Deforestation's Challenge to Green Growth in Brazil[1]

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1 Introduction

Understanding Brazil's green growth and emissions story requires a second look. Brazil's energy matrix is approximately 46% renewable, so when one compares the share of greenhouse gas (GHG) emissions from energy in Brazil to that of most OECD countries, Brazil is doing relatively well (IPEA 2010, 133). However, looking at energy alone misses the core GHG story in Brazil: The principal drivers of GHG emissions in the country are not energy production or heavy industry, but rather deforestation and agriculture. Deforestation is responsible for about 55% of Brazil's GHG emissions, and agriculture for another 25% (McKinsey & Company 2009, 7). In fact, the two areas of emissions are intimately linked: deforestation is principally a problem of agriculture. Cattle ranching and soybean and sugar cane farming are the major industries contributing to Brazil's emergence today as an agricultural and agroenergy superpower – and are directly and indirectly responsible for deforestation in Brazil's largest forests, the Amazon and Atlantic (Banco Mundial 2010, Barros 2009, Margulis 2004, McAllister 2008b, Nassar 2009, Nepstad et al. 2008, Sennes and Narciso 2009). By extension, because Brazil's large and growing renewable energy sector is principally based on agriculture, it has ties to deforestation and may not be as green as it first appears.

Brazil therefore faces contradictory imperatives on the road to green growth: First, cattle ranching and soybean farming revenues – which contributed 25% to Brazil's gross domestic product (GDP) in 2008 – risk being squeezed by enforcement of legal restrictions on cultivation and grazing in the Amazon forest.[2] Second, Brazil's energy grid has a comparatively high proportion of renewables in it, but each major renewable – sugar cane-based ethanol, biodiesel, and hydropower – comes at some cost to forests and biodiversity because of its extensive land use. In short, the problem of deforestation cuts across several of Brazil's fastest growing economic sectors, including renewables. As a result, the potential

[2] This study defines *green growth* as "job creation or GDP growth compatible with or driven by actions to reduce greenhouse gases" (see Huberty et al. 2011, 3).

for divergence between "greenness" and "growth" in the Brazilian case is particularly great. The analysis below explores this problem in greater depth.

This study examines the problems of deforestation-related GHG emissions and green growth in Brazil in cattle ranching and agriculture; sugar cane-derived ethanol and other biofuels; and in hydropower. Section 2 begins this analysis by discussing Brazil's GHG emissions profile in greater depth, detailing the contributions made by deforestation, agriculture, and energy. Section 3 shows how ranching and agriculture contribute to Amazon deforestation, the leading cause of GHG emissions in Brazil; and profiles the strengths and limitations of Brazil's current policy responses. Section 4 argues that, despite its potential to reduce energy-related GHG emissions, renewable energy production in Brazil in the forms of ethanol, biodiesel, and hydropower threaten to increase GHG emissions from deforestation in the medium run if strict zoning and environmental laws are not effectively enforced. Finally, Appendices I and II provide overviews of Brazilian environmental and sugar cane ethanol policy.

2 Overview of GHG emissions in Brazil

Brazil is a federal democracy of almost 200 million people, has a diversified economy (Baer 2008, 1-3),[3] and is the fourth largest greenhouse gas emitter in the world – responsible for 5% of world emissions, or 2.2 GtCO2e in 2008 (World Resources Institute, cited in McKinsey & Company 2009, 2).[4] However, unlike the United States of America and other OECD countries, the majority of GHG emissions in Brazil stem from deforestation – the logging and burning of large tracts of forest to clear land for cattle pasture or agriculture in the Amazon rainforest – not from energy and industry.[5] Thus, GHG emissions in Brazil are primarily an *agricultural*, not an *industrial*, problem.[6]

[3] In 2005, Brazil's GDP per capita was US$3,326. That year, services accounted for 56.09%, industry for 34.86%, and agriculture for 9.05% of total GDP (Baer 2008, 405). However, agribusiness straddles the divide between agriculture and industry: Counting production, industry, commerce, and inputs, agribusiness is estimated to have contributed to 31% of Brazil's GDP in 2003, and to 26% of Brazil's total employment in 2002 (*ibid.*, 303).

[4] GtCO2e refers to *gigatons of carbon dioxide equivalent*.

[5] The Brazilian Legal Amazon consists of nine states (Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins), and originally had approximately 4.3 million km2 of forest (Baer 2008, 336).

While annual GHG emissions data from deforestation in the Amazon are not available, it is clear from Brazilian satellite data that high deforestation rates there since 1988 have caused the release of massive amounts of CO2 and other GHGs into the atmosphere. Deforestation does appear to be declining: the Brazilian National Institute for Spatial Research (INPE 2011) uses satellite images to calculate annual deforestation rates in the Amazon, and finds that after spikes in 1995 and 2004, the annual deforestation rate dropped to an estimated 6,451 km2 in 2010 (IPEA 2010, 82; INPE 2011) – largely due to less competitive commodity (beef and soybean) prices resulting from the appreciation of Brazil's currency (the *real*) against the U.S. dollar, but also partly to conservation policies and stronger environmental law enforcement efforts (Banco Mundial 2010, 40).[7]

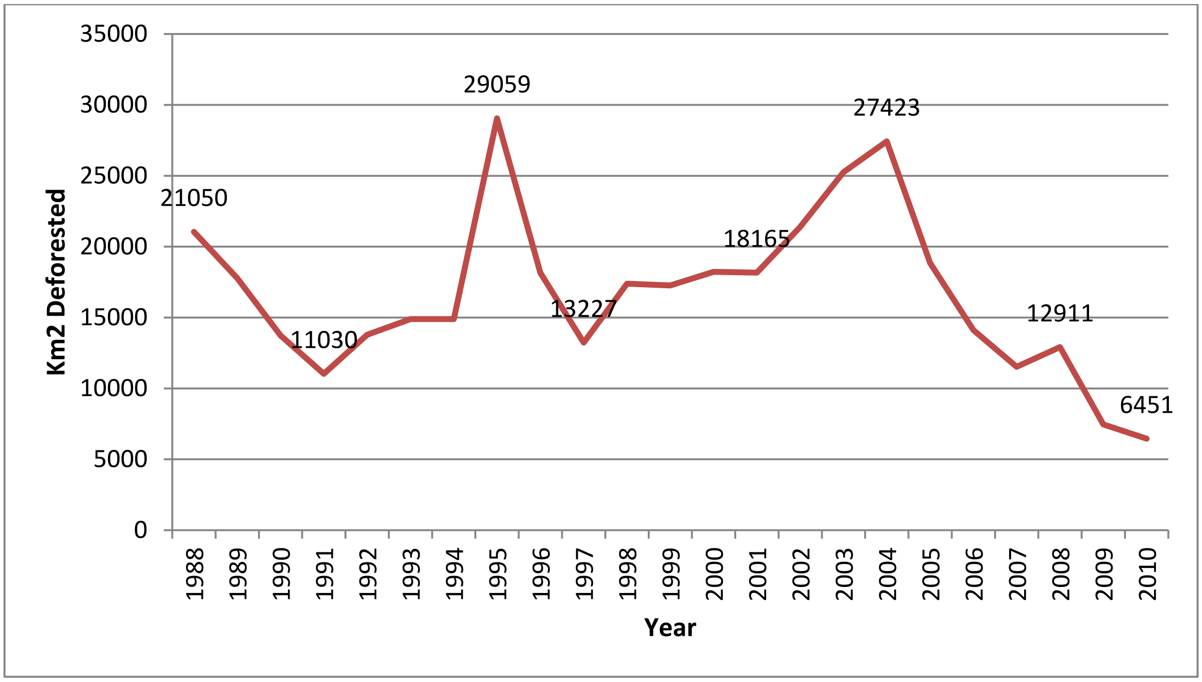

Figure 1: Deforestation Rates in the Brazilian Amazon, 1988-2010 (IPEA 2010, 82; INPE 2011)

According to Baer (*ibid.*, 332), the Amazon "stores about 60 billion tons of carbon, or 8 percent of the total carbon present in the atmosphere in the form of carbon dioxide."

[6] McKinsey & Company (2009, 5) estimates Brazilian per capita GHG emissions at 12 tCO2e, comparable to industrialized countries. However, "if we exclude the forestry sector, Brazilian *per capita* emissions drop to 5 tCO2e, which would bring this country down to the level of low/moderate emitters" (*ibid.*).

[7] INPE counts Amazon deforestation rates in the nine states of the Brazilian Legal Amazon (see fn. 4).

But despite the recent decline in deforestation, forest loss in the Amazon and elsewhere has been severe: The World Bank estimates that the Amazon lost 18% of its forest cover from 1970 to 2007. During the same period, the neighboring Center-West savannah, the Cerrado, lost 20% of its forest cover, and the coastal Atlantic Forest – of which only 7% of its historical expanse remains today, according to São Paulo-based NGO S.O.S. Mata Atlântica (2011) – lost 8% (Banco Mundial 2010, 39-40). Cattle ranching and soybean cultivation contributed to forest loss in the Amazon and Cerrado, while sugar cane farming, coffee plantations, logging, urbanization and other population pressures have over centuries decimated the Atlantic forest (McAllister 2008b, S.O.S. Mata Atlântica 2011).

Agriculture, including cattle ranching, is Brazil's second-largest greenhouse gas emitter, at 25% of Brazil's total GHG emissions – and much of the sector's growth involves deforestation on the Amazon frontier.[8] Cattle ranching and soybean farming contribute directly and indirectly to particularly high deforestation rates in the Amazonian states of Mato Grosso, Rondônia, and Pará (Greenpeace 2009; INPE 2011; Margulis 2004). In addition, deforestation rates are exacerbated by the fact that the productivity of cattle ranching is generally lower in the Amazon than elsewhere, due to the widespread and increasing availability of land.[9] Section 3 will study the relationship between ranching, agriculture, and deforestation in greater depth.

Finally, in contrast to OECD countries, Brazil's energy sector contributes very little to Brazil's GHG emissions. Depending on how energy-related GHG emissions are calculated, estimates vary from 13% (McKinsey & Company 2009, 6) to 16% of Brazil's total GHG emissions (IPEA 2010, 128).[10] Whatever the true number, energy in Brazil contributes

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[8] Brazilian agriculture is responsible for 10% of world agricultural GHG emissions, second only to China (McKinsey & Company 2009, 24). McKinsey & Company (2009, 24-25) expects agriculture-related GHG emissions to grow by 40% from 2005 to 2030, of which cattle rearing will account for 37% of the growth (*ibid.*).

[9] In the South, Southeast, and parts of the Center-West regions of Brazil, cattle ranching competes with sugar cane farming for land, so ranchers there are forced to adopt more efficient methods of production (Nassar 2009, 62). Margulis (2004, 35-36) finds that cattle ranching productivity also varies within the Amazon region, depending on factors such as climate, the productivity of grass, and the mortality rate of cattle.

[10] The McKinsey & Company (2009, 6) estimate of 13% includes electric power generation and fuels for transportation. The 16% number, from IPEA (2010, 128), includes energy generation as well as consumption in the energy sector itself, which accounts for 10% of national energy consumption. Exact calculations used for each of these estimates are unavailable.

comparatively little to Brazil's GHG profile because the sector is relatively green, with 46% of energy generation stemming from renewable sources such as wood, biomass, ethanol and biodiesel, and hydroelectricity in 2008 (*ibid.*, 133-134).[11] However, Brazil plans to double the supply of energy in the next twenty years, which will exacerbate two trends that threaten to increase the sector's GHG emissions: First, the share of fossil fuels (oil and gas) in Brazil's energy matrix will increase from the current 9% to 14% by 2030, which will triple energy sector emissions from 30MtCO2e in 2008 to 90 MtCO2e (McKinsey & Company 2009, 13). Second, investments in expanding the supply of energy from hydroelectric dams, sugar cane-derived ethanol, and other biofuels will place greater pressure on land, which could lead to higher emissions from deforestation.[12] Section 4 will examine the environmental risks of Brazil's renewable energy industries.

3 Ranching, Agriculture, and Amazon Deforestation

The story of green growth in Brazil must begin with a look at agriculture and the deforestation of the Amazon, since together these contribute the largest share of Brazil's GHG emissions and, in the case of agriculture, a growing share of Brazil's economy. Brazil's problem is that two of its most lucrative industries are agriculture and ranching, and both of these industries have a long history of expanding into the Amazon – facilitated by industry subsidies, poor property protection, and institutional weakness. Brazil has only recently begun to try to correct incentives and halt deforestation, but with mixed results. It is too early to say whether Brazil will be able to control deforestation successfully, especially if doing so requires slowing the growth of core industries. However, to do so it needs to make significant progress in imposing rule of law and creating market incentives to enhance the sustainability of these industries.

[11] According to McKinsey & Company (2009, 13), "Brazil emits an average of 94 t[ons] of CO2e per gigawatt hour (GWh) produced. The global average is 580 tCO2e per GWh and, in countries that rely heavily on coal fired power plants, can be as high as 1,000 tCO2e per GWh."

[12] In addition to the controversial Belo Monte mega-dam project in the Amazonian state of Pará, there are 311 hydroelectric plants of various sizes planned or being built, which will add over 15,000 MW to Brazil's energy grid (IPEA 2010b, 137).

3.1 Background on Ranching and Agriculture in the Amazon

The rapid growth of ranching and agriculture in Brazil, due to growing domestic and international demand for beef and soybeans, is the leading driver of deforestation in Brazil.[13] To ensure that the recent decline in Amazon deforestation (see Figure 1 above) continues and to reduce GHG emissions in the long run, increases in ranching and agricultural productivity, payments for avoided deforestation, domestic and international consumer pressures, and more consistent environmental law enforcement are needed.

Much of the expansion of beef production (along with leather and other cattle-derived products) has been in the Amazon region, and it is estimated that 70% of area deforested there is converted to cattle pasture (McAllister 2008b, 10,875).[14] From 1995 to 2006, Brazil's cattle herd grew by 10%, from 153 million to 169 million heads of cattle. However, "[w]hile outside the Amazon region total numbers decreased by 4 million head, inside numbers increased by almost 21 million, to 56 million head in 2006" (Greenpeace 2009, 13). During this period, the Amazonian states of Mato Grosso, Pará, and Rondônia increased their cattle stock by 36%, 111%, and 120%, respectively. Meanwhile, ranches in Amazonian states have increased in size by 90% (*ibid.*), a result both of the low price of available land and the opening up of new lands through illegal logging (Margulis 2004). Increases in cattle head and ranch area correspond to alarming deforestation numbers: By 2007, Mato Grosso had lost about 38% of its original forest area, Rondônia 39%, and Pará 20% (Greenpeace 2009, 14-15).[15]

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[13] In the 2000s, Brazil became the world's largest exporter of beef. Beef exports grew over 450% in volume and 385% in value from 1994 to 2005 (McAllister 2008b, 10,875). In 2008, agriculture and ranching (including both production and distribution) accounted for 25% of Brazil's GDP, and 36% of Brazil's total exports (Greenpeace 2009, 3). That same year, Brazil accounted for 31% of the global trade in beef, and 36% of the global trade in soybeans – and its share in each is expected to increase to 61% and 40%, respectively, by 2018 (*ibid.*, 2).

[14] Nepstad et al. (2006, 1599) estimate that "more than 80% of the Brazilian Amazon could sustain profitable cattle production."

[15] Margulis (2004) traces the micro-processes by which cattle ranching drives illegal Amazon deforestation: Loggers enter virgin forest, build roads, and remove the valuable timber. They then sell the land to cattle ranchers. Without the possibility of selling the land on to cattle ranchers, loggers' incentives to deforest would be greatly reduced (Margulis 2004, XVIII).

3.2 Systemic Problems Create Incentives for Deforestation

The relationship between deforestation and the expansion of beef and agriculture in the Amazon involves a system of *perverse incentives* provided by the Brazilian federal and subnational governments, as well as domestic and international consumer behavior. These perverse incentives encourage expansion into the Amazon in spite of the problems expansion creates. They include weak property rights, subsidized credits and tax exemptions from the Brazilian government, weakness of federal and state agencies, and collusion between state agencies, cattle ranchers, and soy farmers. Together, these factors reduce the ability of the federal and subnational states to enforce environmental laws.

Like most policy areas in Brazil, environmental governance is decentralized: The federal Ministry of the Environment enacts norms and broad policy, but state environmental agencies have considerable policy and administrative autonomy. Combined with their relatively low capacity and periodic collusion with illegal deforestation activities, decentralization poses risks to the Amazon: Hochstetler and Keck (2007, 151) characterize Amazonian politics as one of "state absence," in which elites refuse to crack down on illegal logging because they benefit from the revenues from beef and agricultural exports.[16] Even where the state is present, it may be unable to enforce environmental laws. Indeed, there have been several cases of corruption in state agencies: In December 2008, the Federal *Ministério Público* (Public Procuracy) charged 33 people – including the former Secretary of the Environment for Pará – with trafficking in illegal wood in Pará ("Ex-secretário…" 2008). Other reports indicate that corruption is endemic in Amazonian state environmental agencies (Hochstetler and Keck 2007; Luíse 17 March 2011; McAllister 2008a).

Corruption and weak state capacity lead to high rates of impunity for environmental crimes in the Amazon. Although Brazil's *Ministério Público* has constitutional autonomy and both enforces environmental laws and roots out corruption in federal and state environmental

[16] "'[I]nstitutional weakness' and 'absence of the rule of law' often cited by studies of the 'failure' to enforce environmental standards or pursue miscreants is not an accident of recent settlement but rather a strategy deliberately pursued by powerful operators in the region for which a more robust state geared to maintaining law and order would be highly inconvenient" (Hochstetler and Keck 2007, 153).

agencies (McAllister 2008a), it cannot always ensure that punishments for environmental transgressions are carried out: A 2009 study by the Amazonian Institute for Man and the Environment (IMAZON) think tank in Belém, Pará, found low rates of punishment for illegal deforestation in the Amazon's extensive network of environmentally protected areas, due to the inefficiency of the police and court system (Barreto et al. 2009). In this context, ranchers and farmers often have incentives to increase production by expanding their landholdings, rather than investing in productivity increases.

Expansion of landholdings is also due to lack of effective land titling, which when combined with low levels of environmental law enforcement on the Amazonian deforestation frontier, worsens deforestation by depressing incentives to invest capital in productivity and raising incentives to expand horizontally – into neighboring fallow pastures or virgin forests (Barreto et al. 2008). This process exacerbates the problem of illegal and often violent land seizures on the Amazon frontier: Land grabbers invade and deforest public and unclaimed lands (*terras devolutas*) – as well as the lands of the small settlers, whom they expel – and falsify titles to them.[17] In 2009, the Brazilian federal government enacted a program of Amazonian land titling, part of a larger effort to reduce deforestation by identifying property owners who may be held accountable for illegal logging on their properties (*O Estado de São Paulo*, 3 June 2009).[18] It is too soon to evaluate the effects of this program on deforestation rates.

Furthermore, the Brazilian state has only recently begun to embrace a sustainable development model in the Amazon. Indeed, from the late 1960s to the 1980s, Brazilian Amazon settlement policy promoted deforestation to ensure national security and to expand agricultural production, and settlers in the region were required to deforest their lands to lay claim to them and become eligible for subsidized credits. Mineral extraction

[17] Falsification of land titles is widespread in Brazil, especially in the Amazon, and known as *grilagem*, after *grilo*, the Portuguese word for cricket. Sometimes, land grabbers write a false title, and then place it in a jar with crickets. The crickets chew on the paper, and this makes the land title look old, so that land agency bureaucrats are less likely to suspect that the claim is false.

[18] This program is controversial, as formalizing property rights implies forgiving the past transgressions of land grabbers. Some Brazilian environmentalists fear that this program may actually increase deforestation, as new land grabbers see the potential to occupy land illegally and then argue for legal title.

and industrial development in the Amazon were key economic goals for Brazil's 1964-1985 military dictatorship, and from 1965 to 1974, subsistence farmers were expelled from the agricultural frontier "to make way for enormous cattle ranches, whose pastures required the burning of huge swaths of forest" (Hochstetler and Keck 2007, 145). In 1974, the current agribusiness and ranching model of development was consolidated, setting the trajectory of deforestation seen today. In addition to national Amazon settlement policy, subsidized credits and tax exemptions for agribusiness lowered production costs and stimulated deforestation for many years (Binswanger 1991).

Over the last decade, some of the perverse incentives driving Amazon deforestation detailed above have been removed. At the same time, cattle expansion has become profitable independently of state subsidies – thus, now market mechanisms are the principal drivers of cattle ranching expansion and consequent deforestation, rather than policy (Margulis 2004). However, the Brazilian federal government continues to be a major investor in Amazonian agribusiness, through institutions such as the Brazilian National Development Bank (BNDES) (Greenpeace 2009, 3), which gives the government conflicting incentives vis-à-vis tradeoffs between production and environmental sustainability. The Brazilian government has also indirectly subsidized the soy industry in the Cerrado and Amazon by investing in transportation infrastructure (Fearnside 2001). Finally, studies find that the more access farmers and ranchers have to rural credit, the more deforestation occurs (IPAM 2008). This suggests that access to credit needs to be more strongly conditioned on environmental sustainability, but doing so will require more coordination between Brazil's developmental and environmental ministries.

3.3 Mixed Results: Efforts to Fix the System

In conjunction with the removal of some perverse incentives, federal and state government initiatives have helped to reduce Amazon deforestation. These initiatives, however, must be combined with productivity enhancements, stronger law enforcement, and domestic and international consumer pressures if they are to contribute to reducing deforestation in the long run.

At the federal level, the Action Plan to Prevent and Control Deforestation in the Legal Amazon (PPCDAM) and the Amazon Protected Areas Program (ARPA) have sought to increase law enforcement and land area designated as environmentally protected. In addition, the federal government enacted a National Climate Change Plan in 2009, which includes the ambitious goal of eliminating deforestation by 2040 (Governo Federal 2008), and reducing carbon dioxide emissions by 36.1-38.9% by 2020 (Seroa da Motta 2011, 31). Finally, the Amazonian states of Acre and Amazonas have sought to create markets for sustainably produced forest products, and Amazonas has enacted a program to pay smallholders monthly stipends not to deforest (Viana 2009; 2010, 38-42), and nine states have enacted laws aiming to reduce carbon emissions (though only São Paulo has enacted a law that includes mandatory reduction targets) (Romeiro and Parente 2011, 47).[19]

Conflicts between those who favor development at any cost and those who support conservation and sustainable development continue, but the programs described above (and in greater depth in Appendix 1) indicate that Brazil is becoming serious about reducing GHG emissions from deforestation, and about protecting biodiversity.

3.4 Enhancing Ranching and Agricultural Productivity

The alternative to expanding agriculture into new areas is to do more with existing areas. Thus, while federal and state initiatives have helped to reduce deforestation, meeting Brazil's National Climate Change Plan target of zero deforestation by 2040 while maintaining the country's stature as an agro-industrial powerhouse will require further investments in enhancing the productivity of agriculture and ranching. Subsidized credit for inputs such as machinery and fertilizer have increased productivity in both industries: Some older ranches on the Amazon frontier have managed to increase their beef production per hectare (Margulis 2004), and, as Figures 2 and 3 below show, though the area in the Center-West Cerrado devoted to soybean production continues to grow, soybean productivity has also increased steadily from 1,452 kg/hectare in 1976 to 3,135

[19] See Appendix 1 for more details on federal and state environmental programs. On 13 September 2011, the lower house of the Brazilian Congress passed a provisional measure to pay poor smallholders to leave trees standing, similar to the Amazonas program. The measure must be approved by the Senate before it can be enacted (*Jornal da Câmara*, 14 September 2011).

kg/hectare in 2010. A combination of advances in farming techniques that enabled soybean farming in the Cerrado in the 1980s, and the fertile virgin soil of that region and the Amazon have contributed to this (Luna and Klein 2006, 120).

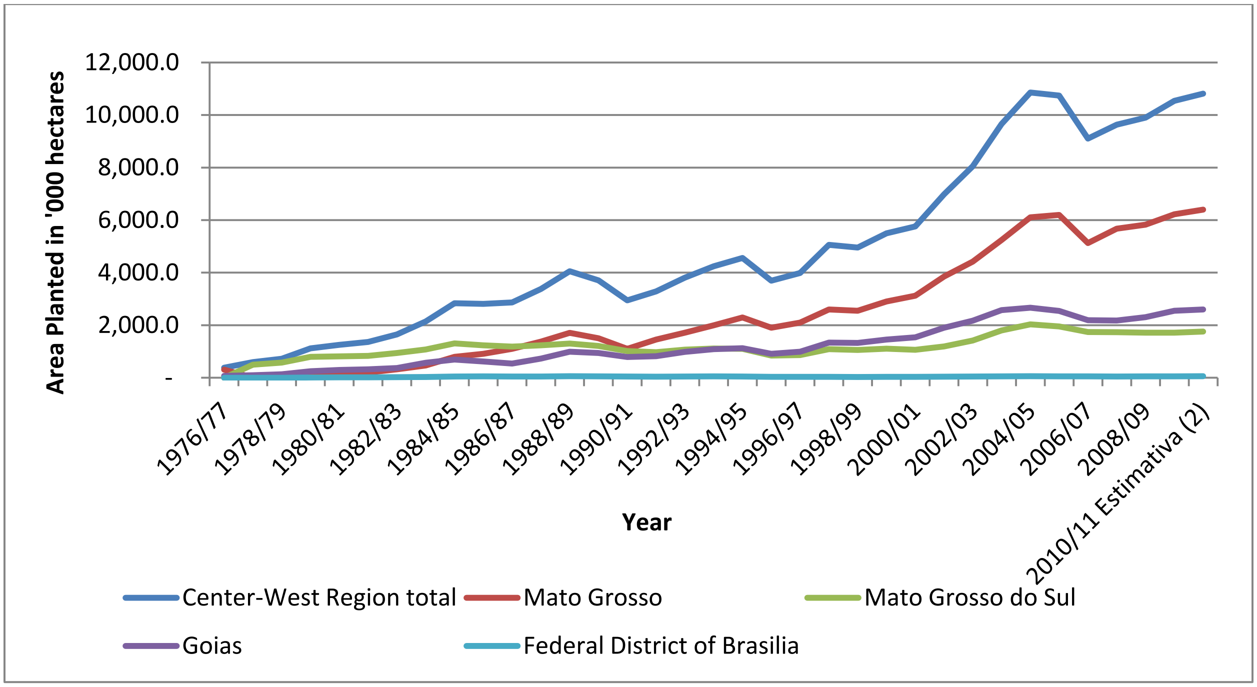

Figure 2: Area of Soy Planted in the Center-West (CONAB 2011)

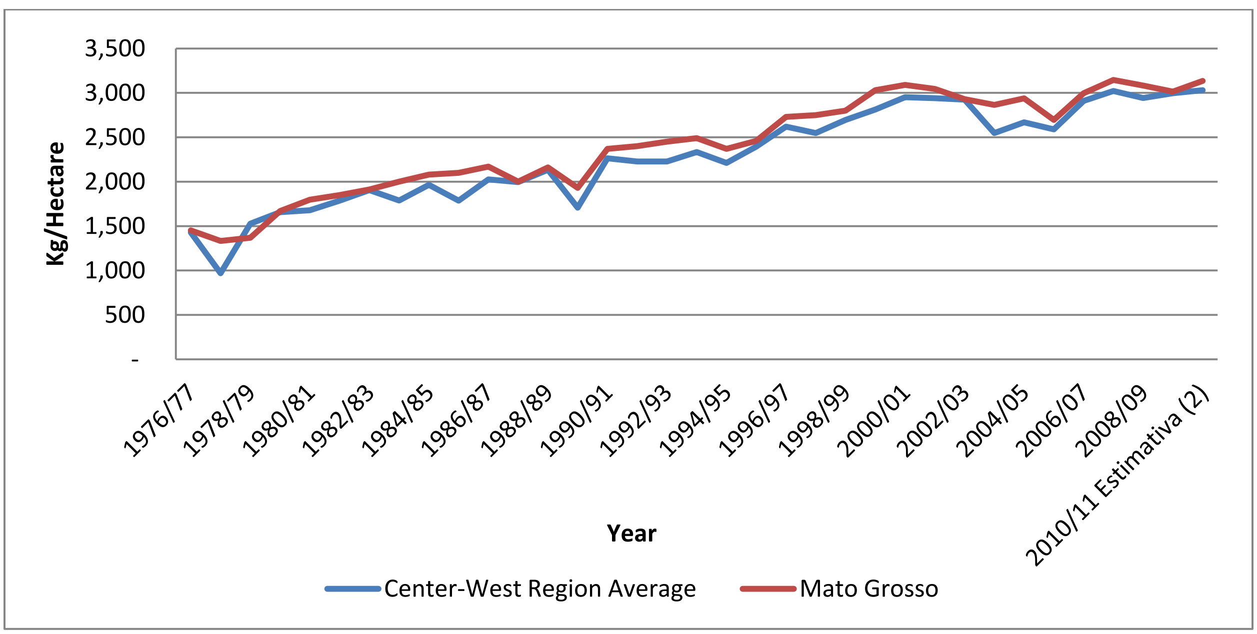

Figure 3: Soy Productivity in Center-West and Mato Grosso (CONAB 2011)

Increasing cattle and soy productivity is to be celebrated for its potential to reduce ranchers' and farmers' dependence on deforestation for expansion, but it is not sufficient to render ranching and farming "green" in the medium run. Indeed, continued increases in productivity and profits in these industries may place stronger pressures on state and federal governments to loosen forest conservation laws.[20] Continued government investment in improving law enforcement in the Amazon region and the effective implementation of Brazil's policies to reduce deforestation are necessary to ensure that these sectors' productivity increases do, indeed, lead to reductions in GHG emissions from deforestation.

Finally, domestic and international consumers could help to ensure that environmental laws are enforced by demanding that beef and soybeans be produced sustainably. Some efforts have already begun: "A large Swedish grocery store chain" (Nepstad et al. 2006, 1600) has demanded that Brazilian soybeans meet environmental criteria, the U.K.'s National Beef Association called for a boycott of Brazilian beef (*ibid.*), and international NGOs, producers, and consumers imposed a "soy moratorium" for three years on Brazilian soybeans, from 2006 to 2009 (Greenpeace 17 June 2008). In addition, domestic beef retailers in Brazil, such as the supermarket chains Carrefour and Pão de Açúcar, and the meat processors Friboi and Bertim, are seeking to sell beef "produced on ranches that obey environmental legislation and use good land-management techniques" (Nepstad et al. 2006, 1600). More effort is needed on this front to promote environmental sustainability in the beef and soybean industries.

In their current states, the agriculture and ranching industries present Brazil with a real dilemma between "green" and "growth." Solving this problem – and achieving green

[20] Pressures to loosen conservation laws are already being felt in the ongoing acrimonious debate in the Brazilian Congress over revising the 1965 Forest Code. The agribusiness sector would like the legal reserve requirement (the percentage of land on private property in different biomes that must be preserved in its natural state) in the Amazon to be significantly reduced from its current 80%. The environmental movement and environmental bureaucracy oppose this change (Noronha 2011). Revisions to the Forest Code to loosen conservation rules for small-scale farmers and ranchers passed in the lower house of Congress on 25 May 2011, but are expected to have a tough fight in the Senate. President Dilma Rousseff is also expected to veto certain provisions in the legislation, such as amnesty for illegal deforestation on private lands prior to July 2008 (Brooks 2011).

growth – means finding a way to decouple growth in these industries from rising emissions. Without significant progress in increasing the productivity of cattle ranching and soybean farming, enforcing environmental laws, implementing anti-deforestation policies responsibly, and cultivating domestic and international consumer pressures, it is unlikely that Brazil will move off of its current track of deforestation-driven increasing GHG emissions.

This section has shown how cattle and agribusiness in the Amazon region drive deforestation, and how through deforestation and their own emissions they contribute to about 80% of Brazil's total GHG emissions. Brazil's energy sector, discussed in the next section, provides a contrasting perspective on the potential for green growth in Brazil, but there are environmental risks there as well: like cattle and soy, agroenergy production is land use-intensive, and risks increasing competition for land among different crops. This is especially true in the small but growing biodiesel sector, which currently extracts fuel largely from soybeans and bovine fat (IPEA 26 May 2010, 28). Meanwhile, large hydropower projects in the Amazon threaten to flood large tracts of forest and disrupt ecosystems.

4 Brazil's Energy Generation: A Renewable Powerhouse with a Possible Dark Side

Brazil's energy matrix is remarkably green, with 45.9% of its domestic energy supply provided by renewables in 2008 – well above the world average of 12.9% (IPEA 2010, 133). As can be seen in Table 1 below, though petroleum and derivatives account for the largest source of energy in the country, the renewable energy sources of sugar cane products and hydroelectricity come second and third, respectively (EPE 2010, 31). This impressive performance results from policies enacted since the 1970s that have aimed to secure Brazil's energy independence, and growth is expected to continue due to recent technological breakthroughs (e.g. flex-fuel cars), global demand for ethanol, and government investments in ethanol, biodiesel, and hydroelectric dams.

Nevertheless, there is a possible dark side to renewable energy in Brazil: Growth in the production of ethanol requires increases in both crop productivity and the amount of land cultivated, which may displace food crops (raising the price of food), and force more farmers to move into the Center-West Cerrado by increasing the price of land in coastal regions, exacerbating deforestation on the Amazon frontier (IPEA 2010, 417). Expanding land area in the Southeast and Northeast of Brazil under sugar cane cultivation, meanwhile, is expected directly to worsen deforestation in the Atlantic Forest (IPEA 2010, 431-432). Meanwhile, because the major ingredients in biodiesel are soy and bovine fat, Brazil's current investments in biodiesel production may increase Amazon deforestation in the medium run. Finally, large hydroelectric dams, such as the proposed Belo Monte dam in Pará, require logging of surrounding lands and displacement of local residents, and may have deleterious downstream ecological effects from diverting river flows.

This section will examine the potential for green growth in Brazil's renewable energy sector. It will first profile the share of renewable energy sources in Brazil's energy matrix. Then, it will analyze growth and environmental risks in the ethanol and biodiesel sectors. Finally, it will discuss the environmental tradeoffs of hydroelectricity.

4.1 Profile of Brazil's Energy Matrix

Brazil has succeeded in providing a large share of its domestic energy supply from renewable sources such as ethanol, biomass, and hydropower – and in the coming years increasingly from biodiesel. Table 1 below shows the changes in Brazil's energy supply from 1940 to 2009 by source. Overall domestic energy supply rose from about 23 million tons of oil equivalent (toe) in 1940 to 243 million toe in 2009. Concomitant with growth in the domestic supply of energy, production grew among all sources of energy. The use of petroleum in Brazil has steadily increased over time, but the substantial rise in production of sugar cane products (ethanol, biomass) and the generation of electricity from dams have reduced petroleum's overall share in the energy matrix. The growth of sugar cane and hydroelectric energy production was especially high between 1970 and 1980, when the

1973 OPEC oil shock induced Brazil's military dictatorship to reduce national dependence on imported oil.[21]

Source	1940	1950	1960	1970	1980	1990	2000	2005	2008	2009
Petroleum, Natural Gas, and Derivatives	1,522 (6.4)	4,280 (12.9)	12,668 (25.7)	25,420 (38.0)	56,485 (49.2)	62,085 (43.7)	96,999 (50.9)	105,079 (48.1)	111,344 (46.8)	113,567 (46.6)
Mineral Carbon and Derivatives	1,520 (6.4)	1,583 (4.8)	1,412 (2.9)	2,437 (3.6)	5,902 (5.1)	9,615 (6.8)	13,571 (7.1)	13,721 (6.3)	14,562 (5.8)	11,572 (4.7)
Hydropower	352 (1.5)	536 (1.6)	1,580 (3.2)	3,420 (5.1)	11,063 (9.6)	20,051 (14.1)	29,980 (15.7)	32,379 (14.8)	35,412 (14.0)	37,064 (25.2)
Wood and Vegetable Carbon	19,795 (83.3)	25,987 (78.1)	31,431 (63.9)	31,852 (47.6)	31,083 (27.1)	28,537 (20.1)	23,060 (12.1)	24,468 (13.0)	29,268 (11.6)	24,610 (10.1)
Sugar Cane Products	563 (2.4)	892 (2.7)	2,131 (4.3)	3,593 (5.4)	9,217 (8.0)	18,988 (13.4)	20,761 (10.9)	30,147 (13.8)	42,866 (17.0)	44,447 (18.2)
Other				223 (0.3)	1,010 (0.9)	2,724 (1.9)	6,245 (3.3)	8,869 (4.1)	12,185 (4.8)	12,670 (5.2)
Total	23,752 (100)	33,278 (100)	49,222 (100)	66,945 (100)	114,761 (100)	142,000 (100)	190,615 (100)	218,663 (100)	252,638 (100)	243,930 (100)

Table 1: Brazilian energy supply by source in 10^3 tons of oil equivalent (Percentage share of each source in total energy supply). Adapted from EPE (2010, 31-32).

Table 1 also illustrates the changing shares of each source of energy in Brazil's energy matrix. The share of petroleum in total domestic supply peaked in 2000 at 50.9%, and has since fallen marginally to 46.6% in 2009.[22] Meanwhile the share of hydropower has risen substantially, from 1.5% in 1940, to 9.6% in 1980 and 25.2% in 2009. Much of this is consumed as electricity. At the same time, sugar cane products (ethanol and biomass from bagasse) have increased their share from 2.4% in 1940 to 8% in 1980 and 18.2% today. This changing balance between renewable and non-renewable sources of energy over time makes Brazil an impressive case of energy systems transition.

This section will focus its analysis on three important and growing renewable energy sectors: ethanol, biodiesel, and hydropower.

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[21] Today, most of Brazil's petroleum is produced domestically, though some light petroleum is imported from elsewhere to mix with Brazil's heavy crude in the refining process (Sennes and Narciso 2009, 33-34).

[22] Petroleum's share may rise in the coming decades as Brazil begins to explore its recently discovered pre-salt oil fields.

4.2 Ethanol

Ethanol is Brazil's signature biofuel, and its production and consumption both within Brazil and abroad are growing due to the advent in 2003 of flex-fuel cars in Brazil (which can run on any combination of petroleum-based gasoline and ethanol), and to world demand for renewable energy sources. Though Brazil's sugar cane-based variety of ethanol may reduce GHG emissions by up to 92% (from production to burning), sugar cane requires land on which to grow, and extension of farm land devoted to sugar cane may directly worsen deforestation rates in Brazil's Atlantic forest, as well as indirectly increase Amazon deforestation by displacing other crops and cattle ranching in coastal regions and the Cerrado toward the Amazon.

Ethanol is widely considered to be a carbon-efficient fuel when compared to petroleum because it burns more cleanly than oil and is extracted from crops, the next generation of which re-absorbs some of the carbon emitted from the burning of the previous generation. Studies indicate that Brazil's sugar cane-based ethanol is especially advantageous, reducing GHG emissions up to 92% per liter of ethanol when compared to one liter of petroleum-based gasoline (measuring life cycle emissions of each from production to burning). The U.S.'s corn based-ethanol, by contrast, only reduces carbon emissions by 19-47% (La Rovere et al. 2011, 1031). In addition, at about US$23/liter in 2005, Brazilian ethanol is more efficient to produce than sugar cane-based ethanol produced in other leading countries, such as Thailand and Australia (Nassar 2009, 70). Part of these advantages lies in climatic conditions, and part is due to the fact that all ethanol distilleries in Brazil power the production of ethanol by burning their own sugar cane bagasse, rather than fossil fuels – which reduces their own energy costs as well as net carbon emissions (Hofstrand 2008; Nassar 2009, 71).

State support (including subsidies and the creation of a domestic market through minimum ethanol-petroleum blending requirements in gasoline) since the implementation of the Pro-Álcool Program in 1975 has enabled the sugar cane-based ethanol industry to grow and thrive, and there are currently 434 ethanol distilleries in operation in Brazil (IPEA 26

May 2010, 14). Production is driven both by high domestic and global demand: In 2007, Brazil exported 185 million gallons of ethanol to the U.S. and produced just under 6 billion gallons for domestic consumption (Hofstrand 2008).[23]

However, as land area in Brazil dedicated to sugar cane farming for ethanol grows to meet domestic and world demand for biofuels, other crops and cattle ranching may be displaced toward the Cerrado and Amazon, which may indirectly worsen GHG emissions from Amazon deforestation by increasing competition for land there (McAllister 2008b, 10,876). Furthermore, if environmental laws in the coastal Atlantic Forest areas are not effectively enforced, ethanol production may lead to higher rates of deforestation there in the coming decades. Figure 4 (below) shows the growth in the land area devoted to sugar cane cultivation (to produce both sugar and ethanol) from 1975 to 2009.

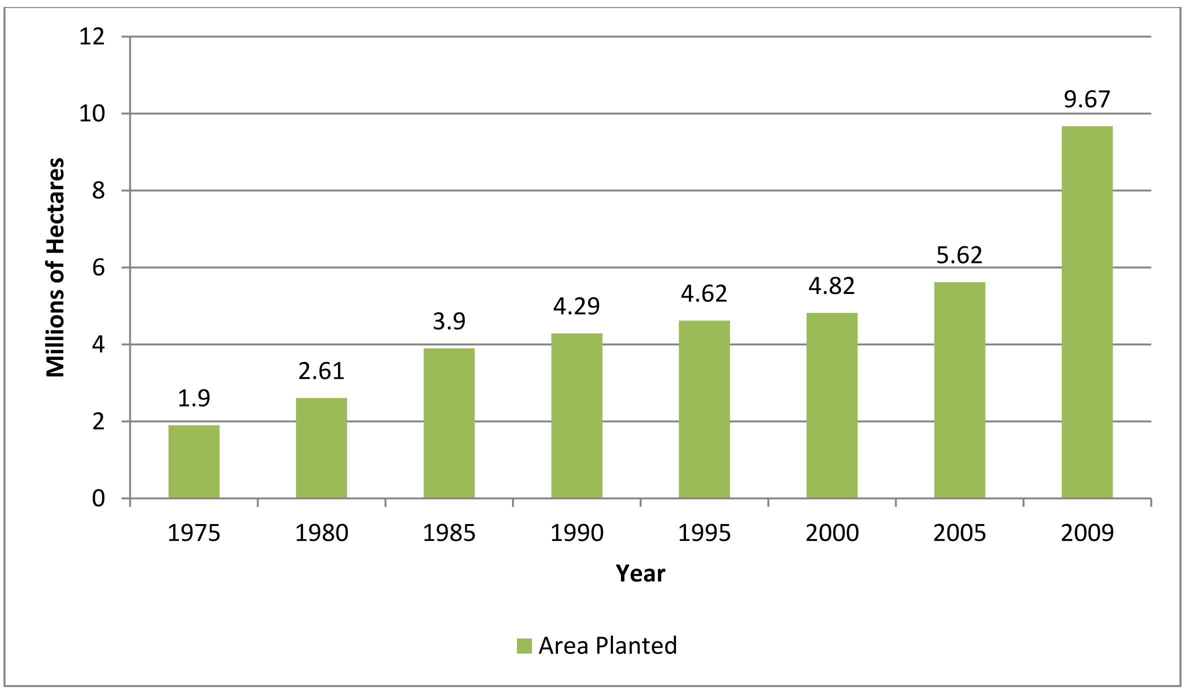

Figure 4: Area of sugar cane planted in Brazil, 1975-2009 (MAPA 2010)

Land area devoted to sugar cane cultivation grew especially rapidly in the 2005-2009 period, due to growing domestic and global demand for ethanol. To give a sense for

[23] For an extended discussion of the development of Brazil's ethanol industry, see Appendix 2.

ethanol's contribution to the trajectory shown in Figure 4, in the 1975/76 harvest, only 14% of sugar cane harvested on 1.9 million hectares was used to produce ethanol – the other 86% was converted to sugar. In contrast, in the 2009/10 harvest, 57% of the sugar cane harvested on 9.67 million hectares was used to produce ethanol, while only 43% was converted to sugar (MAPA 2010). Based on this pattern, we may conclude that a continuing rise in world demand for ethanol will lead to growth in the land area used to cultivate sugar cane in Brazil, which may exacerbate deforestation.

Indeed, econometric modeling by the Brazilian Institute for Advanced Economic Studies (IPEA) indicates that sugar cane cultivation will lead to more deforestation in the Atlantic forest over the next two decades. IPEA (2010, 431) estimates that sugar cane crop area will grow to 22-23 million hectares by 2035, with most growth concentrated in the Southeastern states of Minas Gerais, São Paulo, and Rio de Janeiro, and a lesser share in the more arid Northeast region. These two regions contain much of what remains of the Atlantic Forest, and if strict ecological zoning policies to protect forests are not implemented and enforced, sugar cane production may reduce the Southeast's remaining forest cover by 67%, and the Northeast's by 21% (*ibid.*, 432).[24]

Some policy progress is being made to address the long-term environmental risks of ethanol growth, but more must be done to ensure that ethanol remains environmentally sustainable. A national law proposed in 2009 would prohibit sugar cane cultivation in the Pantanal and Amazon biomes (IPEA 2010, 144) – a measure that will have little effect, since sugar cane is expected only indirectly to affect the Amazon, as it does not grow well there (Nassar 2009, 68). More positively, in 2007 the state of São Paulo and the president of that state's sugarcane producers' union signed an Agroenvironmental Protocol, which sets deadlines to phase out and eventually eliminate sugarcane harvest burning – a major source of agricultural GHG emissions in the state – and commits sugar cane farmers to reforesting 400,000 hectares of degraded lands (Lucon and Goldemberg 2010, 343-344). São Paulo is also in the process of implementing an ecological-economic zoning program to

[24] Rosa et al. (2009, 16) are more optimistic: they calculate that there are 90 million hectares of land in Brazil still "available for the expansion of agriculture without deforestation."

minimize biodiversity loss in sugar cane expansion areas (Author's interviews with personnel of São Paulo's Forestry Foundation, July 2010). Finally, unlike in poorer states in Brazil, São Paulo's state environmental and forestry agencies are relatively competent, and the state's *Ministério Público* vigilantly enforces environmental laws (McAllister 2008a).

Finally, the productivity of sugar cane production has improved considerably since 1975. Tons of sugar cane produced per hectare has risen from 65 in the 1977-78 harvest to an average of 85 in the 1989-2004 period. Similarly, liters of ethanol produced per hectare of sugar cane planted increased from 4,550 to 6,800 over the same period (IPEA 26 May 2010, 13). Productivity is expected to continue to rise to about 7,160 liters of ethanol per hectare by 2020,[25] and if this is combined with effective ecological-economic zoning and environmental law enforcement, ethanol's potential to contribute to deforestation may decline from current estimates.

4.3 Biodiesel

Brazil has been investing in biodiesel production since 2005, and the country's 2008-2017 Decennial Plan aims to produce enough biodiesel not only to power vehicles, but also integrate into the electricity grid (IPEA 26 May 2010, 21). Though the industry remains small, growth in the coming decades may directly worsen deforestation rates: Despite Brazilian government efforts to diversify the agricultural ingredients in biodiesel, current inputs are largely soy and bovine fat, and soybean farmers and cattle ranchers in the Cerrado and Amazon regions – the principal economic drivers of Amazon deforestation – are beginning to invest in biodiesel production to take advantage of government supports for the sector.

Soy and bovine fat account for 75.04% and 17.79% of raw materials used in biodiesel, respectively.[26] These raw materials are produced by the same industries that, as discussed in Section 2 above, are responsible for the majority of deforestation in the Amazon.[27] In

[25] See Table 3 in Appendix 2.
[26] Cotton and other oils and fats account for only 7.17% of raw materials included in biofuels (IPEA 26 May 2010, 28).
[27] On 18 March 2011, the Brazilian meatpacking company Minerva opened a bovine fat-based biodiesel plant in the Center-West state of Goiás (*Business News Americas* 16 March 2011). Together with four other large meatpacking

regards to the international market for biofuels, McAllister (2008b, 10,876) notes that "…the production of biofuels elsewhere in the world may [increase]… the price of soybeans or cattle on the international market, thus stimulating further production of these commodities in the Amazon and the resultant deforestation." A mechanism by which this may happen is through the displacement of soybeans for corn cultivation for ethanol in the U.S., which may raise the price of Brazilian soybeans on the world market and induce Brazilian farmers to increase production (*ibid*.).

Although in 2008 biodiesel accounted for less than 1% of Brazil's domestic energy supply, it is being gradually integrated into the energy matrix: Currently, national standards require that all diesel gasoline sold in Brazil contain 3% biodiesel as of 2008 – and most diesel sold now contains 5% biodiesel (IPEA 26 May 2010, 20-22).[28] A 2005 law established state support for biodiesel, including research support and financing from BNDES and other public institutions.[29] These investments have begun to yield results: From 2006 to 2008, production of biodiesel in Brazil jumped from 69 million to 1.167 billion liters, placing Brazil fourth in world production, behind only Germany (3.193 billion liters), the U.S. (2.644 billion liters), and France (2.063 billion liters) (*ibid.*, 27).

Growth in biodiesel is good news for Brazil's energy-related GHG emissions profile, but its effects on land use and its consequent potential to contribute to GHG emissions from deforestation means that enthusiasm over biodiesel's overall greenness must be tempered. Indeed, if biodiesel production grows considerably in the long run, the potential for an increase in deforestation in the Amazon is alarming. Area devoted to the planting of soybeans in Brazil has increased from 6.9 million hectares in 1976 to an estimated 24.2 million hectares today, of which 6.4 million hectares are in Mato Grosso state, one of the two leading Amazon deforesters after Pará (to put this in perspective, in 1976 Mato Grosso had only 310,000 hectares under soybean cultivation) (CONAB 2011 data).

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companies – Bertim, Independência, JBS, and Marfrig – Minerva controlled over 50% of Brazil's beef export market in 2007 (Greenpeace 2009, 6).

[28] Biodiesel has been integrated into diesel gradually since 2005: 2% in 2005-2007, 3% 2008-2012, 5% starting in 2013, per Law No. 11,097/2005.

[29] Law 11,097/2005 introduced biodiesel into the Brazilian energy matrix, though BNDES Resolution No. 1,135/2004 established its Financial Assistance and Investment in Biodiesel Program (IPEA 26 May 2010, 23). From 2005 to 2009, through its Programa Biodiesel, BNDES provided R$9.156 billion to 47 programs or actions related to biodiesel, including energy generation (R$520 million), bioelectricity (R$580 million), marketing (R$627 million), agriculture and industry (R$2.406 million), and credit for industry, commerce and services (R$3.295 million) (*ibid.*, 32-33).

As the world market for ethanol grows, and as new technologies to extract biodiesel from soybeans and bovine fat are developed and implemented, agroenergy is likely to contribute more directly to deforestation than it currently does. This, in turn, will partially offset ethanol biodiesel's potential contribution to reducing Brazil's GHG emissions.

4.4 Hydropower

Finally, hydropower presents another paradox in Brazil's quest for green growth: Hydropower has the third largest share in Brazil's domestic energy supply (Table 1 above), and is essential if domestic electricity generation is to meet growing demand over the coming decades (OECD/IEA 2006, 9-10). However, large hydropower projects in the water-rich Amazon require that massive tracts of land be deforested – with the corresponding release of massive amounts of GHGs – and dams may damage ecosystems upstream and downstream by altering river flows.

Brazil's 852 hydroelectric plants produce 72.5% (79,182.3 MW) of Brazil's domestic electricity supply, and 311 new plants are under construction (potentially adding another 15,336.7 MW) (IPEA 2010, 137). The Bi-National Itaipú Dam, whose management is shared between Brazil and Paraguay, alone "accounts for 20 percent of the Brazilian energy supply, providing most of the energy consumed in the country's Southeastern region," Brazil's industrial hub (Sennes and Narciso 2009, 47-48).

Hydropower is key to the Brazilian government's renewable energy strategy, but it is one that in some cases generates opposition from the domestic and international environmental movements. This is the case of a proposed mega-dam on the Xingú River in eastern Pará. If constructed, the Belo Monte dam will be the world's third largest, and the Brazilian government estimates that it will produce 11,200 MW of electricity (Inter-American Dialogue 2011). However, to build the dam will require the displacing of local indigenous communities, and the logging and flooding of 400 km2 of currently standing forest – a process that is expected to generate "enormous quantities of methane" (Amazon Watch 2011). Finally, dam construction will attract an estimated 100,000 migrants to the region, which will exacerbate deforestation problems there, as dam construction is only expected to create 40,000 new jobs – the rest of the migrants will likely become loggers and cattle ranchers (Amazon Watch 2011). Worse, critics argue that the Belo Monte dam will only produce 10% of its expected annual mega-wattage during the 3-5 month long dry season – or only 39% of its nominal annual capacity (Amazon Watch 2011). Thus, Belo Monte's long-run clean energy generating potential may be canceled out by its up-front environmental impacts.

It is still unclear if the dam will be built, but what becomes clear in the debate over Belo Monte is that the green benefits of hydropower are contingent on the ecological vulnerability of surrounding areas.

5 Conclusion

This study has demonstrated that deforestation presents a challenge to prospects for truly green growth in Brazil. Cattle ranching and soybean farming contributed to 25% of Brazil's GDP in 2008, and must continue to grow if Brazil overall is to grow economically (absent major restructuring of its economy). However, agribusiness produces approximately 25% of Brazil's annual GHG emissions, and the industry is a direct driver of deforestation, which produces another 55% of annual GHG emissions. Finally, as stated in the introduction, each option for renewable energy in Brazil may directly or indirectly worsen deforestation rates in the Amazon and Atlantic forests: Soy- and bovine fat-derived biofuels directly affect deforestation rates in the Amazon by making cattle ranching and soybean farming more lucrative; sugar cane-derived ethanol may directly contribute to deforestation in the Atlantic, and indirectly to deforestation in the Amazon by displacing other farming and ranching activities; and the construction of large dams to produce electricity requires deforestation and the flooding of fragile ecosystems. Thus, Brazil faces contradictory imperatives with respect to green growth, and responsible governance by federal and subnational states is necessary to ensure that agro-industrial growth has a minimal impact on the environment.

Brazil will continue to invest in renewable energy and agricultural exports, but to reduce its overall emissions, it must do so in a way that minimizes GHG emissions from deforestation and forest degradation. More consistent environmental law enforcement on the Amazon frontier and other rural areas, and the effective application of punishments for transgressors are necessary to raise the perceived costs of deforestation relative to investments in enhancing agricultural productivity. Compensation mechanisms for avoided deforestation must also be implemented – the federal government, and state governments, may look to Amazonas' *Bolsa Floresta* as a model. Finally, credits for farmers and ranchers must be strictly conditioned on environmental sustainability.

Appendix 1: Details of Brazilian Anti-Deforestation Policy

Brazil's environmental laws date back to the 1934 Forest Code. This was Brazil's first attempt to regulate logging and land occupation practices, and was revised in 1965 (Drummond and Barros 2006, 87-89). In 1981, Brazil enacted a National Environmental Policy (*ibid.*, 92), and environmental concerns were later codified in the 1988 Constitution (*ibid.*, 96) and in the Environmental Crimes Act of 1998 (*ibid.*, 90). Nevertheless, these laws have often generally been only weakly enforced, and have not effectively prevented illegal deforestation.[30]

In recent years, progress has been made by both the federal and state governments to enhance conservation by gathering information about deforestation from satellite images, increasing the land area under legal environmental protection, and enforcing environmental laws. Federal programs such as Action Plan to Prevent and Control Deforestation in the Legal Amazon (PPCDAM) and the Amazon Protected Areas Program (ARPA) have been implemented in coordination with Amazonian states, and benefit from financial and technical support from federal and state agencies, as well as the World Bank, the Global Environment Facility (GEF), the German Cooperation Fund (KfW), the German Technical Cooperation Agency (GTZ), and others (Soares-Filho et al. 2009, 11 fn. 11). These initiatives involve collecting and analyzing satellite data, promoting environmentally sustainable economic activities, and undertaking institutional reforms and ecological-economic zoning (to determine what lands need to be protected, and what lands can be cultivated); and, in the case of ARPA, creating 340,000 km^2 of new environmentally protected areas in the Amazon from 2003 to 2009 (IMAZON 2011, 23).[31] Finally, in 2009 Brazil enacted a National Climate Change Plan, which proposes to reduce Amazonian deforestation by 80% relative to its 1996-2005 average by 2020, and to reduce deforestation in the Cerrado by 40% relative to its 1999-2008 average, also by 2020 (Seroa da Motta 2011, 33). The plan also proposes the creation of a carbon credit market, called

[30] For a detailed historical discussion of the development of public environmental institutions in Brazil since the 1970s, see Hochstetler and Keck (2007) and McAllister (2008).

[31] Nevertheless, challenges remain: many protected areas in Brazil lack effective management, most are under ecological pressure from nearby populations, and few states have implemented their ecological-economic zoning plans (IMAZON 2011).

the Brazilian Emissions Reduction Market (Mercado Brasileiro de Redução de Emissões, or MBRE) (*ibid.*, 37). The plan is currently in the early stages of implementation (*ibid.*).

In conjunction with the aforementioned federal programs, some states have implemented their own plans to promote green growth by reducing deforestation: Acre and Amazonas have both sought to create or expand markets for sustainably produced forest products, in an attempt to offset smallholders' incentives to deforest. Acre's program began in the 1990s, and has focused on implementing extractive reserves and creating markets for forest products (Kainer et al. 2003); Amazonas' began in 2003, and builds on the state's longstanding Free Trade Zone of Manaus to create a "Green Free Trade Zone," in which producers of sustainable forest products have greater market access and can fetch better prices than before. As of 2008, Amazonas has also enacted a program to pay poor families for not deforesting their lands – a program based on Reduction of Emissions from Deforestation and Forest Degradation (REDD) principles and called *Bolsa Floresta* (Forest Basket) (Viana 2009). *Bolsa Floresta* supports families with US$25/month direct payments via debit cards, and benefited 6,325 families in 2009 (Viana 2010, 38). *Bolsa Floresta* also provides funding for various social programs and sustainable income generating programs (Viana 2009; 2010, 38-42). In conjunction with green free trade and income support, since 2003 the government of Amazonas has greatly expanded the state's network of environmentally protected areas (CEPAL 2007, Viana 2010), which now covers 23.5% of the state's territory (IMAZON 2011, 21).

There are limitations, however, to the contributions to deforestation reduction in Acre and Amazonas: the worst deforestation rates occur in Mato Grosso, Pará, and Rondônia, while Acre and Amazonas already have relatively low rates of forest clearing – 2,636 km2 in Amazonas and Acre in 2003 (the year Amazonas began its sustainable development program), versus 21,147 km2 in Mato Gross, Pará, and Rondônia that same year (INPE 2011). In contrast to Acre and Amazonas, whose rural areas are largely populated by traditional populations (including rubber tappers, fishing communities, and indigenous tribes) and a comparatively small cattle ranching sector, Mato Grosso, Pará, and Rondônia have large, organized beef and soy industries in their country sides, with an interest in expanding the territory available for production. These states have unsurprisingly been slower to enact policies to reduce deforestation, though recently Pará passed a state plan (Governo do Estado do Pará 2009), and the former governor of Mato Grosso, Blairo Maggi – a soy mogul and longtime enemy of conservation – recently embraced the environmental cause (Patury and Edward, 16 September 2009).

Appendix 2: A Brief History of Brazil's Ethanol Industry

Brazil has been producing sugar cane-based ethanol since the 1920s (IPEA 26 May 2010, 3), but the development of the modern ethanol industry began with the Pro-Álcool program in 1975, as the Brazilian government sought to secure energy independence by creating alternatives to expensive petroleum imports to power Brazil's industrialization process (IPEA 26 May 2010; Sennes and Ubiraci 2009).[32] Pro-Álcool involved four policies to stimulate ethanol production: A minimum required ethanol purchase by the state-owned oil company, Petrobrás, to create demand; US$4.9 billion in low-interest loans to stimulate ethanol production; subsidies to ensure that ethanol's retail price was 41% lower than gasoline; and a requirement that all fuels be blended with a minimum 22% ethanol (Hofstrand 2008).

Pro-Álcool's policies stimulated both production and demand: ethanol production grew rapidly, and sales of domestically-produced automobiles that ran exclusively on ethanol reached 85% of total automobile sales in Brazil by 1985. Unfortunately, in that year oil prices dropped and in 1986, the newly democratic government removed ethanol subsidies, which reduced ethanol producers' profit margins. By 1989, consumers faced ethanol shortages at the pump, and sales of ethanol-only cars plummeted to only 11.4% of total car sales in 1990.

Over the course of the 1980s and 1990s, the Brazilian government deregulated the ethanol sector, and in 2001 state market controls were completely removed (IPEA 26 May 2010, 4). Nevertheless, during that time the government continued to require that all gasoline contain 20% ethanol, thus maintaining a market for the industry (Levi et al. 2010, 77). Demand and production began to rise again in 2003, with the advent of flex-fuel cars, whose engines can run on any combination of petroleum gasoline and ethanol (IPEA 26 May 2010, 3-4). By 2007, over 70% of new cars purchased in Brazil were flex-fuel cars, and ethanol-only cars have virtually disappeared from the market (Hofstrand 2008). Almost all

[32] At the time, Brazil imported over 80% of its crude petroleum, and the cost was causing economic growth to slow (Hofstrand 2008).

gas stations in Brazil now sell both petroleum-based gasoline and ethanol, and demand for flex-fuel cars continues to grow, while demand for gas- or ethanol-only cars is declining in Brazil: from 2004 to 2008, sales of flex-fuel cars rose from 328,380 to 23.3 million, while sales of gas-only cars fell from over 1 million to 217,000 (IPEA 26 May 2010, 5). Since the advent of flex-fuel cars, the ethanol industry has grown, and there are now 434 ethanol distilleries in operation in Brazil (IPEA 26 May 2010, 14).

As countries around the world have become concerned about global warming and instability in the oil-producing countries of the Middle East, international demand for ethanol has grown. Although the U.S. has a domestic corn-based ethanol industry, and imposes tariffs on Brazilian ethanol, it imported 453 million gallons of Brazilian ethanol in 2006, and 185 million gallons in 2007 (out of total U.S. ethanol imports of 731 and 439 million gallons, respectively, in 2006 and 2007) (Hofstrand 2008). In fact, the United States is Brazil's largest ethanol export market, accounting for 47% of exports in the 2006/7 harvest year, while the next largest market, Holland, accounted for only 11% (Hofstrand 2008).[33] Production for the domestic market is also rising, from just over 5 billion gallons in 2006 to just under 6 billion gallons in 2007.[34]

Concurrent with the rise in demand for ethanol, technological changes have increased the sector's productivity, as shown in Table 2 below:

[33] In 2009 and 2010, the trade relationship was reversed: Brazil imported ethanol from the U.S. because adverse weather conditions reduced the size of Brazil's sugar cane crop in those years (Crooks and Meyer 2011).
[34] The potential to use ethanol as a base for a new generation of biofuels known as "drop-in fuels" is also driving partnerships between Brazilian ethanol firms and international investors, including oil companies and other investors. For instance, Brazil's third-largest sugar producer, Cosan, has established a joint venture with Anglo-Dutch oil company Shell and the California-based alternative-fuels firm Codexis to explore the possibility of using sugar cane as a base for drop-in fuel, a hydrocarbon derived from plants that may someday replace fossil fuel-based hydrocarbons (*Economist* 28 October 2010).

Period		Productivity		
		Agricultural (tons/hectare)	Industrial (liters/ton)	Agro-industrial (liters/hectare)
1977-1978	Initial phase of Pro-Álcool: Low efficiency in the industrial process and in agricultural production	65	70	4,550
1978-1988	Consolidation of Pro-Álcool: Agricultural and Industrial Productivity Increase Significantly	75	76	5,700
1989-2004	Process of production operates with best available technology	85	80	6,800
2005-2010*	First Stage of Process Optimization	81	86.2	6,900
2010-2015*	Second Stage of Process Optimization	83	87.7	7,020
2015-2020*	Third Stage of Process Optimization	84	89.5	7,160

*Estimates.

Table 2: Evolution of sugar cane and ethanol productivity in Brazil. Adapted from IPEA (26 May 2010, 13).

These productivity increases have been made possible in part by the growing profitability of the industry, but also by new government investments in ethanol: the Brazilian state currently provides price guarantees to maintain ethanol's competitiveness in the domestic market, and requires minimal blending of 25% with petroleum-based gasoline. The state also finances the ethanol sector through BNDES – indeed, the sugar-alcohol sector is one of the largest borrowers from BNDES in Brazil. The bank provided R$6 billion in loans to the sector in 2009 (up from R$1.97 billion in 2006). Meanwhile, Petrobrás Biocombustíveis – a subsidiary of the national oil company, Petrobrás – seeks to control 15% of the ethanol market, and to invest R$500 million in the sector through 2013. Finally, Brazil's Decennial Energy Expansion Plan estimates that by 2017 R$147 billion will be invested in biomass energy from sugar cane bagasse and *capim elefante* (IPEA 26 May 2010, 16).[35] In terms of socio-economic development, UNICA (the Brazilian National Sugar Cane Industrial Association) estimates that the sugar cane and ethanol sector generates from 588,000 to

[35] *Capim elefante* is a type of grass used in biomass, introduced into Brazil from Africa in the 1920s (Carbonovo do Brasil 2009).

1.4 million jobs, accounting for seasonal variation (though salaries are on average lower than in the petroleum sector) (*ibid.*, 16-17).[36]

State support is related not only to growing demands for renewable fuel sources, but also to the Brazilian government's continued concern for energy independence and its growing role as a leader in Latin American energy integration efforts (IPEA 25 May 2010, 7; Ubiraci and Narciso 2009). The Brazilian government has also actively advocated for global standards for ethanol and biofuels in international forums, to ensure continued international market space for ethanol and the country's small, but growing, biodiesel industry (IPEA 26 May 2010, 7; Levi et al. 2010, 79).

[36] Optimism is not universal: Hira and Oliveira (2009, 2455) counter that the mechanization of sugar cane harvesting to reduce emissions from burning the sugar cane at harvest time has "…created massive unemployment among labourers in the industry of up to 100,000 of a total of 1.2 million workers…."

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