Green for gold: social and ecological tradeoffs influencing the sustainability of the Brazilian soy industry

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In this study we assess the sustainability of the Brazilian soy industry over the past 40 years in comparison to alternative land uses. We conclude that Brazilian soy production performs as well as or better than sugarcane or cattle production in a number of areas, including macroeconomic contributions, local economic development and land use efficiency, though it involves similar tradeoffs between growth and equity, and food production and conservation. While there is no evidence that soy has reduced food security in Brazil, tax redistributions and value-added activities from soy remain limited, particularly in comparison to sugarcane production. Emerging environmental governance measures have helped to reduce the land cover impacts from soy; however, little effort has been taken to minimize the impacts of intensification.

Keywords: soybean; agribusiness; Brazil; environment; equity; development

1. Introduction

In the last 50 years, Brazil has emerged as one of the largest agricultural exporters in the world, playing a major role in the global supply of beef, poultry, soy, sugar, oranges and coffee. The expansion and intensification of Brazilian agriculture has generated substantial economic benefits for Brazil (Awokuse 2009). Unlike most other economic sectors in Brazil, agriculture has a positive trade balance, with exports exceeding USD 95 billion in 2012 (IMEA 2013). Nevertheless, these benefits have come at a huge environmental and social cost (Martinelli et al. 2010; Lapola et al. 2013). Over the last 40 years, 18 percent of the forest in the Legal Amazon region, 50 percent of the native vegetation in the Cerrado, Pampas and Caatinga, and 88 percent of the native vegetation in the Atlantic Forest has been cleared, primarily for agriculture (INPE 2014; Ferreira et al. 2012; Ribeiro et al. 2009). Agriculture now occupies 30 percent of the total land area of the country (Sparovek et al. 2010). Much of this agricultural land is controlled by large farms, particularly in sectors oriented toward export markets, such as sugarcane, soy and rice (Martinelli et al. 2010). 'Family farms',¹ which typically produce a diverse set of agricultural products for domestic consumption, occupy only 25 percent of the area (Lapola et al. 2013).

Amid these broader trends of increasing export-oriented agriculture in Brazil, soy production has increased faster than any other crop. Between 1970 and 2010, soy yields

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¹'Family farmers', alternatively referred to as small-holders, are defined here as farmers with up to four fiscal modules (20 to 400 hectares depending on the county) that rely almost entirely on house-hold labor for production, following Brazilian Law number 11,326 (MDS 2014).

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doubled and planted area increased by 22 million hectares, contributing to a 10-fold increase in soy production (FAO 2013). While much of the recent literature has focused on the impacts of Brazilian soy production on land cover change, land concentration and social conflict (Soares-Filho et al. 2006; Vera Diaz, Kaufmann, and Nepstad 2009; Richards et al. 2012; DeFries et al. 2013; Morton et al. 2006; Macedo et al. 2012; Steward 2007; Baletti 2014; Fearnside 2007, 2001; Brannstrom 2009; Sparovek et al. 2010; Lapola et al. 2013), we provide a more nuanced assessment of the sustainability of the Brazilian soy sector by considering a broader suite of ecological and social impacts and tradeoffs.

Sustainable development is defined as development that leaves future generations with as many opportunities as current generations have, if not more (Serageldin 1996). It implies that current generations use resources in ways that increase the well-being of the current generation and the *potential* well-being of all generations that follow (Arrow et al. 2012). Applying this definition to soy production in Brazil, a 'sustainable soy sector' is one that meets the needs of current generations (by providing food, improving access to healthcare and education, and creating broadly distributed income and employment opportunities), without compromising future generations' opportunities to meet whichever needs they may have. This means, chiefly, that soy production must not deplete the natural capital stock on which all current and future generations' well-being depend (Daly 1991). However, this definition of sustainability creates challenges for policy design because it does not tell us exactly how much food, income and employment the soy sector should generate, or how much environmental degradation is possible without irreparably damaging the natural capital stock and endangering the well-being of future generations. Nor does it tell us anything about path dependency and what sorts of policy and development pathways are feasible given past trajectories.

For this reason, it is easier to view the goal of Brazilian soy sustainability, or any form of sustainability, for that matter, as a moving target – to achieve greater potential well-being *relative to* historical land use and development pathways, echoing the approach of Matson (2011) for the wheat sector in Mexico. In practice, this means that soy production is becoming *more* sustainable if it creates: (1) higher local incomes, (2) more jobs, (3) improvements in local infrastructure, (4) fewer greenhouse gas emissions, (5) less conversion or more restoration of native vegetation, particularly around streams, and (6) improved soil quality *relative to* previous production practices. It is becoming *less* sustainable when it: (1) increases income inequality, (2) exposes people to new health risks, (3) marginalizes/ excludes small farmers and (4) reduces biodiversity. This multi-criteria definition follows the efforts of Loos et al. (2014) to broaden the discussion of 'sustainable agriculture systems' beyond a limited set of environmental criteria.

To understand the historical impacts of Brazilian soy we begin this paper by providing a brief overview of soy development and expansion in the region. We then analyze a wide range of secondary data and existing literature to identify the relative impacts of the soy sector on current well-being versus other potential land use activities. In describing impacts on current generations' well-being (i.e. inclusive development) in Brazil, we focus on the contributions of soy production to the economy of Brazil (macroeconomic conditions), national and household food security, access to goods and services in rural areas, and rural equity. In assessing hypothetical impacts on future generations' well-being (i.e. sustainability) we focus on the soy sector's influence on natural capital within Brazil and globally through land cover change, greenhouse gas emissions and pollution. We conclude by discussing the potential of current social and environmental governance mechanisms to improve the sustainability of the soy sector, including federal policies and industry and civil society-led market mechanisms.

Impacts	Scale	Variable
Macroeconomic conditions	National	Total exports and share of agricultural exports Tax revenue GDP from agriculture Agricultural loans
Food security and quality	National	Direct food security measures Changes in domestic staple production Protein production per hectare of soy versus other crops
Access to goods and services	National County	Local infrastructure development and urbanization HDI-total, HDI-income, HDI-longevity, HDI-literacy (2003)
Equity	National	Foreign ownership of land Employment in soy compared to other crops GINI coefficient for land compared to other crops
	County Case studies	Theil index of income inequality (2000) Exclusion of existing land users Displacement
Land cover change	Biome	Historical and total land cover change Soy area per biome Carbon debt from land conversion to soy Watershed impacts of land cover change on soy farms
Input intensification	Biome	Fertilizer used on average soy farm in Amazon and Cerrado N and P emissions from soy fields in Cerrado and Amazon

Table 1. Variables examined in this analysis.

2. Methods

We examine the influence of the Brazilian soy sector on intergenerational well-being using a variety of socio-economic and ecological variables at four different scales: national, biome, county and community. While the use of multiple scales in this study limits tradeoff analysis, it is necessary since many data are not available, quantifiable or relevant at all scales. Details on variables examined at each scale are presented in Table 1. Below is a short synthesis of our approach:

- Macro-economic impacts are analyzed at the national scale, the only scale relevant for these impacts.
- Food security impacts are analyzed at the national scale, since no data are available at the local level for all regions.
- Natural capital/ecological impacts are analyzed at the biome scale, since this is the scale at which the use of agricultural inputs and impacts from land cover change from agricultural expansion vary the most. We also include data on land cover and watershed impacts from the state of Mato Grosso, which spans multiple biomes, since this is the largest and most well studied soybean production region in the country.
- Household well-being and equity impacts are analyzed at the municipal scale, since data is available for almost all counties (n = 5539) through secondary sources. We applied an analysis of variance (ANOVA) test followed by the post-hoc Tukey test to examine whether mean levels of well-being are different for counties that are 'soy dominant' in comparison to counties that contain other dominant land uses. A county is classified as soy dominant (SOY) if in 2000 it had more than 50 percent of its crop area planted in soy, sugar dominant (SUGAR) if it had more than 50

Class	Soy	Sugar	Cattle	Other AG	Non AG
Criteria	>50% of crop area in soy	>50% of crop area in sugar	>31,000 head cattle, <50% of crop area in soy or sugar	>10% of area in crops <50% of crop area in sugar and soy <31,000 head cattle	<10% of area in crops <31,000 head cattle
No. of cases	337	373	1167	1663	2099

Table 2. Methods for classifying dominant land uses.

Note: Where 'soy' = soy dominant counties; 'sugar' = sugar dominant counties; 'cattle' = cattle dominant counties; 'other AG' = counties dominant in other forms of agriculture; and 'non AG' = non-agricultural counties. Source: (IBGE 2013a, 2013b).

percent of its crop area planted in sugarcane, cattle dominant if it had above-average cattle herd size but less than 50 percent of its crop area planted in soy or sugarcane (CATTLE), and other agricultural (OTHER) if more than 10 percent of the county area contains cropland but cattle herd size is below average and not more than 50 percent of its crop area is planted in soy or sugar. Finally a county is characterized as non-agricultural (NON-AG) if less than 10 percent of the county area is comprised of cropland and the county contains a below-average cattle herd (Table 2). Average household well-being in each county is represented by the Human Development Index (HDI) from 2003, which includes three components: income, literacy and longevity. The HDI values range from 0 to 1, signifying that the population in a county achieving a score of 0.8 will have higher average per-capita income, years of education and life expectancy than the population in a county achieving a score of 0.5. The HDI measure represents only *average* income, literacy and longevity in each county, not the *distribution* of income, education or health. Therefore, to examine equity, we use the Theil Index of income inequality from 2000. The Theil values also range from 0 to 1, signifying that the population in a county achieving a score of 0.8 will have higher income inequality than the population in a county achieving a score of 0.5. Unfortunately, there are no data on the variance of health and education levels within each county. The following controls are included in the statistical analysis since they may also influence HDI and Theil levels: lagged transportation costs to São Paulo (1995), the date the county was established, population (1996) and the percentage of the population that is urban (1996). Distance to São Paulo, date of establishment and percentage of the population that is urban are included to reflect the history of the county and/or the composition of the economy, in particular the presence of service and manufacturing opportunities. For example, an urban municipality near São Paulo that was established 150 years ago may have better health services than a remote, recently established county. Population is included as a control because it may influence the resources available within a county, i.e. health and education infrastructure may be more abundant in a county with a high population. Descriptive statistics and data sources for all non-land use variables are presented in Table 3.

 Local development and equity outcomes were also examined at the community level through first and second author observations from over five years of fieldwork in soybean-producing regions in Brazil, and by reviewing previously published field studies, which examine more complex social outcomes, such as investments in local infrastructure, agro-urbanization, displacement, exclusion and rising costs of living.

Variable	Soy Mean (SD)	Sugar Mean (SD)	Cattle Mean (SD)	Other AG Mean (SD)	Non AG Mean (SD)
HDI-total	0.77 (0.04)	0.72 (0.09)	0.72 (0.06)	0.71 (0.09)	0.67 (0.08)
HDI-income	0.68 (0.06)	0.63 (0.10)	0.63 (0.08)	0.61 (0.09)	0.57 (0.10)
HDI-literacy	0.86 (0.05)	0.79 (0.10)	0.80 (0.07)	0.78 (0.09)	0.76 (0.09)
HDI-longevity	0.77 (0.05)	0.73 (0.08)	0.72 (0.06)	0.72 (0.09)	0.69 (0.08)
Theil	0.56 (0.12)	0.47 (0.10)	0.56 (0.11)	0.50 (0.10)	0.52 (0.10)
Transport cost to São Paulo (index)	1166 (474)	1296 (1031)	1642 (1194)	1396 (896)	1903 (1350)
Population (1000 people)	20.3 (41.6)	31.5 (65.7)	40.8 (111.7)	15.5 (24.4)	41.6 (289.2)
% of population that is urban	58 (23)	74 (18)	62 (22)	50 (22)	55 (24)

Table 3. Distribution of HDI and Theil by dominant land use.

Note: Where 'soy' = soy dominant counties; 'sugar' = sugar dominant counties; 'cattle' = cattle dominant counties; 'other AG' = counties dominant in other forms of agriculture; and 'non AG' = non-agricultural counties. Sources: IPEA. Total and urban population are from the demographic census (http://www.sidra.ibge.gov.br).

One of the main limitations of our quantitative analysis is that our indicators of well-being are not available for more recent years, nor do we possess a time series of these data. Instead, we must infer the relationship between soybean production, human development and equity from spatial variations in land use, HDI and income inequality. Nevertheless, this analysis is helpful for understanding how 'soy counties' compare to 'sugar and cattle counties', since evaluations of the sustainability of soy production frequently lack comparisons with other land use alternatives. Without this type of information, it is impossible to understand whether another land-use strategy might be capable of providing more benefits to society than soy, with fewer ecological impacts.

3. A brief history of soy production in Brazil

Soy production in Brazil began in the South, in the Atlantic Forest and Pampas ecosystems (Figure 1), where the naturally fertile red latosols soils require fewer inputs than the soil of other regions in Brazil. There, soy was double-cropped with wheat, a commodity that was heavily subsidized by the federal government in the 1960s and 1970s to reduce dependence on imports (Faminow and Hillman 1987). The varied topography and intergenerational land fragmentation limited the size of farms in this region. While soy became one of the larger land uses in this region, it never fully displaced livestock, which continues to be the largest land use in the region (Table 4; IBGE 2006).

Soy production advanced into the Cerrado savanna ecosystem in the Center–West region of Brazil during the 1960s and 1970s as part of a larger government process to modernize and increase the legibility of this 'empty space' (Oliveira 2013; Hecht 2005; Scott 1998; Hecht and Mann 2008). The high-modernism ideology of the period included an unwavering confidence in the potential of science and technology to achieve social progress (Scott 1998), which led the government to invest heavily in agricultural research and development. Plant geneticists and agronomists from the Brazilian Agricultural Research Corporation (Embrapa) were sent to the United States for training and charged with the task of developing new agricultural technologies for the heretofore un-arable landscape (Hecht and Mann 2008; Oliveira 2013). This federal investment led to the development of so-called miracle soy cultivars capable of tolerating the metal-heavy, nutrient-poor, acidic soils of the Center–West, with high levels of biological nitrogen fixation. (Spehar



Figure 1. (a) Soy area by state in Brazil; (b) major geographical regions and ecological biomes in Brazil. Source: (IBGE 2013a).

		% of agricultural ^a area in each land use				
Region	Land use	1980	1985	1995	2006	
North	Permanent crops	1	1	1	3	
	Annual crops	3	3	2	4	
	(Soy)	<1	<1	<1	1	
	Pastures	19	33	42	48	
Northeast	Permanent crops	5	5	3	5	
	Annual crops	11	11	10	15	
	(Soy)	<1	<1	1	2	
	Pastures	39	38	41	40	
Southeast	Permanent crops	5	5	5	7	
	Annual crops	12	13	11	17	
	(Soy)	1	1	1	2	
	Pastures	59	58	59	51	
South	Permanent crops	3	2	1	4	
	Annual crops	28	28	26	33	
	(Soy)	13	13	11	17	
	Pastures	44	45	47	38	
Center-West	Permanent crops	<1	<1	<1	1	
	Annual crops	5	7	6	11	
	(Soy)	1	2	3	7	
	Pastures	60	60	58	56	

Table 4. Major land uses by region (1980–2006).

Source: (IBGE 2006).

^aAgricultural area includes pastures and forest reserves.

1995; Sousa and Busch 1998; Luna and Klein 2006; Alves, Boddey, and Urquiaga 2003). Embrapa also facilitated the transfer of no-till/direct planting technology, which was critical to the long-term sustainability of soy production in the region by reducing erosion, enhancing soil permeability for water infiltration, and increasing organic material in the soil (Gasques and Bastos 2010).

In contrast to the predominantly state-led colonization programs in the Amazon, families moved to the Cerrado during the late 1970s and 1980s, through a combination of state efforts, spontaneous migration and organized private colonization (Rausch 2014). When state support was not available, private colonization firms helped migrants navigate the complicated government bureaucracy, volatile markets and lack of infrastructure (Jepson 2006a). Despite harsh initial conditions, competition and collaboration between multiple settler groups accelerated the development of the region (Rausch 2014). Soy production in the Cerrado soon became one the most lucrative rural land uses in Brazil, particularly since the relatively flat terrain allows for large farms and economies of scale. Soy farms in the region now average 1000-2000 hectares in size, but sometimes exceed 10,000 hectares, much larger than the national average soy farm size of roughly 130 hectares (IBGE 2006; Garrett, Lambin, and Naylor 2013a). Given the low natural fertility of the Cerrado soils, soy production requires large applications of potassium, phosphorus and lime, but is now capable of achieving soy yields averaging 3 tons per hectare there (IBGE, 2013a), rivaling, if not exceeding, productivity in the United States (Ash 2012).

Soy expansion in the Amazon forest ecosystem in the North of Brazil did not proceed in earnest until the 1990s. By the time soy first arrived in the region, many of the 'soy-suitable'² regions of the Amazon, particularly in Pará and Rondônia, were already settled by previous colonization projects (Brown et al. 2005; Steward 2007). In these regions, particularly post-2006, soy expansion occurred mainly on areas that had been previously cleared for small-holder production and pastures (Rudorff et al. 2011; Brown et al. 2005; Steward 2007). Consequently, the expansion of soy in these regions was fraught with cases of resistance, conflict, displacement and indirect land-use change, typified by the highly publicized soy-producing regions of Paragominas and Santarém (Steward 2007; Gardner et al. 2013). In contrast, soy expansion in Southern Amazonia (Northern Mato Grosso and Southern Rondônia) was implicated in a large amount of direct deforestation of primary forest in the early 2000s (Morton et al. 2006), but fewer reported social impacts.

In addition to investments in agricultural research and development, the government promoted the expansion and modernization of Brazilian agriculture through supportive monetary and agricultural policies. The Bank of Brazil and the National Rural Credit System were established to provide cheap credit to farmers, with interest rates fixed below the rate of inflation (Warnken 1999; Sousa and Busch 1998). In the Cerrado, the government created the Superintendency of the Development of the Center–West (SUDECO) to implement fiscal incentives for migration, the Development Program for the Cerrado (POLOCENTRO) to fund agricultural research and extension, improvements to roads and electricity infrastructure, and the Japanese–Brazilian Cooperative Program for Cerrado Development (PRODECER) to subsidize the construction and purchase of silos and farm equipment (Jepson, Brannstrom, and Filippi 2010; Fearnside 2001; Jepson 2006a). More broadly, the government also provided minimum price supports for commodities such as soy, corn and wheat (Damico and Nassar 2007), but high global prices have rendered these price supports largely unnecessary in recent years.

The private sector took the leading role in the development of the soy industry during the 1990s as a result of changes in macroeconomic, trade and agricultural policies (Jepson 2006a). The Brazilian government lowered import tariffs, exempted soy exports from the interstate movement tax, joined MERCOSUR (a regional free trade agreement),³ and stabilized the national currency (Flaskerud 2003; Chaddad 2006; Luna and Klein 2006). These changes made Brazilian soy more competitive in international markets and helped Brazil double its agricultural exports between 1990 and 2005 (Chaddad 2006). Brazil's liberalized markets, macroeconomic stability and investments in infrastructure continued to attract foreign investment to the Brazilian soy industry throughout the 2000s (Luna and Klein 2006; Jank, Leme, and Nassar 2001). As foreign investment by multinational food companies increased, the soy sector became more vertically coordinated and internationally integrated. Multinational agribusinesses connected distant consumers to the far reaches of the Brazilian Cerrado through advanced logistics services (Jank, Leme, and Nassar 2001). They also helped reduce producers' risks from price instability by offering futures contracts and improved access to storage facilities (Vera-Diaz et al. 2008).

Throughout the 1990s and 2000s, the soy industry became increasingly concentrated through mergers and acquisitions, displacing domestic processing, transportation and

 $^{^{2}}$ Defined as regions with both adequate biophysical conditions (rainfall greater than 1200 mm and less than <2200 mm per year, a distinct dry season to help control pests and weeds, flat topography, soils with adequate drainage) and good transportation networks (access to paved roads, federal highways and or major waterways).

³MERCOSUR is regional trade agreement between Argentina, Brazil, Paraguay and Uruguay, and associate members Chile and Bolivia, established in 1991 (Belik and Santos 2002; Polaquini, Souza, and Gebara 2006).



Figure 2. The value of soybean, oil and meal exports in comparison to the value of all other agricultural exports in Brazil (1970–2010). Source: (FAO 2013).

retailing firms. A small number of soy firms, including Archer Daniels Midland (ADM), Bunge, Cargill, Louis Dreyfus and Maggi Group now control a majority of the soy market in Brazil (Jank, Leme, and Nassar 2001; Goldsmith and Hirsch 2006). Cooperatives also played a critical role in the development of soy production in the Cerrado by facilitating land acquisition and tenure, increasing producers' access to inputs, providing technical assistance and helping producers market their grain for higher prices (Jepson 2006b; Garrett, Lambin, and Naylor 2013b, 2013a; Jepson, Brannstrom, and Filippi 2010). Infrastructure remains the largest challenge inhibiting soybean profitability in the Center–West of Brazil, where limited road and rail networks pose extremely high costs for the industry. In Northern Mato Grosso (one of the largest soy producing regions in the country), transportation costs account for 25 percent of the total price of soy (Vera Diaz, Kaufmann, and Nepstad 2009).

4. Impacts on current generations' well-being

4.1. Macroeconomic conditions

The value of soy exports (unprocessed beans and processed oil and meal) has increased exponentially since 1970, reaching USD 28 billion in 2013, which is roughly equal to the value of all other agricultural exports combined (MDIC 2013; Figure 2). The export revenues from soy production have contributed to an increase in the value of the Brazilian currency, which increases consumers' purchasing power in world markets. On the other hand, the appreciation of the Brazilian Real reduces the competitiveness of Brazilian manufactured goods in world markets, which may decrease employment opportunities in the manufacturing sector (Gaulard 2012).

Soy production requires a large number of supporting services and thus has a fairly complex supply chain (Figure 3), including input provision, financing, marketing, distribution and processing (Garrett, Lambin, and Naylor 2013b). In 2007, the soy supply



Figure 3. Typical Brazilian soy supply chain.

chain generated USD 17.2 billion toward the Brazilian gross domestic product (0.7 percent of the national GDP; Barros, Fachinello, and Silva 2011). Roughly 45 percent of this GDP came directly from soy production, 40 percent from services, 8 percent from processing and 7 percent from inputs. Still, an increase in the level of domestic soy processing could further amplify the revenues obtained from Brazilian soy production given that more than 50 percent of all the soy produced in Brazil is exported without any processing (FAO 2013).

Even without the addition of more value-added activities, soy production and associated agribusiness generate substantial tax revenue for the country. The tax contribution from domestic sales of whole soybeans alone was USD 1 billion in 2004⁴ (Lazzarotto and Roessing 2004). A portion of the tax revenues generated by soy production and processing (through the federal tax programs Fundo de Assistência ao Trabalhador Rural (FUN-RURAL), Programa de Integração Social (PIS), and Seguro Acidente de Trabalho (SAT)) are used to support welfare programs, such as conditional cash transfers, social security, unemployment insurance and local rural development.⁵ On the other hand, since the passage of the federal Kandir Law in 1996 (Law no. 87), soy destined for export is exempt from the interstate movement tax (ICMS), a major source of tax revenue for states. The Kandir Law was part of the suite of policies developed during the 1990s to increase foreign investment and exports. States' loss of this revenue is theoretically compensated by redistributions of federal funds to the states and municipalities. However, state governments claim that the redistributions fall short of the ICMS losses, though the benefits of greater investment brought by lower taxation on the production of commodities destined for export likely outweigh any such shortfalls (Varsano 2013). Finally, municipal property taxes, which are based on land values, can be channeled directly into improving local services and infrastructure in soy-producing regions. Nevertheless, the overall tax rate on soy production, like that on other Brazilian farming activities, is fairly low, and there are no taxes on soybean, meal or oil exports.

⁴No later estimates were available that we could locate.

⁵The rates and names of these taxes are not the same in every state and can be substituted by other tax programs. For producers, they also differ depending on whether the farm is run as a corporation or a family.

Contributions to national export revenues, GDP and taxes must be evaluated alongside contributions that the soy industry receives from the federal government. In contrast to the United States and Europe, Brazil provides little direct support to farmers through subsidies, payments or insurance (OECD 2010). However, Brazilian soy farmers benefit substantially from state-supported/subsidized agricultural loans at below-market interest rates. Agricultural loans to cover soy production costs, value added activities and commercialization totaled more than USD 7 billion in 2012 (using an exchange rate of 1 BR Real = 0.55 USD; BCB 2012). The total value of agricultural loans and credit subsidies for soy production exceeded every other crop between 1969–1990 (Helfand 2001). The soy industry also benefits greatly from federal investment in new roads and pavement of existing roads in key production regions, such as Mato Grosso and Pará (Soares-Filho et al. 2004), but these investments have not been quantified.

4.2. Food security and quality

Food security is defined as access by *all people at all times* to enough food for an active, healthy life (World Bank 1986). The expansion of soy production in Brazil – a commodity crop with few direct food uses – raises questions about tradeoffs between global and local food security, as well as between physical and economic food security. According to Brazil's Survey of Demography and Children and Women's Health, 38 percent of Brazilian families reported some form of food insecurity in 2006, with higher levels of food insecurity in the North and Northeast, particularly in rural areas (PNDS 2006). Among the food insecurity, approximately 90 percent of food-insecure families reported that they were worried that their food would run out before they received more money, could not afford to purchase balanced meals and relied on low-cost foods for children (Reis 2012). Thus, poverty tends to be a far more important driver of food security than physical food scarcity in Brazil.

Approximately 50 percent of the soy produced in Brazil is exported, but this leaves more than 30 million tons of soybeans for domestic use, which can be converted into oil and meal to be consumed directly in cooking and indirectly via pork and poultry production, or else exported at a higher value (FAO 2013). Per capita consumption of poultry and pork in Brazil have grown by 280 percent and 56 percent over the last three decades (1980–2010),⁶ meaning that Brazilians are now indirectly consuming more soy than ever before in the form of animal proteins.

Nevertheless, the use of soy as a livestock feed brings up the issue of food quality versus quantity, and the land intensity of food production. While processed meats provide fat and protein, more diversified farming systems produce foods with a wider range of nutrients. Producing domestic staples, fruits and vegetables, alongside export crops like soy and cotton, can increase farmers' autonomy from volatile commodity markets, resilience to climate change and weather shocks, and sovereignty over the means of production (Altieri and Toledo 2011; Schneider and Niederle 2010). In terms of domestic food supply, soy has not reduced the availability of rice, beans and manioc in the country, since production of these crops has actually increased over the last 20 years through a reorganization of cropping patterns and intensification of production (Brown, Rausch, and Luz

⁶The second author calculated these figures using data from FAOSTAT Food Balance Sheet and Brazilian Population Census data (IBGE 2010; FAO 2013).

2013; Lapola et al. 2013). In many regions, soy is double-cropped with another product – corn in the Center–West and wheat, rice and beans in the South. Soy production has replaced (or displaced) some pastures for grazing cattle over the past decade (Rathmann, Szklo, and Schaeffer 2010; Walker 2011), but total pasture area has not increased and the national cattle herd has continued to grow through intensification on the existing land base (IBGE 2013b; Soler, Verburg, and Alves 2014; Martha Jr, Alves, and Contini 2012).

The use of soy as feed in confined livestock operations is argued to be a land-intensive source of protein (Brown et al 2014), meaning that it takes a relatively large amount of land to produce a unit of food. Yet it is still more land efficient, on average, than open-range, grass-fed cattle production in Brazil. Given a meal-to-oil ratio of 80:20 and soy and conversion efficiencies of 7:1 for cattle meat, 4:1 for pork and 2:1 for chicken (in a confined system; Brown 2006), a soy yield of 3000 kg per hectare will produce 343 kg of cattle meat, 600 kg of pork or 1200 kg of poultry per hectare if used in confined livestock operations. In contrast, cattle production, which occupies the largest area of any agricultural sector in Brazil, roughly 200 million hectares, produces on average only one head and 250 kg of cattle meat per hectare (Walker, Patel, and Kalif 2013). Furthermore, soy production is technically more land efficient in producing *nutritious* food than sugarcane cultivation, since sugar offers little nutritional quality and is often deleterious to human health (Brownell et al. 2009).

4.3. Access to services

Soy production is a capital-intensive process that facilitates improvements in rural infrastructure and service provision since farmers require adequate access to dynamic input markets, dryers and silos, and transportation systems to compete in the global economy. Soy farmers and agribusiness owners sometimes build new roads and finance new health and education facilities (RDG personal observations in Mato Grosso and Pará). When farm owners actually live in the same county where their farm is located, they spend money locally on goods and services, which can promote developments in infrastructure that benefit all members of the local community (de Souza and Ravache 2009). 'Agrocities' emerge in these nascent soy regions as new businesses are established to sell nonagricultural goods and services to farm and agribusiness employees, leading to new employment opportunities outside of the agricultural sector (Da Silva and del Grossi 2001; Alves Sobrinho 2009; Jonasson and Helfand 2010). The wage level in these nonfarm jobs may be lower than in surrounding regions due to competition in the labor market from increased in-migration (Jonasson and Helfand 2010). However, these agrocities often offer a variety of health and educational services, restaurants and consumer goods, including upscale gyms, vocational colleges, federal university branches and luxury condominiums patronized by soy producers and soy sector employees, as well as individuals not directly involved in the soy sector (authors' personal observations; Hecht and Mann 2008).

Statistical analysis of land use and the HDI supports these observations of broader local development alongside the soy sector. 'Soy-dominant' counties have significantly higher HDI (across all categories of the index – income, literacy and longevity) than 'sugar- or cattle-dominant' counties and counties that do not contain high levels of cropland as a proportion of the total area (Table 5). These results are consistent with the results of previous quantitative studies by Weinhold, Killick, and Reis (2013) in Pará and VanWey et al. (2013) in Mato Grosso linking soy production to HDI. However,

HDI-total	Non AG <other <soy<="" <sugar,="" ag="" cattle="" th=""></other>
HDI-tncome	Non AG <other <soy<="" <sugar,="" ag="" cattle="" td=""></other>
HDI-literacy	Non AG <sugar, <soy<="" ag="" cattle,="" other="" td=""></sugar,>
HDI-longevity	Non AG <cattle, <cattle="" <soy="" <soy<="" <sugar="" nonag="" otherag="" td=""></cattle,>
Theil	Sugar <non <cattle,="" <other="" ag="" soy<="" td=""></non>

Table 5. Results of Tukey test for HDI and Theil by dominant land use.

Note: '<' signifies that the mean value for the Human Development Indicator (HDI) and Theil in a particular land use group to the left of the '<' is significantly less (p < 0.05) than the mean value of the land use group to the right of the '<'. ',' denotes no significant difference between groups. Where 'soy' = soy dominant counties; 'sugar' = sugar dominant counties; 'cattle' = cattle dominant counties; 'other AG' = counties dominant in other forms of agriculture; and 'non AG' = non-agricultural counties.

our results also add new fodder to the discussion of the well-being impacts of soy production because they compare the relationship of soy production on HDI with that of other land uses. This implies that soy production may generate higher on-farm wages and/or off-farm employment opportunities than sugar, cattle or other land uses in Brazil, and/or that soy production tends to result in more local investment in infrastructure to provide goods and services than other land uses. These results are particularly interesting given the findings of Martinelli et al. (2011), which show that sugar counties in São Paulo that have high levels of sugar production and a mill to refine the sugar do better than counties with high levels of cattle production or sugar production but no mill. They highlight the important additive role played by value-added processing activities in influencing local well-being improvements through higher incomes and employment.

The HDI analyses relating specific crop area to HDI differ greatly from the cross-sectional studies relating deforestation levels and forest cover to HDI (Rodrigues et al. 2009) and suggest that soy agro-cities differ in important ways from the dangerous frontier towns associated with extractive boom and bust cycles in the Amazon (see Schmink and Wood 1992). Among these differences is that soy production in the Amazon does not typically take place on deforestation frontiers, but instead follows some other activity, such as ranching, for which the forest is cleared (Morton et al. 2006). Successful soy production also depends on making long-term investments in infrastructure and soil quality, as well as being sufficiently established on the land to diminish the risk of making a considerable investment in planting but having to leave or being unable to harvest the crop. Soy agrocities also differ substantially from the planned agropolis/agrovila system established by the National Institute of Colonization and Agrarian reform (INCRA; discussed in Goodland and Irwin 1975) in that development is sustained by local market forces rather than inconsistent federal infusions.

4.4. Equity

Soy production occurs on more than 171,000 individual farms across Brazil (IBGE 2006). Many 'family farmers' participate in the production of soy (Table 6); however, the distribution of these soy lands, in terms of land area per owner, is more unequal than that of cattle ranching and staple crop production (rice, beans and manioc), but less unequal than that of sugarcane production (Martinelli et al. 2010; Lapola et al. 2013). The concentration of land in the hands of fewer people inherently exacerbates rural income inequality if there are few off-farm employment opportunities. The soybean industry is even more concentrated at the soy trading and processing nodes of the supply chain.ADM, Bunge, Cargill and Louis

Region	Soy	Sugar	Livestock	Horticulture
	(% of farm	ners)		
Brazil	71	72	78	87
North	32	84	79	90
Northeast	8	82	84	90
Southeast	44	61	72	84
South	77	83	82	88
Center-West	31	67	66	78
	(% of area)		
Brazil	10	´	20	35
North	2	25	23	37
Northeast	0	13	33	45
Southeast	5	7	24	38
South	26	19	27	47
Center-West	2	4	9	17

Table 6. Percentage of farmers that produce soy that fall into the legal category of 'family farmer' (Law 11,326).

Source: IBGE 2006.

Table 7. Rural population, farm size and agricultural employment by region.

Region	Rural population (1000)	Avg farm size (ha)	Ranching	Sugar % of rura	Soy al popu	Cereal lation em	All Agriculture
Brazil	31,948	141	15	2	1	6	52
North	6178	1104	9	<1	<1	1	27
Northeast	8612	1761	21	3	<1	13	89
Southeast	6902	401	15	4	<1	2	48
South	4791	69	17	2	7	7	61
Center-West	1549	840	38	4	4	3	65

Source: IBGE (2006, 2010). Farm size calculated from a distribution of farms in various sizes. Employment proportion calculated as % of 2010 rural population data.

Dreyfuss now trade a majority of genetically modified (GM) soy produced in Brazil, having acquired many of the domestic trading firms (Jank, Leme, and Nassar 2001). Brazilian soy giant Grupo Andre Maggi is the largest trader of certified non-GM soy (Garrett, Rueda, and Lambin 2013), but there are numerous small producers and traders participating in the non-GM soy chain as well.

Like most mechanized, agro-industrial systems, specialized soy production requires very little on-farm labor, particularly in comparison to ranching or other crops (Table 7). In the South, where the farms are much smaller, soy production employs a larger proportion of the rural population. In the Amazon and the central and eastern Cerrado production zones, however, soy farms tend to be much bigger and employ only a small proportion of the rural population (Table 7; Fearnside 2001; Hall et al. 2009). The low requirement for on-farm labor is simultaneously a blessing and a curse. On the one hand, there are few new employment opportunities for current residents to benefit from the emergence of soybean production. On the other hand, the negligible of role of non-skilled labor in soy production means there are fewer opportunities for the types of indentured and migratory labor that occurred in Brazilian sugarcane production (Chase 1999; Fearnside

2008; Sawyer 2008). Humane working conditions on soy farms (and all other farms) are also incentivized by the 'dirty list of slave labor' published by the President's Secretary of Human Rights. Employers included on this list are barred from accessing public financing, such as subsidized rural credit, which operates as a strong disincentive in the soy industry since soy cultivation depends heavily on subsidized rural credit. Indeed, only 10 out of 583 (<2 percent) of the farms implicated on the list produce soy (Reporterbrasil. org 2014). There are also slave labor prohibitions in the Soy Moratorium and Roundtable on Responsible Soy certification, which are discussed in more detail below.

Most employment opportunities in the soy sector occur off farm, in related agribusiness (transportation, industry and services). However, existing residents are often unable to acquire the new positions created by soy agribusiness since they do not possess adequate skills (Zoomers 2010). New jobs created by soy agribusiness in the Center–West and North are often taken by migrants from the South, leading to conflict between migrants and existing populations or outmigration of the existing rural population.

Another criticism of the soy sector in Brazil is that the revenues generated by soy production are increasingly captured by non-Brazilians, due to growing foreign investment in farmland, termed by some as 'land grabbing'. In the contemporary Brazilian context, though, foreign investment in farmland is considerably more complex than the term land grabbing suggests. While many corporate farms directly export their products to overseas buyers, foreign ownership of land is limited. Foreign non-residents and foreign corporations are not allowed to directly acquire land in Brazil without special federal authorization, although foreign residents can acquire up to three 'undefined exploration modules' (ranging from 5 to 70 hectares in size; Laws 5709 and 6815). As of 2011, roughly 4.5 million hectares (<2 percent of the total agricultural area in Brazil) were owned directly by foreigners (INCRA 2012). Where foreign direct investment does occur, it is more often in the form of foreign-domestic agribusiness partnerships, rather than direct land ownership (Oliveira 2013). Furthermore, foreign investment in land goes two ways, since Brazilian farmers are very active in purchasing land in the agro-industrial soy frontiers of Bolivia and Paraguay. In these regions, Brazilians and other foreigners often control more land than nationals and have been implicated in widespread displacement and evictions (Hecht 2005; Nagel 1999).

Where soy production is profitable and land for expansion is scarce, land prices can rise very quickly (Steward 2007). In some cases, resident small-holders sell their land to soy farmers out of a desire to find new occupations. In other situations, peasants sell to avoid being enclosed by soy farms or because their social networks have been broken by their neighbors' land sales (Steward 2007; Baletti 2014). Land sales often enable families to move to urban areas or invest in new income opportunities, but can also lead to unanticipated livelihood losses when people move to more marginal farming locations or pay higher prices for the new land, or when they are unable to find new employment opportunities (Baletti 2014; Zoomers 2010). In the more extreme cases where tenure rights are not secure, interest in acquiring new land for soy production can lead to the forcible removal of vulnerable populations. Or, if landholders remain, they may be exposed to new economic and biological pressures that reduce local prices and yields. For example, in a recent Ecological Economic Zoning Plan for the BR-163, some lands currently occupied by traditional and indigenous landholders were reassigned as areas designated for soy expansion and extractive industries (Baletti 2012).

Confirming the more qualitative results of previous case studies, we find that counties that are 'soy dominant' have higher levels of income inequality (a higher THEIL index) than counties that are 'sugar dominant' and non-agricultural, although the THEIL index was not statistically different between soy- and cattle-dominant counties (Table 5). These results may be explained by a number of factors. One potential reason is that labor requirements on mechanized soy farms are lower than labor requirements on fruit and horticulture farms that rely on manual harvesting. With respect to sugar production, mechanized soy farming is particularly less labor intensive than sugar production in the northeast where cane burning and manual harvesting remain high (De Moraes 2007; Lehtonen 2012). Another explanation is that most major sugar production regions, especially in the southeast, contain sugar processing mills and biofuel plants, which present additional employment opportunities, typically with higher wages than farm labor (De Moraes 2007). A final possible explanation is that soy production often occurs in areas of change where a new land use activity is expanding rapidly, which attracts migrants who have high hopes of participating in the 'soy economy' but are unable to find high wage employment (RDG personal observations in Mato Grosso). Meanwhile middle-class workers (such as farm managers and agribusiness vendors) often choose not to live permanently in soy-dominant counties located on these frontiers and stay in these areas only during the week, choosing instead to live in the next closest city that has good schools and healthcare (LR personal observations in Mato Grosso). This situation would push the local income data into a more bimodal distribution, increasing the THEIL index, even if the average income level is higher in soy-dominant counties.

5. Impacts on future generations' well-being

5.1. Land cover change

The impacts of historical and recent soy expansion on forests and native grasslands are substantial, but difficult to quantify given soy production's tendency to be an underlying, not proximate, driver of deforestation (Barona et al. 2010; Arima et al. 2011). Nevertheless, soy area expansion in the Cerrado and Amazon over the past two decades, and previously in the Atlantic Forest, has undoubtedly contributed to the large-scale conversion of native vegetation and planted pastures to intensive agriculture by adding to the total demand for land in these biomes.

Historical land cover change in the Atlantic forest eco-region, which originally extended from Rio Grande do Sul in South Brazil all the way to Ceará in the Northeast (Ribeiro et al. 2009), was influenced by a diverse set of land uses, including gold mining, logging, sugarcane and coffee production, cattle ranching and silviculture plantations (primarily eucalyptus and pine), as well as production of wheat, beans and other crops. Soybean production was not the primary driver of change in most of the Atlantic forest, but it was an important factor in changing land-use practices and land-cover change in the southern reaches of the biome (the states of Rio Grande do Sul and Paraná, in particular). The direct contribution of soybean expansion to deforestation in these states was likely limited; during the 1970s, when soybean production expanded most rapidly in this region (from just over 2 million hectares in 1970 to over 6 million hectares in 1980), relatively little new farmland (1.9 million hectares) was added there (Kaimowitz and Smith 2001; IBGE 2006). However, there is some evidence that the rapid expansion of soy in the South contributed to the clearing of old-growth forests in this region, such as the Arucaria pines of Parana, as well as indirect land-use change in the Cerrado and Amazon when other land uses were displaced (Kaimowitz and Smith 2001).

Similarly, soy production is only one of many land uses pursued in the Amazon biome and by no means the largest proximate source of land-cover change; cattle production and small-holder agricultural production are the primary land uses in the region. There is no exact estimate for how much of the total Amazon has been converted directly for soy production, but the current soy planted area in the Amazon biome is less than 2 million hectares (less than 1 percent of the total area; Rudorff et al. 2011). Direct conversion of Amazon forest for soy has largely stopped since 2006, coinciding with the initiation of the Soy Moratorium (discussed below; Macedo et al. 2012). Most soybean expansion has taken place on areas previously cleared for pasture or, to a lesser extent, other land uses.

Within the Cerrado, however, and the transition area between the Cerrado and Amazon, soy production has contributed to the clearing of savanna and forest vegetation on a much larger scale (Redo, Aide, and Clark 2012). Between 1986 and 1999, 70 percent of the Cerrado was converted for agriculture (mainly soy and cattle production), although a considerable amount of the region also experienced forest regeneration during this period (Jepson 2005, Redo, Aide, and Clark 2012). Still, most soybean expansion has taken place on areas previously cleared, mainly for ranching. While cattle ranching is still the dominant land use in the biome (Lapola et al. 2013), as of 2008, soy production occupied roughly 12 million hectares (12 percent of the area; Smaling et al. 2008).

The ecological impacts of this large-scale transformation of the landscape are significant. The eventual conversion of native forests and savannas to cropland directly reduces plant diversity, and indirectly reduces animal diversity by way of reduced habitat and disruptions to the balance of predator and prey species (Tabarelli et al. 2005; Pardini et al. 2010; Moura et al. 2013; Peres et al. 2010). Landscape simplification, from diverse plant communities to a single land-cover type, i.e. soy, limits food and shelter opportunities for wildlife in comparison to more diverse farming systems (Jose 2009; Fargione, Cooper, and Flaspoher 2009), initiating the 'technological treadmill' of modern agriculture (Ward 1993). The diversity of plant, animal and bacteria species within a landscape influences nutrient and water availability, necessitating the use of synthetic fertilizers, herbicides and pesticides, and sometimes irrigation (Altieri 1999; Goodland and Irwin 1975). The application of toxic pesticides and herbicides to control pests and weeds affects the health and diversity of pollinator and predator species, including birds and bees (Kremen, Williams, and Thorp 2002; Schiesari and Grillitsch 2011), which can reduce yields, increasing reliance on new technologies to overcome the latest human-induced environmental challenge.

Converting forest or savanna to cropland releases substantial amounts of carbon dioxide (CO_2) into the atmosphere, contributing to global warming. For example, each hectare of Amazonian forest stores between 280 and 450 Mg of CO_2 in the soil and above- and below-ground biomass, and each hectare of Cerrado savanna stores between 97 and 170 Mg of CO_2 (PMBC 2013). Consequently, CO_2 emissions from land conversion were the largest source of greenhouse gases in Brazil for much of the last two decades (Cerri et al. 2009). In contrast, a hectare of land planted in soy in the Amazon or Cerrado returns only 0.9 Mg of CO_2 to the soil each year (Fargione et al. 2008). Thus, biodiesel made from soy grown on cropland converted directly from native forest or savanna in Brazil can actually have a higher carbon footprint than petroleum-based fuels (Reijnders and Huijbregts 2008; Fargione et al. 2008). Approximately 9 percent of the emissions from deforestation in Brazilian Amazon between 1990 and 2010 can be attributed to soy that was exported from that region during that period (Karstensen, Peters, and Andrew 2013).

Region/biome	N (nitrogen) – Kilograms	P (phosphorus) – Kilograms	K (potassium) – Kilograms	
South/Pampas	4–9	45	40	
Center-West/Cerrado	7-10	76–80	68-80	
North/Amazon	2-10	36-80	33-80	
Northeast/Caatinga	4	39	41	
Southeast/Atlantic	9	73	62	

Table 8. Fertilizer usage by biome.

Sources: FAO (2004); Raucci et al. (2014); Garrett et al. (2013).

Land conversion also alters watershed hydrology, morphology and water quality. The reduction in forest vegetation reduces evapotranspiration influencing nearby precipitation patterns. Total water export can be three to four times higher in watersheds dominated by soy croplands compared with forest (Hayhoe et al. 2011). The creation of impoundments and the reduction of riparian forest surrounding streams and rivers on soy farms influences water flow and sediment levels and contributes to increased water temperatures in streams (Macedo and Coe 2013; Neill et al. 2013).

5.2. Input intensification

Soy production requires high applications of lime, phosphorus and potassium, but very little nitrogen (Alves, Boddey, and Urquiaga 2003), due to inoculation with rhizobia, which live within the soy root system and enable the soy plant to fix nitrogen from the atmosphere (Alves, Boddey, and Urquiaga 2003). In the acidic and nutrient-poor Cerrado and Amazon soils, these applications are particularly high (Table 8; FAO 2004). However, substantial amounts of nitrogen must be applied to soybean areas that are double cropped with corn, ~60 kg/ha (Neill et al. 2013). These amounts are much higher than what is required in ranching, which generally utilizes little nitrogen fertilizer, especially when pastures are mixed with leguminous grasses (Mattos and Uhl 1994; de Andrade et al. 2006) or diversified farming systems, which rely very little on synthetic fertilizers (Altieri and Toledo 2011). Nevertheless, nitrogen applications on soy–corn fields are still lower than sugarcane production, which requires ~80 kg/ha (Martinelli and Filoso 2008).

Nitrous oxides (NO_x) that are released by fertilizer applications present a serious climate problem because they have a larger per-unit impact on global warming than does carbon dioxide (Vitousek et al. 1997). While atmospheric emissions of NO_x are high, nutrient runoff of nitrogen, phosphorus and potassium from soy fields into streams is currently very low in Cerrado and Amazonian soils, since these soils fix and store phosphate and nitrates (Riskin et al. 2013; Neill et al. 2013). On this criterion, soy performs better than sugarcane production in the Atlantic forests of Southeast Brazil, where water pollution has been a common outcome of sugarcane expansion (Martinelli and Filoso 2008).

 CO_2 emissions resulting directly from soy production (rather than land conversion) have decreased with the expansion of no-till or low-till agriculture, which reduces the amount of fossil fuel needed for agricultural production by reducing tractor passes, and increases carbon stored in the soil (Lal, Reicosky, and Hanson 2007). When used in conjunction with Roundup Ready soy varieties, this method of farming can also reduce the number and toxicity of herbicides and pesticides applied in soy and corn fields (Qaim and Traxler 2005), although farmers frequently over-apply pesticides due to lack of knowledge about proper levels (LR, conversation with Embrapa official, November 2013). GM crops also present new ecological and economic risks, such as increasing herbicide- and pesticide-specific tolerance in weeds and insects (Gassmann et al. 2011). Weed resistance to the herbicide glyphosate (Round Up) has become increasingly common on soy farms throughout the United States (Eller 2014) and, in 2014, numerous cases of worm resistance to the Bt pesticide in GM corn were reported in Brazil (Diep 2014).

There is substantial evidence that the greenhouse gas and biodiversity impacts of specialized soy systems could be reduced through the use of more diverse (or *multi-func-tional*) agricultural systems, i.e. systems that include crop, livestock and tree production, particularly in rotation. When livestock are rotated on agricultural fields for a number of years, organic soil matter can recover between harvests. Planting leguminous crops and forages during a rotation period increases the nitrogen content of the soil, reducing the need for synthetic fertilizers (Balbino et al. 2011; Landers 2007). Planting trees and shrubs helps to sequester carbon above and below ground (Jose 2009). Finally, the mosaic landscapes provided by diversified farming systems tend to have lower pest pressure, necessitating fewer chemical inputs, and provide a wider range of habitat to support local fauna in comparison to monocultures (Wilkins 2008; Meehan et al. 2011; Mendenhall et al. 2014).

6. Sustainability governance mechanisms

6.1. Mechanisms related to improved small-holder participation

The modernization and expansion of the Brazilian agriculture sector has undoubtedly left behind many of the country's small farmers (Martinelli et al. 2010; Lapola et al. 2013). To promote socially inclusive economic growth in rural areas, the government has created a suite of policies aimed at improving small-holder livelihoods, both through participation in the soy sector and increased productivity in other agricultural areas. To promote social inclusion in all biofuels sectors, the Brazilian government established the National Program for the Production and Use of Biodiesel (PNPB). This program requires grain traders and biodiesel manufacturers to purchase oilseed crops from small-holder farms (as defined above) and provide technical assistance to these farms (Wilkinson and Herrera 2010; Lima, Skutsch, and Costa 2011). The target for smallholder farm participation is 15 percent in the North and Cerrado and 30 percent in the Northeast, South, and Southeast regions of Brazil. However, Lima, Skutsch, and Costa (2011) find that companies tend to avoid settlements where the existing land holdings are very small and the topography prevents large-scale mechanization, limiting the extent to which this program will really benefit the poorest communities. Consequently, total small-farmer participation has fallen far short of stated goals (Wilkinson and Herrera 2010).

The National Program for Strengthening Family Agriculture (PRONAF) provides subsidized rural credit for individual or collective projects that generate income for family farmers and agrarian reform settlers. The program has the lowest interest rates of any source of rural financing in the country (~1 percent), and covers both costs and investments in farm management and value-added activities. In addition to providing credit, the government helps minimize risk for farmers through the Insurance for Family Farmers (SEAF) program. SEAF provides insurance to farmers who adopt certain technologies that conserve natural resources on the farm and reduce their vulnerability to climatic fluctuations. Finally, in 2010 and 2013, the President of Brazil also approved two new laws (Law no. 12,188 and Law no. 5740) to improve and expand technical assistance in rural areas for vulnerable farmers by making the existing technical programs more participatory, multidisciplinary, equitable and culturally appropriate. Although these targeted credit and technical assistance programs may help small farmers improve their existing practices, it is unlikely that they will help small farmers overcome the structural barriers that prevent them from participating in the production of high-value export crops, including a lack of assets, secure land tenure, education and physical access to markets, as well as higher average costs (Page and Slater 2003; Barrett 2008).

6.2. Mechanisms related to reducing impacts on natural capital

Brazil has some of the strictest land-use regulations and one of the largest networks of protected areas in the world in the Amazon, as the result of widespread domestic and international mobilization for forest conservation in the late 1970s and 1980s (Hecht 2005). Global interest in reducing deforestation in the Amazon has also led to a suite of novel market mechanisms to dis-incentivize land clearing for soy production. Landowners in the Amazon forest are required by the federal Forest Code (Law 12,651) to preserve 80 percent of their property in a Legal Reserve (LR). Producers that are located in the Legal Amazon, but not the Amazon forest, must conserve 35 percent of their property. However, land-cover requirements are less strict outside of the Legal Amazon (including in the highly threatened Atlantic Forest biome), where 80 percent of the area can be legally cleared. Landowners in all parts of the country also have to conserve steep slopes and the 30-500-meter riparian areas adjacent to waterways (depending on the size of the waterway) as Permanent Protection Areas (PPAs). Historically, the effectiveness of these progressive environmental regulations was substantially undermined by a lack of enforcement; the total LR and PPA deficit in Brazil may be as high as 36–50 million hectares (Sparovek et al. 2010; Soares-Filho et al. 2014). In the most recent revisions of the forest code in 2012, the LR deficit was reduced by roughly 58 percent, meaning that some producers are no longer obliged to reforest as much area as they 'owed' under the past Forest Code. A large part of these deficit reductions came from 'small' producers (ranging from 20 hectares in the South and 440 hectares in the Amazon region) who were given amnesty for illegal deforestation that occurred prior to 2008, though some also came from reductions in PPA widths, which may critically influence water quality in the Amazon in the future (Soares-Filho et al. 2014). At the same time, law enforcement in the Amazon (and, to a lesser extent, the Cerrado) has increased since the mid-2000s. Breaking the law is now beginning to have consequences, if not in terms of fines or jail times for illegal deforesters, at least in terms of the transaction costs of maintaining access to credit and markets.

One of the biggest obstacles to Forest Code enforcement has been a lack of information about property numbers, sizes and locations. As early as 2008, some state governments (Bahia, Mato Grosso, Pará and Rondônia) began to create registries of rural properties and promote environmental licensing to bring them into compliance with land-use regulations and facilitate monitoring. A combination of non-governmental organization (NGO) campaigns and incentives from the state, including a temporary amnesty for previous Forest Code violations in exchange for Cadastro Ambiental Rural (CAR) registration, quickly made CAR registration common among soy properties in Pará and Mato Grosso (SEMA-MT 2014; SEMA-PA 2014; authors' personal observations). The revisions to the Forest Code passed in 2012 established a federal CAR, which will integrate the state CARs into a national cadaster. CAR can now be considered a condition to get access to subsidized rural credit in the Amazonian portion of Mato Grosso (Garrett, Lambin, and Naylor 2013b).

The introduction of demand-side pressures to 'green' soy supply chains has enhanced the effectiveness of federal deforestation policies. To sell to the major soy buyers, farmers in the Amazon biome must meet the requirements of the Soy Moratorium, a voluntary agreement by the soy supply chain to not purchase or finance soy produced in areas deforested after July 2006 (ABIOVE 2010). This agreement has created a 'hybrid' governance scenario where deforestation for soy expansion in the Amazon is prohibited by international market actors employing tools of the state (such as the legal definition of the Amazon biome and the mapping services of the state space agency, INPE; Brown and Koeppe 2013; Brannstrom et al. 2012). There is evidence that most soy producers have either complied with the Soy Moratorium or exited the soy industry (Macedo et al. 2012; Rudorff et al. 2011; Baletti 2014). However, the agreement is unlikely to be maintained permanently (FAO 2014) and its impacts are limited to the Amazon biome, where less than 20 percent of the country's soy is produced.

While most of the above mechanisms focus on punitive incentives for deforestation in specific agricultural industries (Nepstad et al. 2014), Brazil's new 'low-carbon agriculture' policies may offer some positive incentives for conservation at a regional scale. In 2009, Brazil passed its National Climate Change Policy (PNMC), and committed to reducing national greenhouse gas emissions by 36.1 to 38.9 percent by 2020, including a reduction in deforestation rates to 20 percent of the 10-year (1996–2005) average within the same timeframe via specific plans crafted for several major sectors. The plan for the agriculture and livestock sector, the Low-Carbon Agriculture Plan (Plano ABC), was announced in 2010. In addition to supporting research and development in new agricultural technologies, the initiative provides technical assistance and subsidized rural credit lines for activities such as integrated crop livestock forestry practices, no-till planting and pasture recuperation (MAPA 2011). It is estimated that the adoption of integrated crop-livestock-forestry practices on just 4.0 million hectares of existing agricultural land in Brazil has the potential to mitigate 18–22 million tons of CO₂ equivalent (MAPA 2011). Nevertheless, uptake of the Plano ABC among producers has been slow, with only 48 percent of the ABC credit resources being distributed in 2012/2013 (Prado Júnior 2013). Low interest in ABC loans has been attributed to the fact that the benefits and risks of ABC practices have not been adequately explained to producers, producers lack knowledge about how to implement ABC projects, and high levels of bureaucracy limit access to ABC credit (authors' interviews with farmers and rural syndicate lawyers, 2013; Prado Júnior 2013; Mendes 2013).

Another important, but niche, initiative is the Roundtable for Responsible Soy (RTRS), which was established in 2006 as the result of a two-year long multi-stakeholder process. The Standard for Responsible Soy production requires that farms comply with existing environmental and social regulations in the producing country and must not convert native forests or other 'high value conservation areas'⁷ to soy fields (although expansion onto land converted prior to 2009 is allowed; RTRS 2013). As of 2013, however, RTRS certified full or partial production from only 30 farms in Brazil, totaling roughly 495,050 hectares and 1,142,100 tons (~1 percent of the country's total production; RTRS 2014). Though RTRS has modified standards to promote the inclusion of smaller-scale farmers, RTRS certification is highly skewed toward large, well-capitalized farmers who can

⁷'High conservation value areas' are critical areas in a landscape, which need to be appropriately managed in order to maintain or enhance the 'outstanding' biological, ecological, social or cultural values present there (RTRS 2013).

afford the costly certification and auditing processes and tap into segregated supply chains (Garrett, Rueda, and Lambin 2013). Critics of RTRS have shown that the standard negotiation process aggravates existing socio-economic inequities in the soy sector because it tends to exclude small-holders, favoring more politically and financially empowered stakeholders in the soy chain, such as Grupo Maggi, in the discourse about what constitutes responsible soy. These entrenched actors are then able to utilize the definition of certification standards to their mutual benefit (Elgert 2012).

7. Discussion

While a large preponderance of the conservation and rural studies literature focuses on the negative impacts of Brazilian soy, there is no denying that the Brazilian soy industry has provided tremendous economic benefits to Brazilian citizens over the last 40 years, particularly when soy farming is coupled with value-added agribusinesses, such as the production of soy foods, livestock and biodiesel. At the federal level, soy production and related agribusiness provide tax revenues that support ambitious social programs and export revenues that raise the value of the Brazilian currency, increasing consumer purchasing power in international markets. At the local level, the soy supply chain stimulates spending and investment in local transport, health and education, infrastructure (which has translated into higher average levels of income, life expectancy and educational attainment) in comparison to counties dominated by other land-use activities.

On the other hand, it is clear that the federal investment in the soy industry has largely excluded the poorest farmers, particularly in the North and Northeast regions, to the benefit of large multinational agribusiness firms, small farmers from the South, and well-capitalized entrepreneurs from the Southeast. In addition, counties with high levels of soybean production tend to have higher income inequality than counties dominated by other land uses. While soy producers do not receive direct subsidies, the Brazilian government has provided the soy industry with substantial financial support, including cheap access to land, subsidized credit with generous repayment terms, relatively low tax rates, tax refunds upon export, and infrastructure investments. Soy production has created these sub-stantial but exclusive economic benefits without reducing domestic food security, since it has not replaced other crops. However, the expansion of soy cropland into native savannas has endangered future generations' well-being by contributing to irreversible climate change and biodiversity loss in ways that are uncertain and immeasurable (Figure 4).

Recent social governance initiatives have attempted to address the problem of smallholder exclusion from the soy supply chain. Targeted agricultural policies, including low-interest credit and improved technical assistance for small-holders, have the potential to provide the rural poor with enhanced opportunities to choose production systems that meet their needs. Nevertheless, the effectiveness of these credit and technical assistance programs remains uncertain.

Meanwhile, new environmental governance measures have successfully reduced deforestation in recent years by encouraging producers to intensify production on the existing land base or expand onto previously cleared pastures. Some critics argue that the greening of the soy supply chain should not be celebrated, since it merely solidifies support for 'neoextractive' activities in Brazil and reinforces the power of the multinational trading companies and NGOs, without addressing the systemic sources of poverty (Baletti 2014). This may be true, but it does not negate the tremendous environmental benefits that have been achieved by these programs in helping to achieve a rapid decrease in deforestation in Brazil over recent years. Furthermore, it is unclear which land-use alternatives



Figure 4. Intra- and intergenerational impacts and tradeoffs of the Brazilian soy industry. The soy industry affects numerous aspects of current and future generations' well-being that are highly interconnected. In some dimensions (access to goods and services, and food security), the modern soy industry is largely helping to promote well-being, particularly for current generations. In other dimensions, the current soy industry is reducing well-being (equity, natural capital and health). To increase the overall sustainability of the industry relative to the past and other land use alternatives, soy production must improve all dimensions represented on the circle, not just one or two.

could replicate the economic benefits and total calorie production of the soy industry without increasing rural inequality and benefiting multinational agribusiness, leaving few options but to improve the existing system.

Current state and private environmental governance mechanisms focus mainly on the land cover impacts of soy expansion, without addressing problems associated with input intensification. They also reflect a 'high forest bias', ignoring entire ecosystems that are threatened by soy production, such as the Cerrado and Chaco biomes (Hecht 2005; Sawyer 2008). In the future, conservation policies should consider more ecological forms of intensification and pay attention to all biomes that are threatened by agricultural expansion if they are going to simultaneously reconcile global demands for increased food production with the protection of the natural capital on which current and future generations depend.

Brazil's ABC plan offers promise in this direction, by promoting more diverse and sustainable agricultural systems in all biomes. The practices incentivized by the program – reducing tillage on existing fields, adopting integrated crop, livestock and forestry practices, and recuperating degraded pastures – can all help to increase the land-use efficiency of agricultural production, while reducing pollution and greenhouse gas emissions. By pursuing the practices advocated in ABC, producers can still tap into major commodity markets and processing opportunities, while reducing their reliance on imported inputs and helping Brazil meet its greenhouse gas reduction commitments, though these benefits will only be realized as the program is made more accessible to farmers.

Despite the large amount of literature referenced above, several significant gaps remain in our understanding of current and future contributions and shortfalls of the soy sector to sustainable development in Brazil. On the socio-economic side, these gaps include better understanding of the impacts of the soy sector on non-farm employment, migration and access to health and education services and mechanisms to include small and vulnerable farmers in soy production. In terms of political economy, there is little understanding regarding processes of cultural homogenization in soy producing regions, impacts on food sovereignty or autonomy, or the influence of soy lobby groups on political power. On the ecological side, there is a huge deficit in our understanding of individual management practices on soy farms and the impacts of lime, fertilizer, herbicide and pesticide applications on climate, water quality and biodiversity. There is also still very little understanding of potential risks associated with transgenic seeds, such as gene transfer and weed and pest resistance, or how these may be changing expansion pathways of soy. Finally, there has been little research on the health risks associated with agrochemical use and runoff in communities adjacent to soy farms. Much of the research on soy production to date has relied on census data and remote sensing, but more in-depth case study research is necessary to understand these more complex socio-economic and ecological processes.

8. Conclusion

The purpose of this paper was to examine the evolving sustainability of the Brazilian soy industry over the past 40 years. In contrast to past studies that focused singularly on the role of soy production in environmental degradation, small-holder displacement and social conflict in isolated case studies, we considered a broader suite of social and ecological impacts of soy production and related agribusiness across Brazil and compared these impacts to alternative rural land uses when possible.

We conclude that the balance between costs and benefits associated with soy production is not uniformly worse or better than that of sugarcane or cattle, particularly in comparison to soy production in neighboring countries. The Brazilian soy industry has contributed to growth in national export revenues at the expense of natural capital stocks. It has also enhanced rural incomes and services, though the cost has been declining rural equity. The soy sector has greatly increased the amount of food produced in Brazil, while also contributing to high carbon emissions and biodiversity loss, and directly generating few rural employment opportunities. Overall, the advancement of mechanized, large-scale agriculture in the Atlantic, Cerrado and Amazon biomes over the past 40 years has come with many social and ecological costs, but it has also generated substantial improvements in well-being throughout Brazil via government revenues for welfare programs, increasing private purchasing power and improvements in rural access to health and education services. Unlike truly 'extractivist' activities that deplete non-renewable resources, such as mining and old-growth logging, the economic benefits of soy production can be reaped and amplified for many years to come, so long as future production proceeds without further deforestation, involves fewer synthetic inputs and is coupled with value-added activities that generate employment.

Recent improvements in environmental governance, new incentives for ecological intensification and the growth in value-added soy industries give us many reasons to be optimistic that some of the tradeoffs between intra- and intergenerational equity and economic growth will be reduced in the future, leading to more benefits across the board. Brazil has already taken many efforts to control deforestation, increase soy processing, reduce land grabbing and include small-holders in biofuels production, especially in comparison to neighboring countries such as Paraguay and Bolivia where soy expansion is still

triggering rampant deforestation, and increasing foreign land ownership and small-holder displacement. Additional policies that can help meet these challenges include government investment in loans, technology transfer and marketing assistance for soy production on small farms, support for ecological intensification/low-carbon agriculture through incentives for integrated practices, and support for soy-processing industries that create highwage employment for rural communities. Voluntary programs that can amplify the social and environmental benefits of these state programs include commitments from soy traders and retailers to purchase only soy that was produced in compliance with existing environmental and labor regulations, as well as a broader set of ecological standards. Our analysis has focused mainly on previously published studies, field observations and secondary data, though we recommend that future researchers undertake coordinated local case studies across the range of impacts identified here to examine whether the national, biome and municipal indicators of soybean sustainability analyzed in this paper hold at finer spatial scales.

Acknowledgements

We are grateful for helpful feedback we received from Eric Lambin and Rosamond Naylor on previous versions of this manuscript, and, in particular, to Susanna Hecht for her extremely helpful comments on the latest version.

Funding

R.D.G. conducted this research partially while funded by the Giorgio Ruffolo Fellowship in the Sustainability Science Program at Harvard University, and partially while funded by the Emmett Interdisciplinary Program in Environment and Resources at Stanford University. Support from Italy's Ministry for Environment, Land and Sea, Richard and Rhoda Goldman, Richard L. Kauffman and Ellen Jewett, and Dan and Rae Emmett is gratefully acknowledged. L.R. is supported by a grant from the Norwegian Government's International Climate and Forest Initiative to the Gibbs Land Use Lab in the Center for Sustainability and the Global Environment at the University of Wisconsin–Madison.

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