



## Supplementary Materials for

### **Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains**

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## **Supplementary Text**

### Estimating Emissions Reductions from the Deceleration of Deforestation

Avoided emissions (2006-2013) are calculated based on each Brazilian Amazon state's reduction in deforestation compared to that state's 1996-2005 annual average (26). The avoided deforested area is converted to CO<sub>2</sub> emissions using the state's average forest carbon content per hectare, derived by applying a zonal statistics function to a recent map of aboveground live woody biomass of the forested portion of each state (42). The average carbon content per hectare is reduced by an emission factor (8 tC/ha) to account for aboveground carbon maintained by pasture or cropland, as used in the Brazil's national Greenhouse Gas (GHG) Inventory (43).

### Policy and Supply Chain Interventions to Slow Deforestation

#### *Negative Incentives and Law Enforcement*

Several major changes took place in the Brazilian Amazon that may have influenced land user and land grabber decisions to clear forest. First is the increase in government capacity to enforce its own policies, especially the Forest Code. This increase in enforcement capacity began with the "Detection of Deforestation in Real Time" (DETER) program that linked the detection of deforestation events by government agencies using data from the MODIS satellite sensor with policing activities of the federal (IBAMA) and state environmental enforcement agencies (Table S2). This important improvement in enforcement was still precariously dependent on catching infractors in the act of clearing forests through expensive field operations. Enforcement capacity increased further through the "Plan for the Protection and Control of Deforestation in the Amazon" (PPCDAm) of 2004 (Table S2), which elevated the issue of Amazon deforestation to the President's chief of staff, who was responsible for coordinating the activities of 15 ministries. For the first time, the Brazilian Government was able to orchestrate sophisticated sting operations across many agencies, including the Federal Police, the Army, and the Public Prosecutors office (the Ministerio Publico) to break up illegal deforestation, logging, and resource grabbing schemes. From 2004 to 2011, nearly 650 sting operations were carried out, resulting in the imprisonment of more than 600 government officials and non-government individuals, and the issuing of BRL7.2 billion in fines (44) (Table S2). Most of these fines were never paid.

This inter-ministerial framework of the PPCDAm permitted the creation of an innovative new government program launched in 2008 called the Critical Counties ("Municipios Criticos") program (Table S2). It suspended the access of farmers in the 36 counties with the highest deforestation rates to federal agricultural credit and markets through a novel agreement between the Ministry of Environment and the Central Bank (Table S2, Figure 2). The decision to implement this strategy at the scale of counties instead of individual farms was intended to foster collective action among farmers, livestock producers, agrarian reform settlements and county governments to reduce deforestation and regain access to credit and markets. Eleven counties came off the "black list" during the first five years following the launch of the program, with steep reductions in deforestation (16) (Figure

S5). The decree that created the Critical Counties Program also linked access to credit to the existing list of embargoed properties by prohibiting government agencies to provide loans to properties on the list (Table S2). The State of Pará formalized a response to the Critical Counties program through its own Green Counties (“Municípios Verdes”) program that supported counties seeking to come off the federal black list (Table S2, Figure S5). Green Counties are defined as those with less than 40 km<sup>2</sup> of deforestation per year and with at least 80% of rural properties registered in the Rural Environmental Registry (CAR) (Table S2).

Parallel to these advances in the government’s capacity to enforce its own laws and slow deforestation, non-governmental interventions in Amazon deforestation were launched through an agreement between the Brazilian soy sector, buyers of Amazon soy, and environmental non-governmental organizations to end the purchase of soy grown on Amazon land that had been deforested after July 26, 2006. This “Soy Moratorium” grew out of a Greenpeace campaign that targeted McDonald’s restaurants in Europe that were selling chicken raised on soy from the Brazilian Amazon and Cargill, the source of the soy, and was favored by soy conglomerate Grupo Amaggi’s prior successful experience monitoring the farms that supplied it (Figure 2, Table S2). The agreement was enforced with great precision through a satellite and air-borne monitoring system that determined the date of clearing for every significant patch of soybeans in the Amazon forest biome from July 2006 onward (13). As of 2013, only 1% of the area of soybean production in the Amazon region has been out of compliance with the Soy Moratorium (Figure S6).

In a similar process, Brazil’s voluntary moratorium on “unsustainable beef”, called the “Cattle Agreement,” was also catalyzed by a Greenpeace campaign. Greenpeace’s 2009 report, “Slaughtering the Amazon,” linked beef industry giant Bertin to deforestation and slave labor and led to demands for greater transparency and traceability of cattle and their byproducts from Brazilian supermarkets and major corporations, including Nike, Adidas, and Wal-Mart (45). Building on the public outcry for greater transparency, the Brazilian government’s Public Prosecutor office took legal action against Bertin, establishing a precedent for government action and further motivating the beef industry to develop rigorous methods for monitoring and tracing the cattle supply chain (46). The two largest beef processors in the Amazon region—JBS (which has now acquired Bertin) and Marfrig—have now established sophisticated systems for tracking the deforestation activities of their suppliers, although full traceability has been challenging due to the complexity of their production chains, as cattle frequently move from calving operations to fattening operations to finishing operations before reaching the slaughterhouse. Since 2009 the Cattle Agreement has gained momentum with collaboration between the Brazilian government, the cattle industry, and the private sector. A major landmark in its progress was the 2013 agreement between Brazil’s Public Prosecutor’s office and the Brazilian Association of Supermarkets (ABRAS), in which major supermarket chains including Wal-Mart Brasil, Pão de Açúcar, and Carrefour pledged to sell only certified sustainable beef (47).

These governmental and non-governmental interventions in Amazon deforestation are currently in a state of transition. The link between county- and property-level deforestation

and access to public agricultural credit is under revision and could become embedded in Brazil's national agricultural credit policy, or, alternatively, it could be weakened. Meanwhile, the Soy Moratorium has been weakened by a growing list of soy farmers who are in compliance with the Forest Code but blocked from markets because they cleared forests (legally) after the cut-off date (48). The Moratorium is scheduled to end before 2015. Similarly, beef processors such as JBS are concerned that they are tracking deforestation on a large number of farms (60,000 in the Amazon region), but are still unable to demonstrate that their entire supply chain is free of deforesters.

The new Brazilian Forest Code (NFC), approved in 2012, has features that could help integrate these governmental and voluntary interventions in Amazon deforestation dynamics. The changes to the law were motivated by the growing capacity of the government to enforce the FC, which ended a period of impunity for many landholders at the same time that market demands for legal compliance continued to grow. The historical level of non-compliance with the Forest Code was very high, and increased after 1996 when the federal government raised the required set-aside from 50 to 80% for properties in the Amazon following the record high deforestation of 1995. In Mato Grosso, the change imposed opportunity costs of more than \$2B on landholders and pushed non-compliance up to 83 percent of properties including 59 percent that were in compliance before the changes were signed into law (10). After this change, deforestation declined for the subsequent two years. This decline has been attributed to the Plano Real, Brazil's economic program that ended exorbitant inflation—a strong driver of land speculation and deforestation (49) (Figure S1).

After an intense debate between the *ruralistas* (a powerful arm of the agricultural lobby) and environmental groups, the New Forest Code was signed into law in 2012 (Table S2). Although many analyses of the Forest Code evaluate the scenario of full compliance with this regulation (17), there is little evidence that broad compliance could have been achieved in the Amazon given there were virtually no provisions implemented to help landholders comply with this radical change in the law in 1995 (10). In the agricultural frontier of Mato Grosso's "transition forests", where much of the region's deforestation was concentrated, the legal reserve requirement rose from 50 to 80% through the federal government, was revised back down to 50% by the state government, then overridden by the federal government once again in 2005 (10). There is no evidence that the Forest Code played an inhibitory effect on deforestation in Mato Grosso. In this regard, we interpret the amnesty for all landholders who had cleared forests illegally prior to 2008 that was extended to property-holders through the New Forest Code (NFC) as an important and necessary change that enabled the soy and beef sectors to move towards legal compliance and overcome the mismanagement by government agencies of a changing legal forest reserve requirement. The NFC also established a minimum property size below which the NFC no longer applied, mandated a CAR program in every state, and introduced new measures for creating positive incentives for legal compliance (10, 17). The requirement that every state establish a CAR program is particularly important as it requires individual properties to report their level of compliance with the NFC legal reserve and permanent preservation area requirements and their plan for achieving full compliance with the NFC.

In return, landholders are granted a two-year grace period during which they can finalize their plans for achieving compliance with the NFC.

The CAR sidesteps the ongoing challenges to full land titling that plague large areas of the Amazon region, as it requires landholders to self-report their property boundaries and focuses instead upon land occupation and georeferenced property boundary databases that facilitate satellite-based monitoring. So far the CAR has been a critical tool for achieving transparency called for in the Cattle Agreement. Prior to 2009 there were just over 400,000 ha registered in the CAR system in the state of Pará, one of Brazil's biggest cattle producing states; in 2010 this number had jumped to over 12.5 million ha (50) (Table S2). The soy sector has also proposed that the Soy Moratorium be replaced by an agreement that focuses on eliminating illegal deforestation from the Amazon soy supply chain, with the CAR providing a powerful tool for determining legality. New measures have also been introduced to encourage participation in the CAR, such as making it a prerequisite for accessing public agricultural credit (Figure S1, Table S2).

#### *Positive Incentives*

The creation of effective mechanisms for rewarding landholders who forgo forest clearing has made less progress than have the negative incentive programs. The main mechanism for establishing positive incentives within Brazilian public policy is REDD (Reductions in Emissions from Deforestation and forest Degradation), an initiative that began in the United Nations Framework Convention on Climate Change (UNFCCC). While REDD has been under negotiation within the UNFCCC, the governments of Acre, Mato Grosso, and Pará states announced ambitious targets in 2009 for reducing state-wide deforestation by 80% and more by 2020. These announcements were motivated by an MOU with California Governor Arnold Schwarzenegger signed in late 2008 that established a collaboration among states and provinces in the context of the REDD international offset provision of California's new "Global Warming Solutions Act" (AB32) (17). The state-level commitments were aligned with and contributed to the Brazilian National Climate Change Policy, announced at the 2009 UN Climate Change Conference in Copenhagen, that establishes national emissions reduction targets of 36 to 39% by 2020 and committed Brazil to reducing Amazon deforestation by 80% below its ten year average ending in 2005 by 2020 (49) (Figure S1, Table S2).

The states were also motivated to establish state REDD programs when the Amazon Fund, a Brazilian government fund established in 2008, received a US \$1 billion performance-based pledge from the Norwegian Government in 2008 (Figure S1, Table S2). Norway's funds will flow as long as Brazil continues to lower its deforestation, and so far approximately half of that funding has been committed to projects on the ground. In the absence of a global finance mechanism for REDD, these bilateral financial flows are the main source of positive incentives for declines in deforestation and associated greenhouse gas (GHG) emissions today, although other mechanisms could begin to operate in the coming years (17). In the last two years, the Amazon Fund has awarded grants to state

governments that have developed REDD legal frameworks and programs, such as Acre, Tocantins and Mato Grosso states, and has awarded other grants designed to provide incentives to small-scale farmers for investing in more intensive and profitable crop and livestock systems (52).

The REDD-related programs designed to support farm and livestock sector transitions to low-deforestation production systems are new or under development, including the national “Low Carbon Agriculture” (Agricultura de Baixo Carbono—ABC) program and line of credit of the National Climate Change Policy, and the sector-wide livestock and smallholder programs stipulated in the state REDD laws of Acre and Mato Grosso. Launched in 2011, the ABC loan program, which makes approximately \$1.5 billion available each year at 5.5% interest for investments in forest restoration and pasture improvement, has had little uptake in the Amazon region, perhaps because of the high level of technical expertise required to access the loans (53). Acre and Mato Grosso’s beef and smallholder programs are not yet completed (51).

Another potential source of positive incentives for farmers who forgo deforestation is price premiums for certification initiatives of agricultural or forest commodities. International standards have now been established for soy, palm oil, sugar cane and timber production (41, 46, 17). The rise in demand for certified production has not kept pace with supply, however, and price premiums have been small. The international standards arising from multi-stakeholder roundtables, such as the Roundtable for Responsible Soy (RTRS), the Roundtable for Sustainable Palm Oil (RSPO) and Bonsucro (for sugarcane sugar and ethanol) were developed within the theory of market transformation, which assumes that price premiums will not be substantial. Within this theory, the goal is to get a sufficiently large share of global demand behind each standard to achieve market transformation, in which only certified producers are allowed to sell into global commodity markets and the costs associated with certified production are incorporated into the commodity’s price (46, 17). Property-level certification under RTRS has begun, and the first Brazilian palm oil companies have achieved certification under the RSPO, which imposes restrictions on deforestation (Figure 3). These roundtable standards are only 3 to 6 years old, however, and have a relatively small share of global (1, 3 and 15% respectively) and Amazon production (41). Their *direct* impact on Amazon deforestation dynamics is therefore small. The roundtables may have had an effect that is difficult to quantify, however, which is the engagement of retailers, processors, traders, farmers, banks and NGOs in the discussion of social and environmental performance standards and their implementation, and a deepening perception of reputational risk for those associated with Amazon deforestation.

Another more informal approach to the delivery of benefits to sustainable farmers has been developed by voluntary farmer support programs, such as the one led by Aliança da Terra, a non-governmental organization dedicated to supporting farmers and ranchers to achieve new sustainability standards (40). Farms join the Registry of Socio-Environmental Responsibility (Cadastro de Compromisso Socio-ambiental—CCS) (Figure 3D) following a social and environmental diagnosis of the property that is the basis for a voluntary set of commitments that are signed by the landholder (40). CCS members have been supported to certify their properties under roundtable standards and are recognized through annual

awards to top producers. A socioenvironmental quality seal is under development. More than 100 members were excluded from the CCS for not fulfilling their commitments or for illegally clearing forests on their land.

#### *Access to Forestland*

There are two major controls on access to unclaimed, loosely claimed, or undesignated forestlands and land speculation-driven forest clearing: formal designation as protected areas (parks and biological reserves, sustainable development reserves and indigenous territories) or passive protection associated with high costs of access. Deforestation and the establishment of cattle pasture is used by land speculators as a way to demonstrate productive use of the land, which is a pre-requisite for obtaining legal control of the property. Regional planning processes organized in response to plans for paving highways (Figure 3A) generated strong local support for the rapid establishment of protected areas to contain land speculation. Environment Minister Marina Silva and Brazil's program for expanding the protected area network (ARPA) provided further political support under President Lula and a policy mandate for taking large areas of forestland out of the regional land market, especially in Pará State (14) (Table S2). From 2004 through 2012, protected areas grew 68% to encompass 47% of the entire Brazilian Amazon region, with many of these areas created in active agricultural frontiers (Figure 1A, 2, 3C). Even if poorly enforced, such land designations inhibit forest clearing (12, 28) perhaps by lowering the likelihood of ever achieving a title for the land, discouraging land speculation.

During the last three decades, Amazon deforestation has taken place where the costs of access are low, near paved highways; as of 1998, three fourths of all clearing had taken place within 50 km of a paved highway (54, 55). The cost of accessing forestland declined from 2000 through 2013 in the eastern and southern Amazon region through the construction or paving of highways. It appears that interventions in anticipation of highway paving helped to mitigate deforestation along these corridors through "frontier governance" (56) (Figure 2). The BR163 highway (Santarém-Cuiabá) was partially paved in the State of Pará. A wave of land speculation-driven deforestation began when plans to pave this highway were announced (Figure 3A, Table S2) and was suppressed when the federal government announced a 14 million-hectare Forest District ("Distrito Florestal") and other federal protected areas within the corridor (Figure 3C) (14). Had the BR319 been paved (Porto Velho-Manaus), a large pulse of clearing was predicted (33). Here, too, the State Government of Amazonas established new protected areas in anticipation of this effect. Paving of the Inter-Oceanic Highway was completed in 2012, providing all-weather access through Acre State across the Andes to the Pacific. Paving of the BR364 was also completed in Acre, linking Rio Branco in the east to Cruzeiro do Sul in the west. In anticipation of these road-paving investments, the government of Acre established a state-wide land-use zoning plan and other measures for containing forest clearing along highways (Table S2).

#### *Demand for Cleared Land*

The motive to clear forests is also influenced by the potential profits of production on cleared land, which are themselves affected by exchange rates, the prices of commodities and the prices of inputs needed to grow them. The demand for deforestation changes in

response to variations in the profitability of soy and cattle production—the two main land-uses associated with Amazon deforestation—and the availability of already-cleared land. The area of soybeans in the Brazilian Amazon peaked in 2005, declined when prices and profitability dropped, and resumed growth in 2008 (Figure S2, Figure S4). Cattle pasture area climbed through 2006 when high beef prices stimulated an increase in the sale and slaughter of steers, depleting the regional herd and reducing pasture area in 2007 (Figure S2, Figure S4).

### Why did deforestation decline?

#### *The role of monitoring and credit policies*

Some econometric studies have attempted to quantify the individual contributions of policies to the reduction in deforestation. Two studies (19, 57) found that command and control policies (Deter and PPCDAm programs) were effective in curbing deforestation, with forest saving ranging from 6,000 and 12,000 km<sup>2</sup> y<sup>-1</sup> during the 2000s. Another study (58) found that the rural credit restrictions imposed by the Critical County program suppressed deforestation by 2,700 km<sup>2</sup> from 2009 through 2011. These results are not comparable, however, since each study covers a different period and adopted different parameter identification strategies within their econometric model. The area of forest spared by each policy cannot be determined since the studies did not control for interactions among Critical Counties, PPCDAm and related resolutions and none of the studies accounted for supply chain initiatives that were underway at the same time.

#### *The role of the Soy Moratorium and Cattle Agreement*

Other lines of evidence allow us to examine the role of the moratoria. The Soy Moratorium stopped soy expansion into newly cleared land. Less than 1% of the steep expansion of soy production after 2008 (Figure 1B, Figure S4) occurred on areas cleared after July 2006 (Figure S6). This achievement did not, by itself, necessarily slow deforestation, since abundant cleared and grazing land was available for expansion in 2004 (Figure 1B, S4). Analysis of indirect land use change driven by soy expansion, pushing other land uses into Amazon forest, was found to be significant for the 2003-2008 period (56), but indirect deforestation is unlikely thereafter because of the decline in the cattle herd and pasture area. The Cattle Agreement was implemented by two beef processors, JBS and Marfrig, who control about 30% of Amazon beef production. Presumably some of the beef producing areas where other companies were operating did not receive the same zero deforestation signal from the slaughterhouses (46) (Table S2).

### Other environmental dimensions of Amazon development: drought, forest fire, fisheries, and rivers.

Deforestation, forest fire, overfishing, and damming of streams and rivers are the major direct forms of ecosystem degradation in the Amazon today. Evidence is growing of the potential for regional forest degradation when severe drought episodes that exceed critical thresholds of tree mortality from water deficits and fire affect landscapes where shifting cultivation and extensive pasture management provide ignition sources that can escape

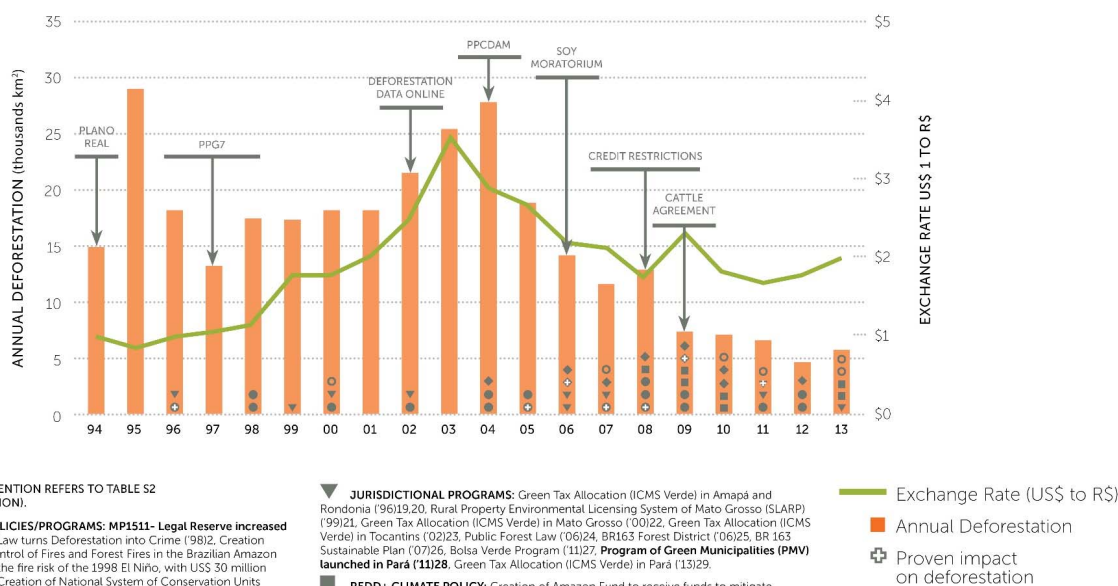


into neighboring forests (55, 4). A large fraction of canopy trees can die during these episodes, opening up the forests to invasion by flammable grasses (23). A pathway to zero net Amazon deforestation by 2020 would help secure the role of forests in maintaining the regional rainfall system (4, 60) and reduce the incidence of fire ignition points and associated forest fire (61, 62) while reducing sedimentation of streams and rivers (63).

The Amazon fishery currently produces 425,000 Mg y<sup>-1</sup> of fish, only half of the sustainable harvest that could be achieved through an effective regional management system (64, 65). Community-based fisheries management systems developed in the middle and lower Amazon regions could, with the support of government policies and supply chain linkages, be expanded along the main channel of the Amazon, bringing much of the Amazon floodplain under sustainable management, and supporting fishing communities while restricting fish harvests to sustainable levels (66). Large-bodied fish and river mammals are overharvested today (67). Natural harvests supplemented with aquaculture featuring native species could provide high quality protein to the region's 35 million inhabitants and an important source of export revenue.

Brazil, Colombia, Ecuador, Peru, and Venezuela rely on hydropower for 50 to 80 % of their electrical grid energy (68). Hydropower plants pose risks to rivers by trapping sediments and altering flow, lowering the amplitude of the flood pulses that provide essential sediments and nutrients to floodplains (69), lowering fisheries production, and interrupting both fish migrations and riverine communities (69, 70). Power generation of the Belo Monte plant, which will be the world's third largest, is perilously seasonal and dependent upon forests. It could decline 40% under a scenario of business as usual deforestation because of deforestation-driven rainfall inhibition (71). Six other major tributaries have similar forest dependencies (72). An integrated transportation strategy is needed to maximize economic benefits while minimizing environmental and social costs.

## DEFORESTATION, CURRENCY EXCHANGE RATE



NUMBER FOLLOWING EACH INTERVENTION REFERS TO TABLE S2 (SUPPLEMENTAL ONLINE INFORMATION).

● **COMMAND AND CONTROL POLICIES/PROGRAMS: MP1511- Legal Reserve increased to 80% (1961).** Environmental Crimes Law turns Deforestation into Crime (1982). Creation of the Program for Prevention and Control of Fires and Forest Fires in the Brazilian Amazon (PROARCO) - This was a response to the fire risk of the 1998 El Niño, with US\$ 30 million loan from the World Bank (98)3 (54). Creation of National System of Conservation Units (SNUC) (00)4. Commitment to increase protected area network in the Amazon (ARPA) (02)5. Program for the Prevention and Control of Deforestation in the Brazilian Amazon (PPCDAM) (04)6. Monthly Monitoring System (DETER) (04)7. **Enforcement Campaign from the Federal Police - Large Operations to detain deforestation (05)8.** BR 163 Designation of areas under provisional administrative limitation and later the creation of protected areas (05)9. **Decree 6321 - Registry and Embargo on deforested areas (07)10.** **Critical County Program and Credit Restriction (08)11.** Credit Restriction to illegally deforested areas - BACEN Res. 3.545 (08)12. Regularizing Rural Properties in Pará and Mato Grosso. Environmental Registry of Rural Properties (08)13. Beef Sector legally binding commitment not to buy meat from illegally deforested areas Terms of Adjustment of Conduct (TACs) (09)14. Regularizing rural properties at the National level - More Environment Program Decree 7029 (09)15. Possible Decentralization of Environmental issues, including forestry licensing and management (Complementary Law n. 410) (11)16. New Brazilian Forest Code approved (NFC) and requirement of environmental registry for rural properties (CAR) (12)17. Green Settlements Programs created by Incra (12)18.

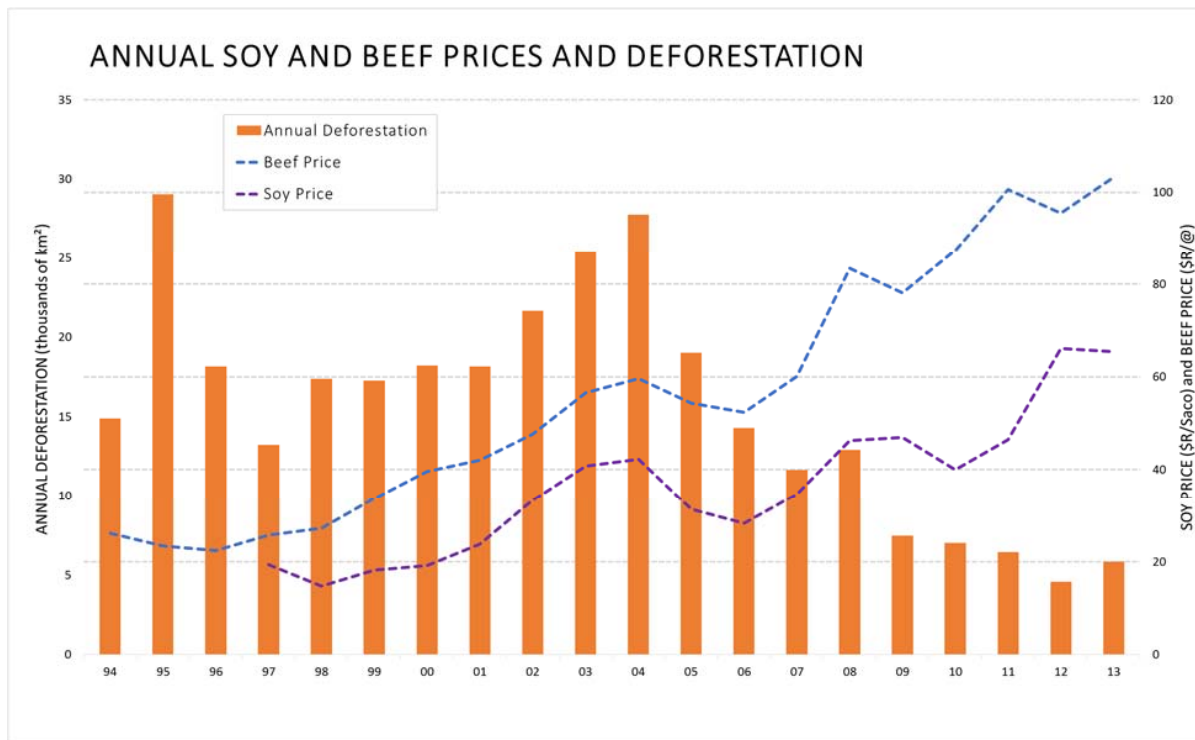
▼ **JURISDICTIONAL PROGRAMS:** Green Tax Allocation (ICMS Verde) in Amapá and Rondonia (96)19.20. Rural Property Environmental Licensing System of Mato Grosso (SLARP) (99)21. Green Tax Allocation (ICMS Verde) in Mato Grosso (00)22. Green Tax Allocation (ICMS Verde) in Tocantins (02)23. Public Forest Law (06)24. BR163 Forest District (06)25. BR 163 Sustainable Plan (07)26. Bolsa Verde Program (11)27. **Program of Green Municipalities (PMV) launched in Pará (11)28.** Green Tax Allocation (ICMS Verde) in Pará (13)29.

■ **REDD+ CLIMATE POLICY:** Creation of Amazon Fund to receive funds to mitigate deforestation (08)30. National Climate Change Plan (09)31. Subnational Efforts - creation of Governors Climate and Forest Task Force (GCF) (09)32. Acre REDD+ Strategy - Law for Incentives of Environmental Services (SISA) (10)33. Low Carbon Agricultural Program (loans) (ABC) (10)34. Mato Grosso REDD+ Strategy - Law (13)35. Proposed National Strategy for REDD+ (13)36.

◆ **SUSTAINABLE SUPPLY CHAIN INITIATIVES:** Roundtable on Sustainable Palm Oil (RSPO) launched (04)37. **Soy Moratorium (06)38.** Roundtable on Responsible Soy launched (RTRS) (06)39. RSPO P6C (07)40. Bonsucro launched (08)41. **Cattle Agreements (09)42.** Brazilian Working Group for Sustainable Beef (GTPS) (09)43. Consumer Goods Forum (CGF) commitment to zero net deforestation (10)44. RTRS P6C (10)45. Creation of Global Roundtable on Sustainable Beef (GRSB) (12)46.

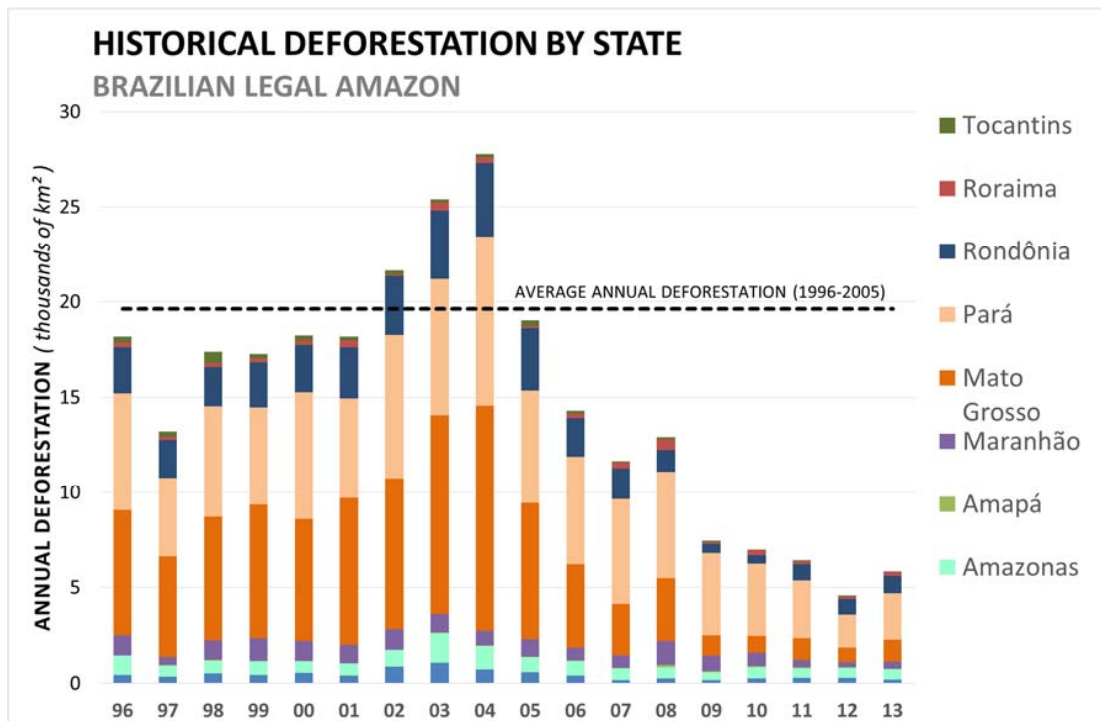
○ **INFRASTRUCTURE:** Plan Advancing Brazil (00-03)47. Plan of Accelerated Growth - Large infrastructure investments in the Amazon Biome (07-10)48. Belo Monte Dam (10)49. Santo Antonio and Jirau Dams (11 and 13)50. Tapajós Dam (13)51.

**Fig. S1** Annual deforestation, Brazilian Real exchange rate, and the principal policy and supply chain interventions that may have influenced deforestation rates. Those interventions with evidence of impact on deforestation are designated with a cross in figure and bolded in legend. Annual deforestation from INPE 2013 (26), sources for interventions are found in Table S2.



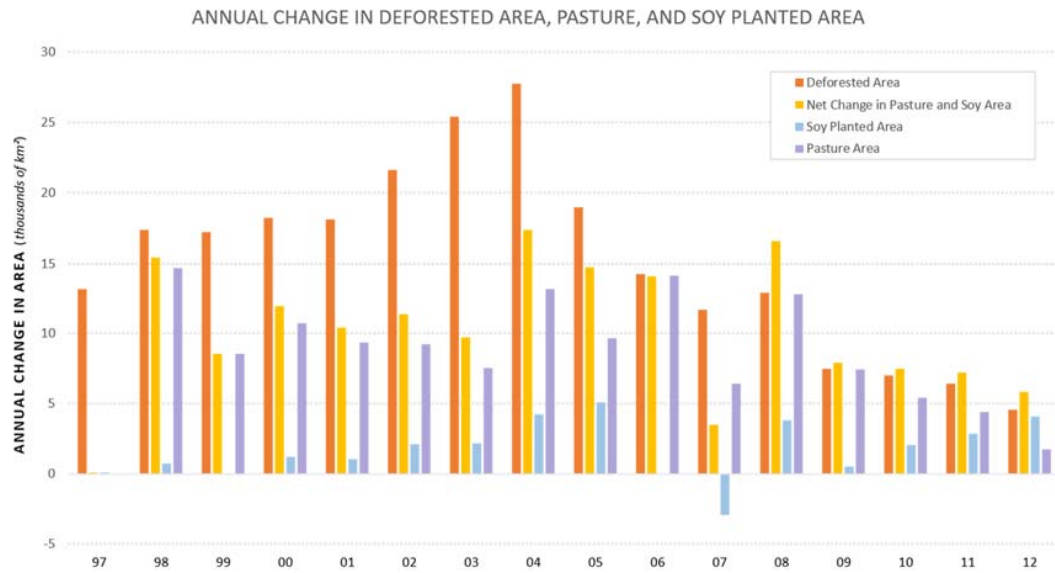
**Fig. S2**

A peak in the price of soy and beef and high deforestation is observed in 2004 in the final years of the Agro-Industrial Expansion phase, followed by a decrease in prices in 2006 as deforestation begins to fall. Soy prices are the annual average for the state of Paraná, and beef prices are the annual average for the state of São Paulo from CEPEA 2014 (73). Annual deforestation from INPE 2013 (26).



**Fig. S3.**

Annual deforestation by state in the Brazilian Amazon (1996-2013), relative to the average annual deforestation rate between 1996 and 2005. Annual deforestation from INPE 2013 (26).



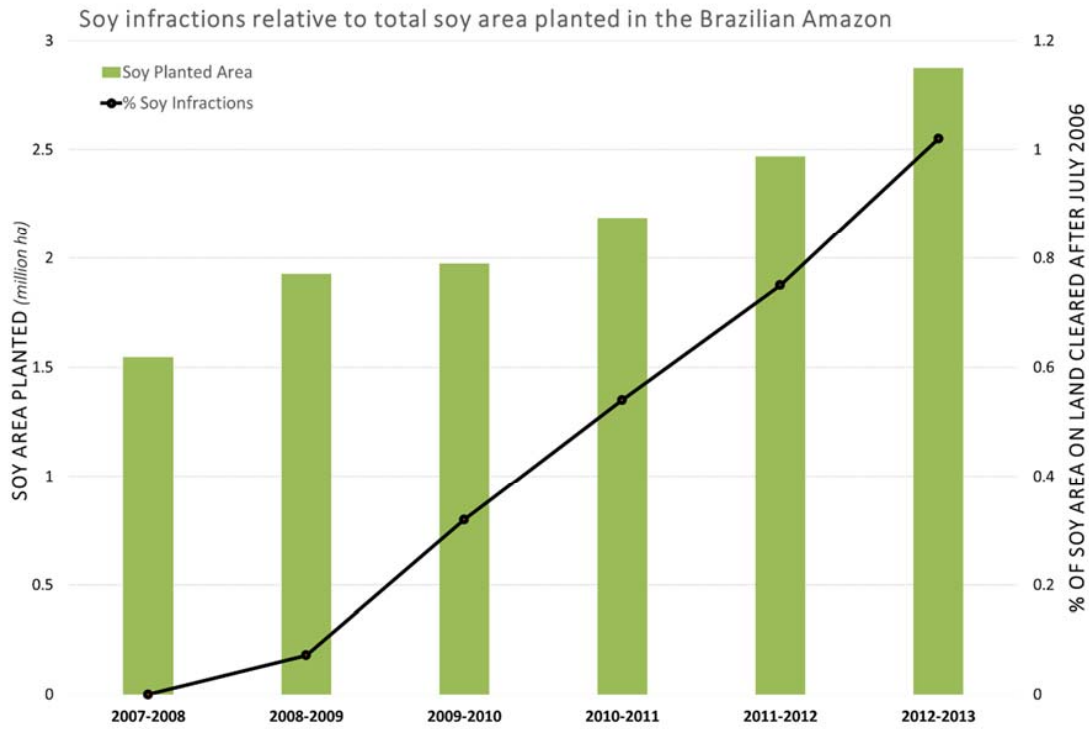
**Fig. S4**

Annual change in area deforested, pasture area, and soy planted area in the Brazilian Amazon between 1997 and 2012. Net change in pasture and soy area is also indicated. Annual deforestation from INPE 2013 (26). Pasture area from Nassar et al. 2014 (9). Soy planted area from IBGE PAM 2013 (31).



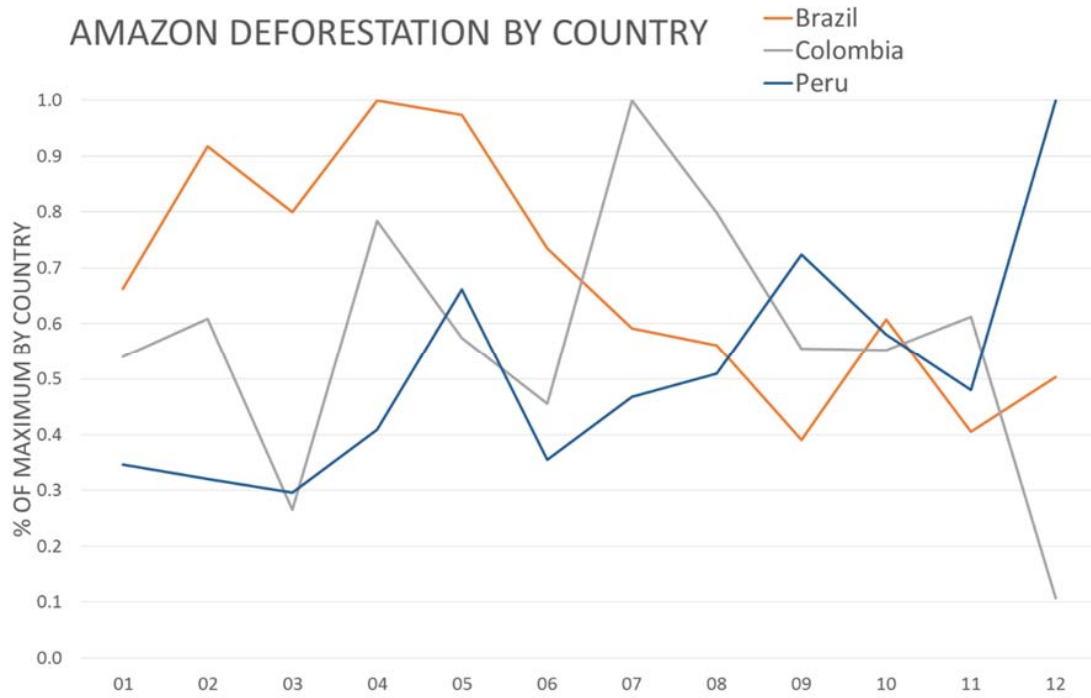
**Fig. S5**

Annual deforestation of six counties that have been cleared from the Critical Counties list due to the decline in deforestation. Counties list is from MMA 2014 (16) Annual deforestation is from INPE 2013 (26).



**Fig. S6**

Implementation of the Soy Moratorium. Total area of soy production and percentage of that area planted on land deforested after the Moratorium cut-off date (July 2006). Production data is from IBGE PAM (31). Soy planted on recently deforested area is from ABIOVE Moratória da Soja (74).



**Fig. S7**

Annual deforestation of Brazil, Colombia, and Peru adjusted to percent of each country's maximum from 2001 to 2012. Annual deforestation data from Hansen *et al.* 2013 (32).



**Table S1.**

Review of studies examining the impact of a series of processes or initiatives on hypothetical landholder (or landgrabber) decisions to clear forest in the Brazilian Amazon from 2005 onward. Processes are described in more detail in Table S2. In each case, “X” indicates that the process was studied with respect to a specific disincentive and reference numbers denote the study that examined the relationship between the process and the decision.

<i>Disincentive for landholder/-grabber to clear</i>	Process Influencing Behavior										
	Soy Moratorium	Beef Agreements	Certification	Land Registries	ABC Credit	REDD	Expansion of PA's	Critical Counties	PPCDAm & Forest Code	Transport Infrastructure	Global market
H1: Risk: Losing access to markets or credit	X (7, 60)	X (7)	X (46)					X (19, 57)	X (59)		
H2: Risk: Fines, imprisonment				X (11)					X (7, 10, 11, 19, 20, 57, 58 59, 75, 76)		
H3: Benefits: payments for ecosystem services (PES), price premiums, reduced administrative burden, better terms for finance, access to new credit lines			X (46)			X (75)		X (57, 19)	X (17, 75)		
H4: Land scarcity: protected areas							X (12)			X (12, 17, 19)	
H5: Land scarcity: poor access							X (12)			X (17)	
H6: Less need to clear: Lower profitability (crops, livestock)							X (12, 17, 20)			X (20)	X (1, 5, 7, 12, 17, 20)
H7: Less need to clear: Intensification; Degraded lands that can be converted											X (7)
H8: Less need to clear: Reduced cattle herd size											X (1, 9)

**Table S2.**

Summary of major public policies, government programs, and sustainable supply chain initiatives that have been implemented in the Brazilian Amazon and that may have influenced the decline in deforestation.

Command and Control Policies and Programs					
Item #	Policy	Description	Year	Comments	Link
1	MP 1.511 Increased Legal Forest Reserve requirement on Private Properties in the Amazon from 50% to 80% of holding	Modified Article 44 of Forest Code (Law N° 4.771 of 1965), restricting conversion of forested areas into agricultural areas within the Amazon Biome. Provisory Measure 1.511, July 18th, 1996 - reissued numerous times. Later included other provisions such as forest fire prevention and suppression techniques (e.g. in 2001, MP 2.166).	1996	MP 1.511 made the Forest Code more difficult to comply with; government agencies did little to help landholders; set stage for farm sector revolt against Forest Code.	<a href="#">MP N° 1.511, July 25th, 1996</a>
2	Environmental Crimes Law (Law N° 9.605 13/2/1998)	Through this law, deforestation became a criminal offence punishable with fines and potential arrests.	1998	All the operations of Federal Police (discussed below) have legal basis in this law	<a href="#">Law N° 9.605, Feb. 12th, 1998</a>
3	ProArco. Decree N° 2.661, Program for Prevention and Control of Fires and Forest Fires in the Brazilian Amazon	PROARCO aimed to prevent and control large-scale wildfires in the Brazilian Amazon; emergency response to severe drought of 1997/98. (Presidential Decree N° 2.661, July 8th, 1998).	1998		<a href="#">Decree N° 2.661, 1998</a>
4	National System of Conservation Units (SNUC)	Enables governments (federal, state, and local) and the private sector to create, deploy and manage of units of conservation (UCs), thus systematizing environmental preservation in Brazil. Categories of UCs are divided in strict protection and areas of sustainable use. (Law N° 9.985, July 18th, 2000).	2000	In effect	<a href="#">Law N° 9.985, July 18th, 2000.</a>

5	Amazon Region Protected Areas Program (ARPA)	Aims to expand and consolidate all of protected areas in the Amazon, to ensure the conservation of biodiversity in the region. Its implementation is in coordination with PPG7. (Decree N <sup>o</sup> 4.326, Aug. 8th, 2002).	2002	ARPA provided a national commitment and formal framework for expanding protected area network (Fig 3B); supported by World Bank and Moore Foundation.	<a href="#">ARPA</a>
6	Plan for Prevention and Control of Deforestation in the Brazilian Amazon (PPCDAm)	A federal program that uses satellite imaging to monitor deforestation on a state and municipal level. PPCD uses three sets of integrated actions: 1) territorial and tenure planning, 2) monitoring and environmental control, and 3) incentives for sustainable production activities.	2004	The first systematic approach to reducing deforestation that has since been replicated and reinforced at the state level.	<a href="#">Plano de Ação para prevenção e controle do desmatamento na Amazônia Legal (PPCDAm): 3ª fase (2012-2015)</a>
7	DETER	Early warning system to support surveillance and control of deforestation. DETER provides a monthly deforestation survey by INPE since May 2004, with MODIS satellite sensor Terra / Aqua Sensor WFI and the CBERS satellite spatial resolution of 250 m. The data are released to the public monthly/bimonthly (varies due to weather conditions/seasons).	2004	System has been used as basis of law enforcement operations in the Amazon.	<a href="#">INPE - DETER</a>
8	Federal Police Operations	In 2005 important operations such as Curupria, Rio Pardo, and Ouro Verde resulted in more than 160 arrests and the dismantling of large schemes associated with illegal deforestation.	2005	These operations sent an important signal to illegal operators in the Amazon that the era of impunity was coming to an end.	<a href="#">Federal Police Actions Combating Deforestation</a>

9	BR 163 ALAP (Area under Provisional Administrative Limitation) - Later BR 163 Protected Areas	Created a special zone of 8.2 million hectares along the BR163 highway in response to land rush and escalating deforestation. Suspended activities and projects that effectively or potentially caused environmental degradation, as well as exploitation and forest cutting and other forms of native vegetation. However, allowed the continuity of agricultural and other economic activities in progress as long as properly licensed according to the law. Later, in Feb. 2013 6.46 million ha were declared as protected areas.	2005/2006	This measure weakened the land speculation market exploding along this highway in anticipation of paving. It posed a barrier to the normal illegal processes of acquiring land through <i>grilagem</i> .	<a href="#">Decree (no number), February 13th, 2006</a>
10	Decree N° 6321 – Registry and embargo on deforested areas	This decree provides for actions related to the prevention, monitoring, and control of deforestation in the Amazon Biome, and amends and adds provisions to Decree N° 3.179 of Sept. 21st, 1999. This decree led the Ministry of Environment to create a list of priority municipalities for the prevention and control of deforestation. The first list was enacted by Ordinance N° 28, January 27th, 2008, and included 36 municipalities, responsible for 50% of deforestation in 2007. This list is also known as the "black list" mentioned below.	2007	This Decree and associated program resulted in rapid declines in deforestation in several counties that were on the list; econometric studies demonstrate effectiveness in lowering deforestation.	<a href="#">Decree N° 6.321, December 21st, 2007</a>
11	Critical County Program and Credit Restriction	Black list of municipalities that had failed to meet their deforestation requirements. Being on this list entailed reduced revenue and constraints in accessing credit. Decree N° 6.321/2007.	2008	See comment under 11.	<a href="#">The list is re-edited annually and can be found on the webpage of the Ministry of Environment</a>
12	Credit Restriction to illegally deforested areas - BACEN (Brazilian Central Bank) Res. N° 3.545	This resolution establishes the requirement of documentation proving environmental regulation compliance, and establishes other constraints for funding farms located within the Amazon Biome. (Res. N° 3.545, Feb 28th, 2008).	2008	Reinforced 10 and 11; see comment under 10.	<a href="#">Brazilian Central Bank, Resolution N° 3.545, February 28th, 2008</a>

13	Environmental Registry of Rural Properties in Pará and Mato Grosso states	Created with the purpose of verifying compliance with the Forest Code. It was established in Mato Grosso through the Law "Legal Mato Grosso" (Law N° 343 of December 24, 2008). However its implementation began only in 2009. In Pará the State Decree N° 1.148, of July 18th, 2008, made the CAR official.	2008	Precursor to CAR. These state level initiatives have roots in the PPG7 program. Innovative, practical approach to registering properties in state-level databases tied to plans for coming into compliance with environmental legislation.	<a href="#">Environmental Agency of Pará (SEMA Pará) - CAR</a> <a href="#">Environmental Agency of Mato Grosso (SEMA Mato Grosso) - CAR</a>
14	Public Prosecutor office action to force beef companies to stop buying beef on illegally cleared land; Terms of Adjustment of Conduct (TACs)	Public Prosecutor office filed lawsuits against large meat buyers for acquiring beef from areas under the embargo imposed by Decree N° 6.321. This resulted in large beef companies signing TACs committing to buy meat only from properties registered under CAR.	2009	This government measure was stimulated by the private sector response to Greenpeace report on illegal beef operations and demonstrates synergy between supply chain and government action	There is no weblink for this reference with a list of all TACs signed in Brazil. However, different TACs can be found through online research.
15	CAR. Rural Environmental Registry. "More Environment Program" (Decree N° 7.029, Dec. 10th, 2009) substituted by Decree N° 7.830 of October 17th, 2012	Establishes a federal program to support environmental regularization of rural properties. The main instrument utilized is the CAR, which requires that landholders submit digital maps of their holdings and plan for coming into full compliance with the law. Under the "More Environment Program", those that enroll under CAR can have some benefits such as the suspension of fines. The program was substituted by Decree 7.830 that regulated the System of Environmental Rural Registry (SICAR).	2009 and 2012	This program has had tremendous success, with more than half of all lands outside of protected areas registered in Mato Grosso and Pará. Provides basis for monitoring legal compliance. The first program (Decree 7.029/09) was substituted	<a href="#">CAR - Official webpage</a>

				(Decree 7.830/12)	
16	Decentralization of Environmental responsibilities, including forestry licensing and management (Complementary Law Nº 140, Dec. 8th, 2011)	This law allows the county to license and authorize deforestation and perform surveillance. The law allows the licensing authority to prosecute as well. However, cooperation arrangements must be made between the entitled parties of the SISNAMA until the municipalities are well prepared.	2011	The effect of this law can be disastrous if all responsibility for overseeing forest clearing is transferred to counties. On the other hand, it may motivate the county to assume this role. Much preparation will be needed by municipalities.	<a href="#">Complementary Law Nº 140, December 8th, 2011</a>
17	Brazilian Forest Code Modification (BFC)	The Brazilian Forest Code requires properties to maintain 80% of their land in forest if located within the Amazon Biome in addition to Permanent Preservation Areas. The new BFC granted amnesty to those who had deforested irregularly prior to 2008	1965 /2012	The new BFC was the result of a two-year, polarized debate. Amnesty provision clears the pathway to legal compliance, which is particularly important in supply chain initiatives.	<a href="#">Law Nº 12.727, Brasilia, October 17, 2012</a>
18	Green Settlements	Plan of Prevention, Combat and Alternatives to Illegal Settlements Deforestation in the Amazon, called Green Settlements Program. It is focused on reducing deforestation in the settlements associated with the Bolsa Verde Program, and the Program Brazil Without Poverty. The goal is to serve 980 settlement projects in 199 municipalities and reach over 190,000 households by 2019.	2012	Important initiative that brings agrarian farm settlements into the deforestation policy debate.	<a href="#">Inra Presents Green Settlement Program</a>
<b>Jurisdictional Programs</b>					
<b>Item #</b>	<b>Policy</b>	<b>Description</b>	<b>Year(s)</b>	<b>Effect</b>	<b>Link</b>

19	Green Tax Allocation (ICMS Verde) in Rondônia	Distribution of percentage of ICMS revenues to counties proportional to area designated as protected areas.	1996	Revoked in 2005.	<a href="#">Green Tax Allocation (ICMS) Rondônia</a>
20	Green Tax Allocation (ICMS Verde) in Amapá	The law establishes the allocation of 1.4% of the ICMS collected to compensate the existence of protected areas as a single factor index composition of Environmental Conservation - IC. The law is likely to be reformulated to take into account the System of Conservation Units (SNUC) of 2000 (Law 322, Dec. 22, 1996)	1996	Under reformulation	<a href="#">Green Tax Allocation (ICMS) Amapá - General information</a>
21	Environmental Licensing System on Rural Properties of Mato Grosso (known as MT-SLAPR)	This system was created in 1999, through the PPG7 program, and is designed to monitor and promote compliance with the Forest Code on private properties. It uses remote sensing and Geographic Information Systems (GIS) to identify properties and deforestation occurring on them. This system covers about 30% of the private properties within the state.	1999	In effect and is now implemented in concert with the National CAR system; the CAR is part of the SLAPR	More information on SLARP - Overview of Subnational Programs (REDD) as Part of the GCF Task Force
22	Green Tax Allocation (ICMS Ecológico) Mato Grosso	Allocates 5% of the tax to municipalities that contain both SNUC and Indigenous Territories	2000	In effect	<a href="#">Green Tax Allocation (ICMS) Mato Grosso</a>
23	Green Tax Allocation (ICMS Ecológico) Tocantins	Allocates 13% of the tax to municipalities based on five categories: 1) Municipal environmental policy 2) Units of Conservation/ Indigenous Territories, 3) Control of fires, 4) Soil conservation, and 5) Sanitation (Law N° 1.323, April 4th, 2002).	2002	In effect	<a href="#">Green Tax Allocation (ICMS) Tocantins</a>
24	Public Forest Law	Establishes the Brazilian forest concession system and the Brazilian Forest Service to implement it. This law established rules for granting private and community actors the right to manage public forests. Allows states to hold full power for issuing of forest management plans, an activity before under jurisdiction of IBAMA (Brazilian Institute of Environment and Renewable Natural Resources).	2006	In effect. However, only a small number of concessions have been issued in part because of competing land claims in public forests.	<a href="#">Law N° 11.284, March 2nd, 2006</a>
25	BR 163 Forest District	Establishes the geo-economic and social complex called Sustainable Forest District - DFS of BR-163 for the purpose of implementing public policies to stimulate sustainable forest production. (Presidential Decree of Feb. 13th, 2006).	2006	Contributed to weakening of land speculation along the BR163.	<a href="#">Decree (without number) of February 13th, 2006</a>

26	BR 163 Sustainable Plan	Establishes the Regional Sustainable Development Plan for the area under influence of the BR-163 that connects Cuiabá, Mato Grosso, to Santarém, Pará - (Decree Nº 6.290, December, 6th, 2007).	2007	In effect. But there are no specific commitments besides collaboration to reduce emissions from deforestation.	<a href="#">Decree Nº 6.290, December 6th, 2007</a>
27	Bolsa Verde	Provides small sums of money to families living in extreme poverty in priority areas for environmental protection to encourage conservation.	2011	In effect	<a href="#">Law Nº 12.512, October 14th, 2011</a>
28	Program of Green Municipalities (PMV) Launched in Pará	In an effort to reduce deforestation and improve the environment, the State of Pará converted the Municipalities Black List into a program of positive incentives, called Green Municipalities. The government of Pará has begun to allocate state-to-municipal governmental transfers to favor declines in deforestation through a program. Decree Nº 31.884/2011, Pará, Brazil (officially created the program).	2011	Response to the Critical Counties Program has fostered collective action to reduce deforestation, but has not yet delivered positive incentives to farmers in target counties.	<a href="#">Green municipalities webpage</a>
29	Green Tax Allocation (ICMS Verde) Pará	Allocates 8% of this tax to counties that have protected natural areas meeting certain requirements. (State Law Nº 7.638, of June 2012). The environmental criteria and the allocation of funds were determined by Decree (State Decree 775 of June 2013). Under the Green ICMS, Pará committed approximately R\$350 million (~US\$152 million) to be distributed over a 4-year period to municipalities. Criteria: first, 25% will be allocated based on the proportion of the municipal area covered by protected areas. Second, 50% will be allocated according to the extension of the municipal territory outside of protected areas and indigenous territories, registered under CAR. Third, 25% will be allocated according to stock and flux deforestation targets set for each municipality. Under this last criterion, meeting forest stocks and deforestation targets are important condition for the municipality to fully benefit from the allocations.	2012-2013	This program could deliver the first performance-based finance at scale for reductions in deforestation	<a href="#">Green Tax Allocation (ICMS), Pará</a>
<b>REDD+/Climate Policy</b>					
	<b>Policy</b>	<b>Description</b>	<b>Year</b>	<b>Effect</b>	<b>Link</b>



30	Amazon Fund	The Amazon Fund is designed to receive donations for non-recoverable investments for prevention, monitoring and combating deforestation, and promoting conservation and sustainable use of forests in the Amazon Biome.	2008	Managed by the BNDES, the Fund has financed projects and, most importantly, state REDD programs in Acre and Tocantins. Highly bureaucratic and slow.	<a href="#">Decree N° 6.527, August 1st, 2008</a>
31	National Climate Change Mitigation Plan (NPCC)	Voluntary commitment to the UNFCCC with the goal of reducing emissions by 38.9% of predicted emissions by 2020. Sets a target of 80% reduction in Amazon deforestation; 40% in the Cerrado.	2009	Establishes sector-specific programs and finance for achieving the 2020 targets and is an important national legal framework for reducing Amazon deforestation.	<a href="#">National Climate Change Mitigation Plan, Law N° 12.187, December 29th, 2009</a>
32	Governors' Climate and Forests Task Force (GCF)	A subnational collaboration between 22 states and provinces from Brazil, Indonesia, Mexico, Nigeria, Peru, Spain, and the United States. The GCF seeks to advance jurisdictional programs designed to promote low emissions rural development and REDD+, and link these activities with emerging greenhouse gas (GHG) compliance regimes and other pay-for-performance opportunities.	2009	This international collaboration has unified and strengthened states and provinces that are developing jurisdictional REDD+ programs, including most Brazilian states	<a href="#">Governors Climate and Forests Task Force official webpage</a>
33	Acre REDD+ Strategy - SISA - Law 2308, October 22nd, 2010	State law and program that creates a system for incentives for environmental services, with a focus on state-wide carbon emissions reductions. It aims to attract funds to reward for conservation and reductions in deforestation at the jurisdictional level.	2010	The world's most advanced jurisdictional REDD program, Acre has attracted investments (e.g. 16M Euros through German REM program) for its emissions reductions.	<a href="#">Law N° 2.308, October 22nd, 2010</a>

34	Low-Carbon Agriculture Program (ABC)	Low interest loans for sustainable agriculture initiatives. It aims to encourage the adoption of sustainable farming techniques that contribute to reducing emissions of greenhouse gases and help in the preservation of natural resources.	2010	R\$3.2 B (US\$1.5 B) in finance made available annually	<a href="#">ABC Plan, Ministry of Agriculture</a>
35	Mato Grosso REDD+ Strategy - Law N° 9878, January 7th, 2013	Creates a REDD system at the jurisdictional level. It aims to attract funds to reward for conservation and reductions in deforestation at the jurisdictional level.	2013	Under implementation (not fully developed).	<a href="#">Law N° 9.878, January 7th, 2013</a>
36	National Strategy for Reducing Emissions from Deforestation and Forest Degradation (EN-REDD+)	As of January 2014 Brazil does not have an official national REDD+ strategy.	N/A		There is no official weblink for this reference.
<b>Sustainable Supply Chain Initiatives (SSCI)</b>					
	<b>Initiative</b>	<b>Description</b>	<b>Year(s)</b>	<b>Effect</b>	<b>Link</b>
37	Roundtable on Sustainable Palm Oil (RSPO) launched	Mutli-stakeholder process that has established an international standard for sustainable palm oil production. Establishes restrictions on deforestation.	Created in 2004; launched in 2007.	Oil palm is not a strong driver of deforestation in Brazil, but RSPO has reinforced the signal that international markets demand sustainable sources	<a href="#">RSPO webpage</a>
38	Soy Moratorium	An agreement between soy industry and civil society to not buy soy produced on land in the Amazon biome that was cleared after July 2006.	July 24th, 2006	Successfully contributed to reduced deforestation. Less than 0.25% of total area of Amazon soy production was out of compliance with this agreement. The Soy Moratorium will end in 2014.	<a href="#">ABIOVE Agreement on soy moratorium, 2006</a>

39	Round Table on Responsible Soy (RTRS) launched	Multistakeholder process that has established an international standard for responsible soy production.	Launched in 2006, First Standard in 2010.	Brazilian soy producers have had trouble certifying because of difficulties encountered complying with the law.	<a href="#">RTRS webpage</a>
40	Roundtable on Sustainable Palm Oil (RSPO) P&C	Industry commitment to sustainable palm oil production through multi-stakeholder engagement. Includes a certification scheme.	P&C finalized in Oct. 2007	In effect	<a href="#">RSPO webpage</a>
41	Bonsucro launched	Multistakeholder process that has established an international standard for responsible sugarcane and sugarcane ethanol production.	2008, P&C published in March 2011	In effect. No certified producers in the Amazon, where production is small.	<a href="#">Bonsucro webpage</a>
42	Beef Moratorium	An agreement between the beef industry and civil society, reinforced by Public Prosecutor office not to buy beef produced in illegally deforested areas.	2009	Has resulted in strong involvement of largest beef companies in commitment to remove deforesters from supply chain	<a href="#">Finance Secretary of Mato Grosso, news release on beef moratorium</a>
43	GTPS (Brazilian working group on sustainable beef)	Brazilian multi-stakeholder process to support sustainable beef production	2009	GTPS has decided not to adopt a standard.	<a href="#">GTPS webpage</a>
44	Consumer Goods Forum (CGF) commitment to zero deforestation	400 businesses that pledge to buy only products free of deforestation by 2020 (beef, soy, palm oil, paper, wood).	2010	Strong leadership from Unilever	<a href="#">CGF Commitment</a>
45	RTRS P&C	Approval of RTRS standards.	2010	In effect	<a href="#">RTRS Standard for Responsible Soy Production</a>
46	Global Roundtable on Sustainable Beef (GRSB)	Industry commitment to sustainable beef production through multi-stakeholder engagement.	2012	P&C Under development	<a href="#">GRSB webpage</a>
<b>Infrastructure</b>					
	<b>Initiative/project</b>	<b>Description</b>	<b>Year(s)</b>	<b>Effect</b>	<b>Link</b>

47	"Avança Brasil" integrated infrastructure plan	Laid out 4-year plan with guidelines, objectives and goals to be followed by the federal, municipal, and state governments for the years 2000-2003.	2000-2003	Several of the planned projects (pavement of the BR163, BR319) were not completed.	<a href="#">Plano Avança Brasil</a>
48	Plan of Accelerated Growth	Laid out 4 year plan for activities with the aim to accelerate economic growth in Brazil, providing total investments of R \$ 503.9 billion by 2010. Priority given to infrastructure investment in areas such as sanitation, housing, transport, energy and water resources, among others. Included large infrastructure projects within the Amazon biome (e.g.. Belo Monte Dam in PA, Jirau and Santo Antonio Dams in RO).	2007-2010	Past action	<a href="#">PAC</a>
49	Belo Monte Dam	Belo Monte Dam was approved by congress in 2005. IBAMA approved the environmental license in 2010. Construction began in 2011.	2010	In effect	<a href="#">Belo Monte Cronology</a>
50	Santo Antonio and Jirau Dams	Inaugurated in December 2011 and March 2013 respectively. Completion anticipated for 2015.	2011 - 2013	In effect	<a href="#">National Agency of Electricity</a>
51	Tapajós Dams	Under preparation. Construction has not begun yet.	2013	Planned	<a href="#">Tapajós Dams</a>

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