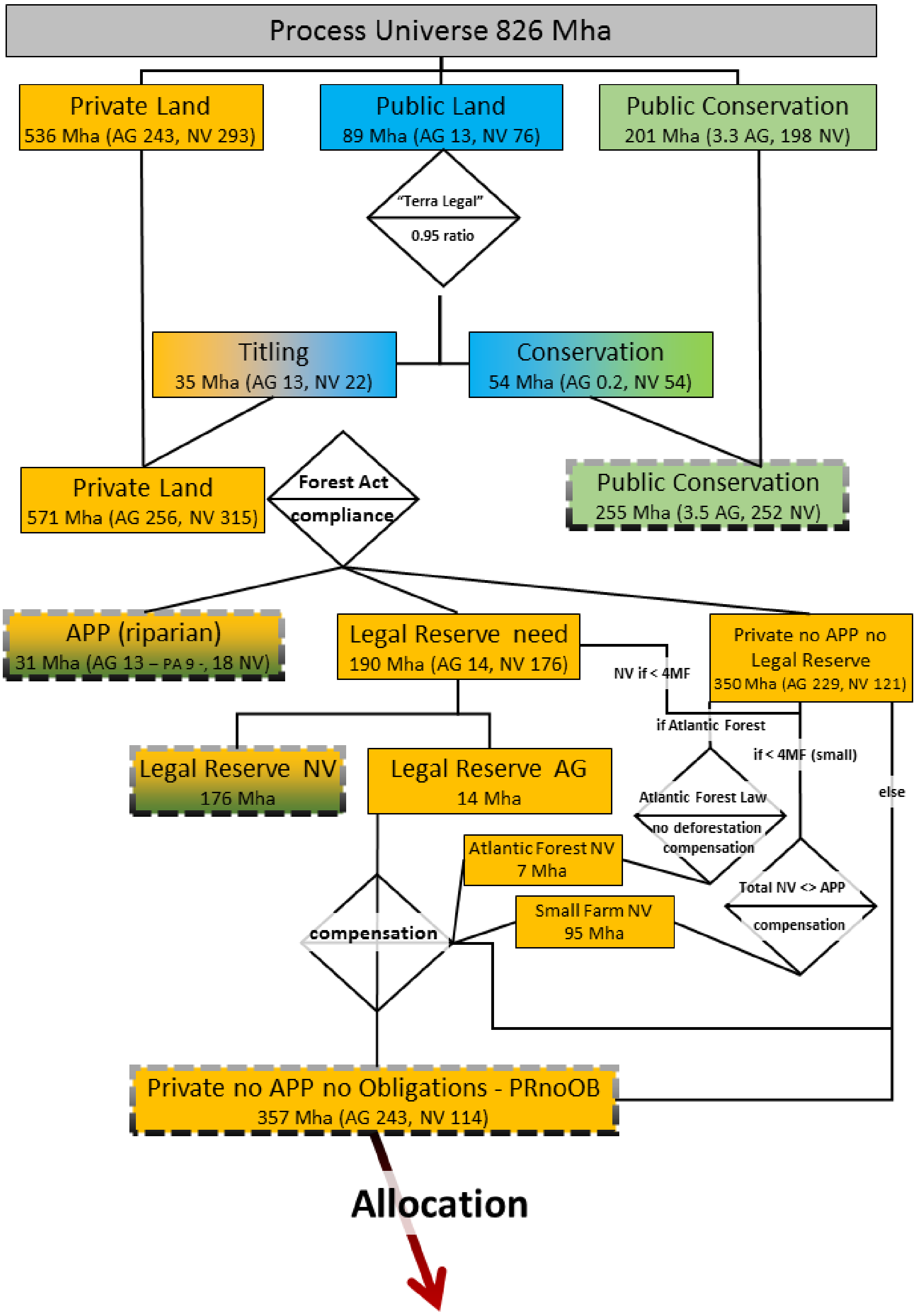

Figure 7. Land governance structure in Brazil; area of land under different types of ownership and regulation and legally available for agriculture. National area totals. The Figure also shows the land allocation principles used in the assessment present

11 SYNTHESIS

11.1 Constraints and barriers

Few techno-economic barriers remain against mobilization of bioenergy supply chains in Brazil: legal conditions for production are settled throughout the country, production systems are mature, and there is technology and capacity to rapidly increase production in response to increasing demand. Progressive infrastructure investments further strengthen capacity. Large GHG savings can be achieved if large LUC emissions are avoided.

Brazilian agricultural production can grow without extensive conversion of forests and other native vegetation. Large areas of extensively used pastures are suitable for cultivation of sugarcane and other bioenergy feedstocks, and land productivity improvements in meat and dairy production can accommodate an expansion of such cultivation. Irrigation can boost agriculture production in Brazil and in many other countries around the world.

However, bioenergy mobilization is hampered by uncertainty concerning future markets and evolving regulations. Specifically for the sugarcane system, low margins for sugar and ethanol are magnifying the importance of surplus electricity sales to the grid but several barriers inhibit development for electricity co-generation in ethanol mills. Furthermore, the recent revision of the Brazilian Forest Act resulted in less protection of native vegetation, and less stringent requirements for restoration planting and assisted regeneration of natural ecosystems on agricultural land. Large areas with native vegetation can legally be converted to agriculture use and ample supply of land reduces the interest in management options to increase land-use efficiency.

Consumer demand for sustainable agricultural products is increasing, but sourcing is challenging due to the variety of issues to be considered and the many suggested indicators for representing these issues. Diverging views on sustainability aspects and indicators around the world may result in leakage effects that reduce the effectiveness of sustainability certification systems — sustainability being defined according to the particular principles and indicators chosen for evaluating the supply chain. Biodiversity and hydrological aspects of grassland and pasture cultivation need further attention.

Finally, the polarized debate about the Brazilian agriculture development and environmental protection may in itself be a barrier against progress, since debate and conflict contributes to uncertainty about future markets, including sustainability standards and regulations imposed on producers.

11.2 Mobilization of sustainable bioenergy supply chains

The last decade has seen significant improvements in the productivity and efficiency of Brazilian agriculture, great reductions in deforestation rates, and growth in environmentally certified production. Science-based information supports the view that agricultural and conservation interests can be met simultaneously, because there is sufficient area to meet both conservation and production objectives. Improving productivity is perceived to be important by the agricultural sectors in Brazil and by those that prioritize environmental values. From this perspective, the current trends and achievements are promising.

Further mobilization of sustainable bioenergy supply chains can be supported by:

- Clear and consistent policy definitions and targets providing stable market conditions. Policies can either guarantee markets or increase fossil fuels prices sufficiently to make ethanol and other bioenergy options competitive. More favourable conditions for power generators and resource planning integrating biopower with other power resources can stimulate development especially in newer sugarcane mills where increasing scale improves conditions for electricity cogeneration.

- Good governance that balances agriculture production and conservation objectives to provide biomass and bioenergy products that meet sustainability requirements. This requires both incentives and alternative regulation (e.g., licenses and conditional credits) that complement governmental command and control to protect native vegetation and promote higher land-use productivity in the agriculture sector.
- Improved productivity in meat and dairy production and best management practices for cultivating low productivity pastures. This will be especially important, since much of the land that can become available through intensification is currently used for extensive grazing.
- Criteria, data, and methods that distinguish highly biodiverse grassland from other land and address hydrological aspects of grassland and pasture cultivation.
- Actor-tailored approaches to achieve further protection of native vegetation may be needed, including better monitoring to detect small-scale deforestation and more incentives-based conservation policies.

A common ground agenda, balancing conservation and agricultural development objectives, may be difficult to establish as long as conflict and dispute is considered desirable by many stakeholders involved with — or affected by — governance of Brazilian land use and biomass production. However, a structured exchange involving nine experts associated with major producer interests (livestock, crops, planted forest, and charcoal) and environmental non-governmental organizations (NGOs) (Sparovek et al. 2015b) revealed agreement that the majority of actions and expected future trends in Brazil reflect achievements and ambitions to balance production and conservation objectives. Decision-support systems that integrate relevant biophysical and socio-economic data were developed and used in this project, and these decision-support systems are now used to guide mobilization of sustainable production systems for food, bioenergy, and biomaterials at several Brazilian ministries.[7]

12 A COMPLEMENTARY GLOBAL OUTLOOK

12.1 Cultivation of bioenergy crops on grasslands and pastures

Grasslands and pastures cover a large part of the global land area, and significant areas are suitable for bioenergy feedstock production. The use of grasslands and pastures for cultivating bioenergy crops has attracted attention since land productivity improvements can free up large grassland and pasture areas for other uses, and since the greenhouse gas emissions associated with establishing bioenergy plantations on such lands are lower than when forests are converted.

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[7] Ministry of Integration, Ministry of Agriculture, and Ministry of Agrarian Development.

At the same time, there are several challenges associated with the use of grasslands and pastures, including the risk of biodiversity losses, water resource competition, and deforestation due to iLUC. It is therefore essential to learn from experiences in locations where large grassland and pasture areas have been converted to bioenergy plantations. Much analysis in the project has concerned the Brazilian experience of cultivating sugarcane on former pasture land, an option that could be promoted in several other countries where sugarcane can be cultivated. Below, we provide a brief global overview of the prospects for expanded cultivation of grasslands and pastures.

The bioenergy mobilization potential associated with grasslands and pastures depends on the evolution of a multitude of social, political, and economic factors, e.g., nature protection measures, land tenure and regulation, diet, trade, and technology. Illustrating how critical parameters influence the prospects for cultivation of grasslands and pastures, Wirsenius et al. (2010) modelled scenarios for the global food system up to 2030 and showed that relatively modest productivity improvements for livestock production systems, above improvement projections by the United Nations Food and Agriculture Organization, could reduce the agriculture land use in 2030 by roughly 500 Mha. Compared to agriculture land use around year 2000, the improved agriculture land use in year 2030 required roughly 250 Mha less land; about 95 Mha more cropland was needed in 2030 but the pasture area decreased by 340 Mha.

In a scenario where 20% of the per-capita consumption of ruminant meat (beef and mutton) is replaced by an equal amount (in terms of kg $capita^{-1}yr^{-1}$) of pork and poultry, agricultural land use was 725 Mha smaller than around the year 2000; the cropland area was roughly 60 Mha larger, but the pasture area was about 780 Mha smaller. Thus, released pasture land could accommodate the cropland expansion and at the same time reduce the conversion pressure on natural ecosystems by providing ample room for bioenergy expansion.

Table 2 shows estimates by Fischer et al. (2009) of technical biomass supply potential associated with rain-fed cultivation on unprotected grasslands and woodlands (i.e., forests excluded) when land requirements for food production, including grazing, have been considered at 2000 levels. Fischer et al. (2009) also emphasized the critical influence of productivity improvements on the numbers presented in Table 2 and concluded that the technical biomass supply potential could increase from 171 to 288 EJ yr^{-1} (globally) if livestock grazing areas were freed up for additional bioenergy production by intensification of agricultural practices and pasture use. As shown below, bioenergy mobilization potentials as well as prospects for agricultural production in general are very sensitive to how management of water resources evolves into the future.

Table 2. Global and regional grassland/woodland areas and technical potential of rain-fed lignocellulosic plants on unprotected grassland and woodland, when land requirements for food production (crop cultivation and grazing) at year-2000 levels have been considered (Chum et al. 2011, Fischer et al. 2009).

Region	**Total grassland and woodland area**	**Protected grassland and woodland area**	**Unproductive or very low-productive areas**	**Technical potential when also excluding grazing land in use**		
	(Mha)	**(Mha)**	**(Mha)**	**(Mha)**	**Av. yield* (GJ/ha/yr)**	**(EJ/yr)**
N America	659	103	391	111	165	19
Europe & Russia	902	76	618	122	140	17
Pacific OECD	515	7	332	97	175	17
Africa	1086	146	386	275	250	69
S&E Asia	556	92	335	14	285	4
L America	765	54	211	160	280	45
ME&N Africa	107	2	93	1	125	0.2
World	**4605**	**481**	**2371**	**780**	**220**	**171**

* Assuming an energy content at 18 GJ Mg^{-1}, dry matter basis. Agronomically attainable rainfed yield levels calculated for grid cells of 5-minute latitude/longitude resolution, based on climate, soil, terrain data, currently available cultivars, adequate applications of nutrients, and adequate chemical control of pests, disease, and weeds.

12.2 Influence of water resource management, irrigation, and water use efficiency

In the case of Brazil it was found that available water resources could support a large expansion of irrigated systems, boosting Brazilian production, since the area that is suitable for irrigation from the physical and logistical points of view is more than four times the presently irrigated area (6 Mha). The low level of the use of irrigation is price driven, and price changes for agricultural products can result in increased use of irrigation in multiple cropping systems (FEALQ/IICA/MI, 2015).

While abundant water availability provides opportunities for biomass production in some regions, water scarcity in other regions seriously restricts land use, and demand for bioenergy may add to the growing pressure on water resources. Water scarcity has been identified as a potential major obstacle for bioenergy expansion, but it is also recognized that bioenergy demand opens up new opportunities to adapt to water-related challenges and to improve the productivity of water use (Berndes 2002 and 2008, Service 2009). The net effect on the state of water depends on the characteristics of the crop (e.g., leaf area index) and land use and water management associated with the bioenergy systems put in place, compared to the previous situation. The brief global overview below gives an indication of how water resource management, irrigation, and water use efficiency can influence the prospects for bioenergy on a global level.

Figure 8 shows how water availability and irrigation strategies can determine the biomass mobilization potential on lands presently not used for agricultural production (excluding forests, wetlands, protected land, and land with severely degraded soils). As can be seen, the influence of irrigation patterns is large, and crop choice further amplifies the variation between scenarios. While lignocellulosic short-rotation woody plants show a greater response to irrigation, the higher land and water productivity of herbaceous plants allows larger total biomass production. The results do not reflect economic costs of expanding irrigation infrastructures and cultivating areas where infrastructure currently is limited. Yet, the results clearly show the large influence of water availability and management, aspects that have received relatively little attention in previous studies of the prospects for bioenergy mobilization.

Complementary to global modelling, investigations at local and regional levels show that biomass can be cultivated in plantings that offer benefits from the perspective of water (Berndes et al, 2015, Dimitriou et al. 2011). For example, some plants can be cultivated as vegetation filters for treatment of nutrient-bearing water (e.g., pretreated wastewater from households and runoff from farmland). Soil-covering plants and vegetation strips can also limit water erosion, reduce evaporating surface runoff, trap sediment, enhance infiltration, and reduce the risks of shallow landslides. Furthermore, expanded cultivation of crops with greater heat and drought durability and greater water-use efficiency (e.g., agave, opuntia, jatropha) into semi-arid, abandoned, or degraded agricultural lands may avoid competition with food and feed crops (Cushman et al. 2015, Gelfand et al. 2013, Qin et al. 2014, Ostwald et al. 2015). Plants that are cultivated in multi-year rotations can also utilize rain falling outside the growing season for conventional crops. Thus, there exist opportunities for improving water productivity in agriculture and alleviating competition for water and pressure on other land-use systems.

However, these opportunities need to be carefully assessed from a water balance perspective (Berndes 2002, Dallemand and Gerbens-Leenes 2013, Otto et al. 2011, Watkins et al. 2015). For example, the use of marginal areas with sparse vegetation for establishing high-yield bioenergy plantations may lead to substantial reductions in downstream water availability, requiring management of trade-off between upstream benefits and downstream costs (Garg et al. 2011). Availability and competing uses of water resources can therefore critically influence the feasibility of cultivating grasslands and pastures, and strategies for expanding bioenergy feedstock cultivation on such lands need to be integrated into wider basin-level planning that accounts for other water needs, including environmental flow requirements. Further, it is important to ensure that promotion of systems for biomass production on marginal/degraded lands does not promote inferior production systems whose only real advantage is that they are judged to have low risk of causing direct or indirect LUC with high GHG emissions.

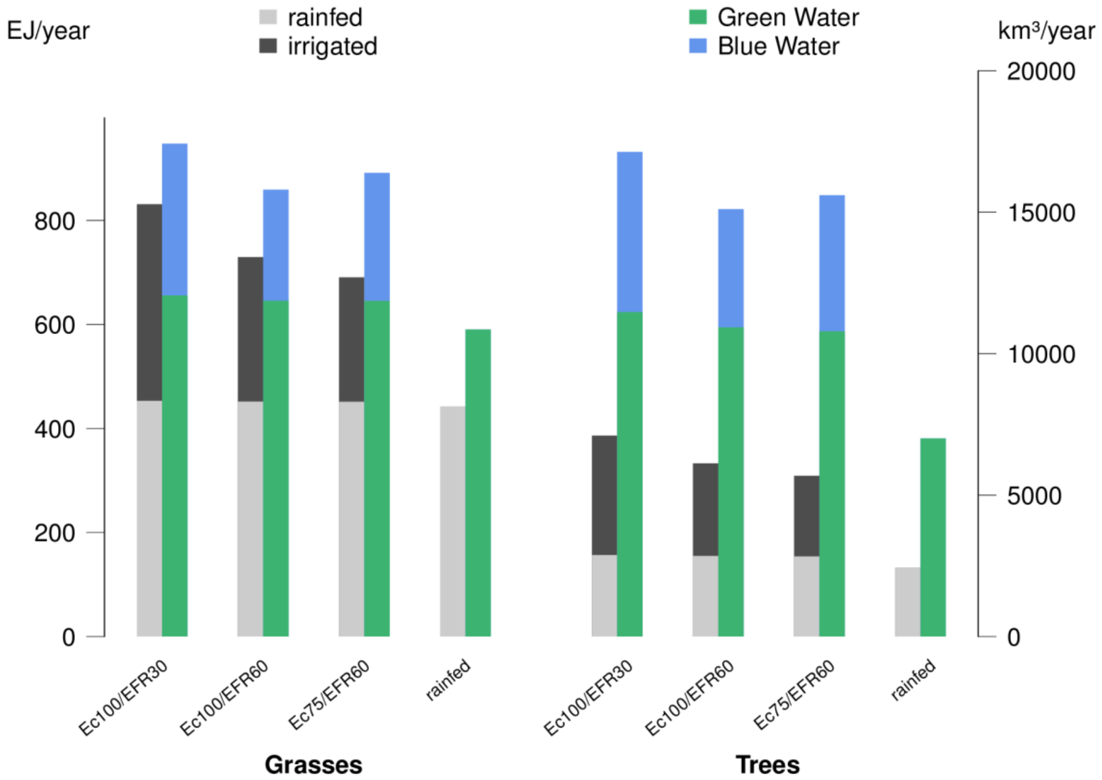

Figure 8. Primary biomass supply potentials (grey-black bars, left y-axis) and associated water consumption (green-blue bars, right y-axis) when grasses and trees are cultivated under scenarios including varying efficiency with which water is conveyed fr

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