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Engagement of scientific community and transparency in C accounting: the Brazilian case for anthropogenic greenhouse gas emissions from land use, land-use change and forestry

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Abstract

To effectively implement the Paris Agreement, capacity in carbon accounting must be strengthened in the developing world, and partnerships with local academic institutions can do the accounting for governments and fill the capacity gap. This paper highlights the Brazilian case, focusing on ways in which climate change science information and transparency are being incorporated in national C accounting initiatives, particularly the national inventory of greenhouse gas (GHG) emissions and removals. We report how the third inventory for the sector of land use, land-use change and forestry (LULUCF) was implemented to address scientific challenges involved in the monitoring of carbon stocks and land-use changes of diverse and complex biomes while addressing international and national policy demands (report and decision support) and transparency to various stakeholders. GHG emissions and removals associated with 2002–2010 carbon changes in aboveground, belowground biomass, necromass and soil carbon by land use and land cover changes were estimated for all Brazilian biomes, and for the Amazon estimates were also presented for the periods of 2002–2005 and 2005–2010. The inventory improved regional estimates for carbon stock and national emission factors with the support and engagement of the scientific community. Incorporation of local context is essential to reduce uncertainties and properly monitor efforts to contribute to GHG emission/reduction targets. To promote transparency and make information more accessible, the national inventory results were made available by the National Emissions Registry System (SIRENE). This system was built to support climate change policies as an important legal apparatus and by increasing access to emissions and land-use change data.

Introduction

The challenges posed by anthropogenic climate change require new governance approaches to manage changes in the C cycle in decision-making processes. These approaches are being developed on a global scale through the Paris Agreement and on a national scale through greenhouse gas (GHG) accounting practices.

New governance approaches demand that we identify the type of scientific information needed to inform governments and consider the implications of C accounting approaches. The evolution of C accounting in the international climate policy regime and the building of a robust transparency mechanism are at the core of the Paris Agreement. Because the Parties' nationally determined contributions are highly variable in ambition and format, an effective transparency mechanism will require accurate and precise measurement, reporting, and verification of GHG emissions from all nations. However, for the last two decades, only developed countries (Annex I Parties of the Kyoto Protocol) have been required to provide regular detailed reports of their emissions to the United Nations Framework Convention on Climate Change (UNFCCC). In a few years, all nations will be expected to report their emissions. Thus, capacity in C accounting must be strengthened in the developing world to effectively implement the agreement. Partnerships with local academic institutions can help governments assess C emissions and removals, fill the capacity gap, and prepare for further improvements.

In this paper, we highlight the Brazilian case, focusing on ways in which climate change science information is being incorporated into new and existing governance frameworks to improve C accounting for the land use and land use change and forest (LULUCF) sector. In 2015, Brazil submitted its nationally determined contribution to the UNFCCC as part of the Paris Agreement (UNFCCC 2015). As for mitigation, Brazil plans to reduce GHG emissions by 37% below 2005 levels by 2025, and by 43% below 2005 levels by 2030. As stated in the document, the contribution is economy-wide and based on flexible pathways to achieve the 2025 and 2030 objectives. The mitigation strategy includes activities in the agriculture, energy, industry, transport, and forestry and land use sectors. For the forestry and land use sectors, the strategy includes (i) strengthening the Brazilian Forest Code (an important environmental law); (ii) strengthening policies and measures to achieve zero illegal deforestation in the Brazilian Amazon by 2030; (iii) restoration and reforestation of 12 million hectares by 2030; and (iv) scale-up of sustainable forest management systems.

Land use and land cover changes represent an important share of global GHG emissions, on the order of 12% (Intergovernmental Panel on Climate Change [IPCC] Working Group III Fifth Assessment Report). The share in Brazil is much larger at 22% in 2010 (MCTI 2013), requiring a better understanding of sector activity to improve mitigation policies. Brazil is one of the most important countries in terms of emissions associated with land use changes and has large areas of remaining native vegetation, representing significant potential sources of emissions (Fearnside 2000a, 2000b). The main Brazilian biomes have lost significant amounts of vegetation cover, primarily through conversion of natural ecosystems to pastures and agricultural crops, which seriously affects biodiversity, as well as GHG emissions. This experience can contribute to promote a mutual learning process in developing countries by identifying and disseminating lessons learned.

Preparation of the third national inventory of GHG

Regularly updated inventories submitted by countries to the UNFCCC are the basis for their commitments to GHG reductions. The national inventory system includes all institutional, legal, and procedural arrangements made by a Party for estimating anthropogenic GHG emissions by sources and removals by sinks not controlled by the Montreal Protocol, and for reporting and archiving inventory information (IPCC 2003, 2006). The guidelines request that national systems be designed and operated to ensure the transparency, consistency, comparability, completeness, and accuracy of inventories.

Inventory preparation remains a challenging task for many countries, and a range of countries lack sufficient resources for inventory improvement, particularly those with extensive areas and complex dynamics of land use changes. Brazil is a non-Annex I country committed to the development, periodic updating, and dissemination of national inventories of anthropogenic emissions. Initially funds came mainly from the Global Environment Fund (GEF), but a grant from the main Brazilian funding agency (CNPq) represented an important contribution for the last national inventory (released in 2014). The CNPq grant allowed the involvement of scientific groups and young fellows who received training on the central issues of C accounting. Over the last decade, the Brazilian National Inventory has evolved from a report to the UNFCCC to an instrument that monitors national policies, strengthens the involvement of the scientific community, and disseminates information about emissions and mitigation efforts to society.

Brazil prepared the First National Inventory with emissions data from 1990–1994 (MCTI 2004). Considering the relevance of deforestation for the country's emissions, starting from the Second National Inventory (MCTI 2010), which included emission estimates from 1990–2005, Brazil undertook a major effort to create a document that was explicit in spatially representing the forestry and land use sector, although this was not mandatory. The Third National Inventory (MCTI 2015), which revised the emissions data since 1990 and updated information from 2002–2010, was improved with regional C stock values and national emission factors in the forestry and land use sector. Along with engagement of the scientific community, these efforts built on early investments in institutional capacity to monitor forest cover based on remote sensing.

Improvements in the national system of inventory were stimulated by the National Policy on Climate Change (Law No. 12,187/2009), which was approved by the Brazilian Congress in 2009 with voluntary commitments for GHG emissions reduction by 2020. The regulatory framework of climate change mitigation in Brazil considers the national inventory as policy instrument and determines the elaboration of the annual estimates of GHG emissions using the same guidelines (Decree No. 7,390/2010). Sectoral mitigation plans were developed with the goal of meeting gradual quantifiable and verifiable anthropogenic emission reduction goals. These plans included actions such as clean development mechanisms and nationally appropriate mitigation actions, considering several sectors such as forest and land use (including deforestation in the Amazon and Cerrado biomes), agriculture, energy production and use, transportation, and industry (Silva *et al* 2015).

In the following sections, we report how the most recent Brazilian National Inventory in the land use, land-use change and forestry (LULUCF) sector was implemented to address (1) scientific challenges involved in the monitoring of C stocks and land use changes of diverse and complex biomes, (2) international and national policy demands (report and decision support), and (3) transparency to various stakeholders.

Engagement of the scientific community and improvements for the LULUCF sector

As part of the development of the National Policy on Climate Change, the Brazilian Network on Global Climate Change Research (Rede Clima) was created in 2007 to develop and disseminate the knowledge required to deal with challenges posed by climate change (Arraut *et al* 2012). This national network, which involves several research groups in universities and research centers (Nobre 2008), consists of 16 sub-networks representing a broad range of thematic areas critical for mitigation and adaptation polices, such as GHG accounting and reporting on impacts and vulnerabilities. In 2011, the objectives of Rede Clima were officially extended to support the periodic national GHG inventories (Rodrigues Filho *et al* 2016). Thus, the Third National Inventory was developed through a collaborative network with the joint efforts of various government agencies and scientific groups.

The Brazilian Inventory is performed on a national scale. Considering the size of the country and diversity of its vegetation, it was a challenge to find an ideal land representation for the whole country. Biomes, municipalities, potential vegetation, soil types, land management, and land use/land cover were used as input data to estimate C stocks, emissions, and removals.

Table 1. Land use and land cover categories and subcategories.

Land cover (IPCC)	Land use (acronym)
Forest	Unmanaged forest (FNM) Managed forest[a] (FM) Secondary forest (Fsec) Forest with selective logging[b] (CS) Reforestation (Ref)
Grassland	Unmanaged grassland (GNM) Managed grassland[a] (GM) Secondary grassland (Gsec) Pasture (Ap)
Agriculture	Cropland (Ac)
Settlements	Settlements (S)
Water, wetlands	Rivers, lakes, and reservoirs (A)
Other land	Other uses (OU) Not estimated (NE)

Source: © The Intergovernmental Panel on Climate Change (IPCC), 2006.

[a] Lands where human interventions and practices are used to perform production, ecological, or social functions (IPCC 2010).

[b] Considered only for the Amazon biome.

The Brazilian territory was divided into six large biomes (Amazon, Cerrado, Atlantic Forest, Caatinga, Pampa, and Pantanal), in accordance with definitions of the Brazilian Institute of Geography and Statistics (IBGE) (IBGE 2004) and the Ministry of the Environment. This division considered environmental factors such as predominant vegetation, topography, and/or climatic conditions. The IBGE's 2010 Digital Municipal Grid (with 5565 municipalities) was used to desegregate information within the polygons of municipalities. Including this information aimed to provide auxiliary information on crops and silviculture census data and to identify land use changes.

The map of the Project of Conservation and Sustainable Use of the Biodiversity (PROBIO 2002) of the Ministry of Environment was also used (scale, 1:250 000). Its converted areas were recategorized based on the previous IBGE vegetation map (IBGE 2004) and visual interpretation of 1994 TM/Landsat-5 images. Plant physiognomies were grouped into forest or grassland according to the IPCC (2006) (table 1).

In the Brazilian context, managed forests and grasslands (FM and GM, respectively) are lands where human activity does not significantly alter the original structure and composition. For national communications, these lands are under demarcation as protected areas (PAs), such as conservation units or indigenous lands (ILs).

Information on land use/land cover (LULC) (table 1) for each year was mapped through visual interpretation of TM/LANDSAT-5 imagery. TM/Landsat-5 images acquired for the Second National Inventory were used to map the years 1994 and 2002. The 2010 LULC map used 368 TM/Landsat-5 images and 29 LISS-III/RESOURCESAT-1 images. A 2005 LULC map was created for the Amazon biome only using 199 TM/Landsat-5 images. All 2005 and 2010 images were georeferenced using the 2002 images as reference.

The LULC map legend indicates forests and grasslands, managed or unmanaged, according to information of the previous vegetation (plant physiognomies) and managed areas (protected areas), respectively. Areas are defined as primary vegetation if they are without LULC change throughout the years. Areas are defined as secondary forests and grasslands (FSec and GSec, respectively) if they are mapped as forest and grasslands but were classified as another land cover type in a previous year. LULC mapping was carried out with 6 ha as the minimum mapping area and a final output scale of 1:250 000.

Carbon maps for the Brazilian biomes and emissions estimates

In addition to mapping land use changes, emission estimates require the determination of biomass and C stocks in the different compartments for plant physiognomies of the six Brazilian biomes. The C stocks were estimated for living biomass (above- and belowground), dead organic matter (standing or lying dead wood and litter), and soil organic C. The biomass of different C stocks in forest and grassland areas was converted to C using IPCC default values (IPCC 2006). Involvement of the scientific community was essential in creating this extensive biomass database, which incorporated both published data and unpublished data provided by experts. Carbon maps generated for Brazilian biomes are presented in figure 1 (additionally, the distribution of Brazilian biomes is shown in figure 1 of the supplementary material available at stacks.iop.org/ERL/13/055005/mmedia). Carbon stocks for the different compartments (aboveground, belowground, litter, and deadwood) of each biome and plant physiognomy are presented in figure 2, and soil carbon stocks are shown in figure 3.

Biomass estimates for the Amazon biome, which comprises almost half of the country (4 196 943 km^2), were based primarily on the forest inventory from the RadamBrasil project and IBGE previous vegetation map (figure 4). Biomass estimates for the biome were mostly based on the forest inventory from the RadamBrasil project and IBGE Vegetation map. The RadamBrasil inventory collected data from trees with circumference breast height greater than or equal to 100 cm, corresponding to a diameter breast height (DBH) greater than or equal to 31.83 cm. A total of 102 837 trees were inventoried. Biomass correction factors (BCFs) described by Nogueira *et al* (2008) (supplementary material, table 1) added the biomass of trees with DBH between 10 and 31.83 cm (AGB$_{\geq 10}$ in t ha^{-1}) and contribution of palms, lianas, understory, other forest components, deadwood (fallen and standing), litter, and belowground biomass. RadamBrasil covered the following nine plant physiognomies, which account for approximately 90% of the Amazon biome: alluvial open humid forest, lowland open humid forest, open submontane humid forest, alluvial dense humid forest, lowland dense humid forests, montane dense humid forest, submontane dense humid forest, submontane semi-deciduous seasonal forest, and wooded campinarana. The biomass stock of other 20 plant physiognomies in the biome (not covered by the RadamBrasil inventory) was estimated based on values found in the scientific literature. The processes used to generate regional biomass estimates in the Amazon biome are described in the supplementary material.

Vegetation biomass of the Cerrado (second largest biome, with 2 036 448 km^2) was based on C stock values for each plant physiognomy of the previous vegetation map. Of the 28 plant physiognomies in the Cerrado, six physiognomies, which had available scientific references and biomass variation across the biome, had their values regionalized according to the Brazilian state. For the three dominant Cerrado physiognomies (wooded savanna, park savanna, and grassland savanna), a study with broad geographic coverage in the Cerrado and number of pools (aboveground biomass, dead wood, and litter) was chosen (Ottmar *et al* 2001). Whenever possible, belowground biomass, litter, and dead wood were estimated based on ratios in the Cerrado (e.g. Miranda *et al* 2014) or IPCC default values (IPCC 2003). When local studies were not available, values for plant physiognomies in other biomes were used, considering factors such as distance and climate/pluviosity (for more details see the supplementary material).

The Caatinga occupies 844 453 km^2 in the northeast semiarid portion of Brazil. For the most representative plant physiognomies of this biome (wooded and forested steppe savannas, which together comprise ~80% of the biome's area) (Albuquerque 2015), C stock values of all pools collected in the Caatinga were used. For the other, less representative plant physiognomies more details are presented in the supplementary material.

The Atlantic Forest biome (1 110 182 km^2) is a mosaic of dense, open, deciduous and semi-deciduous seasonal forests. Most of the aboveground biomass was estimated according to plant physiognomy based on published local studies (e.g. Alves *et al* 2010, Britez *et al* 2006). The other C pools (belowground biomass, litter, and dead wood) were estimated based on local values in the Atlantic Forest (e.g. Amaro *et al* 2013, Vieira *et al* 2011) or IPCC default ratios (IPCC 2003, 2006).

The Pampa biome (176 496 km^2) is located in southern Brazil and is bordered by Argentina and Uruguay. Temperate fields predominate in this biome, but there are forest and shrub formations in the mountains and plains. Local studies were given priority (e.g. Fidelis *et al* 2006), but in the absence of such studies, values from other biomes were used, preferably from the Atlantic Forest, which is adjacent to the Pampa.

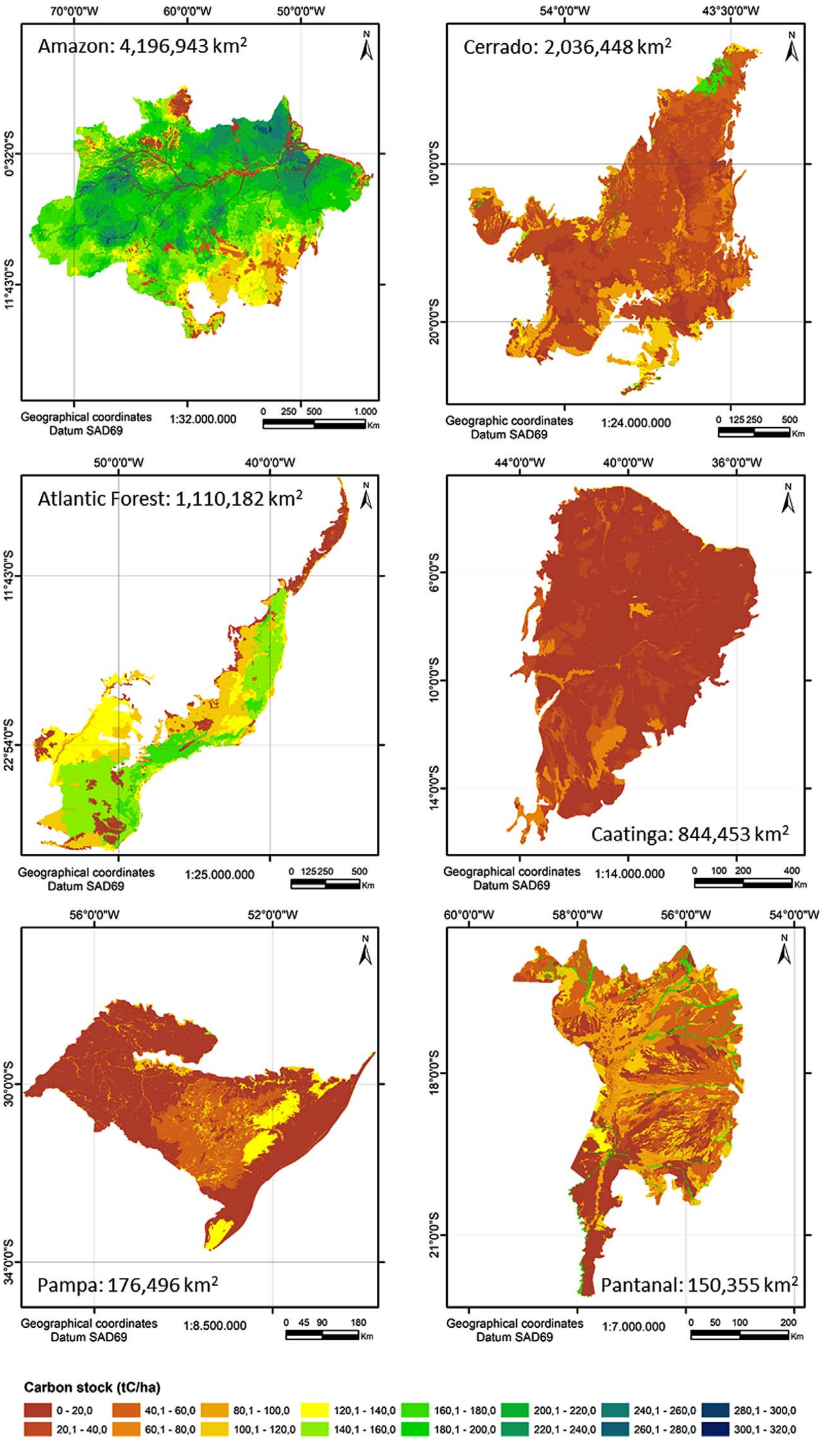

Figure 1. Maps of total biomass C stocks (above-, belowground and necromass) in the Brazilian biomes, taking into account the distribution of the IBGE previous vegetation map. Original data extracted from MCTI (2015).

The Pantanal biome is the smallest biome (150 355 km^2) and is a vegetation mosaic composed of forest, savannah, grassland, and seasonally flooded wetlands. These formations are also bordered by the Chaco to the south, the Amazon to the north, and the Atlantic Forest and Cerrado to the south and east. Aboveground biomass values were available for seven of the 15 plant physiognomies in the Pantanal from tree data collected in this biome (see supplementary material). For other plant physiognomies, values from the same phytophysiognomy but from neighboring biomes such as the Amazon, Cerrado, and Atlantic Forest were used.

Soil C was estimated using the method proposed by Bernoux *et al* (2002). The soil and vegetation association map categorized its 69 classes into the 18 classes of the Brazilian soil classification system. They were then reclassified into six large soil groups, according IPCC/OECD/IEA (1997) and IPCC (2003), which considers soil texture, base saturation, and moisture.

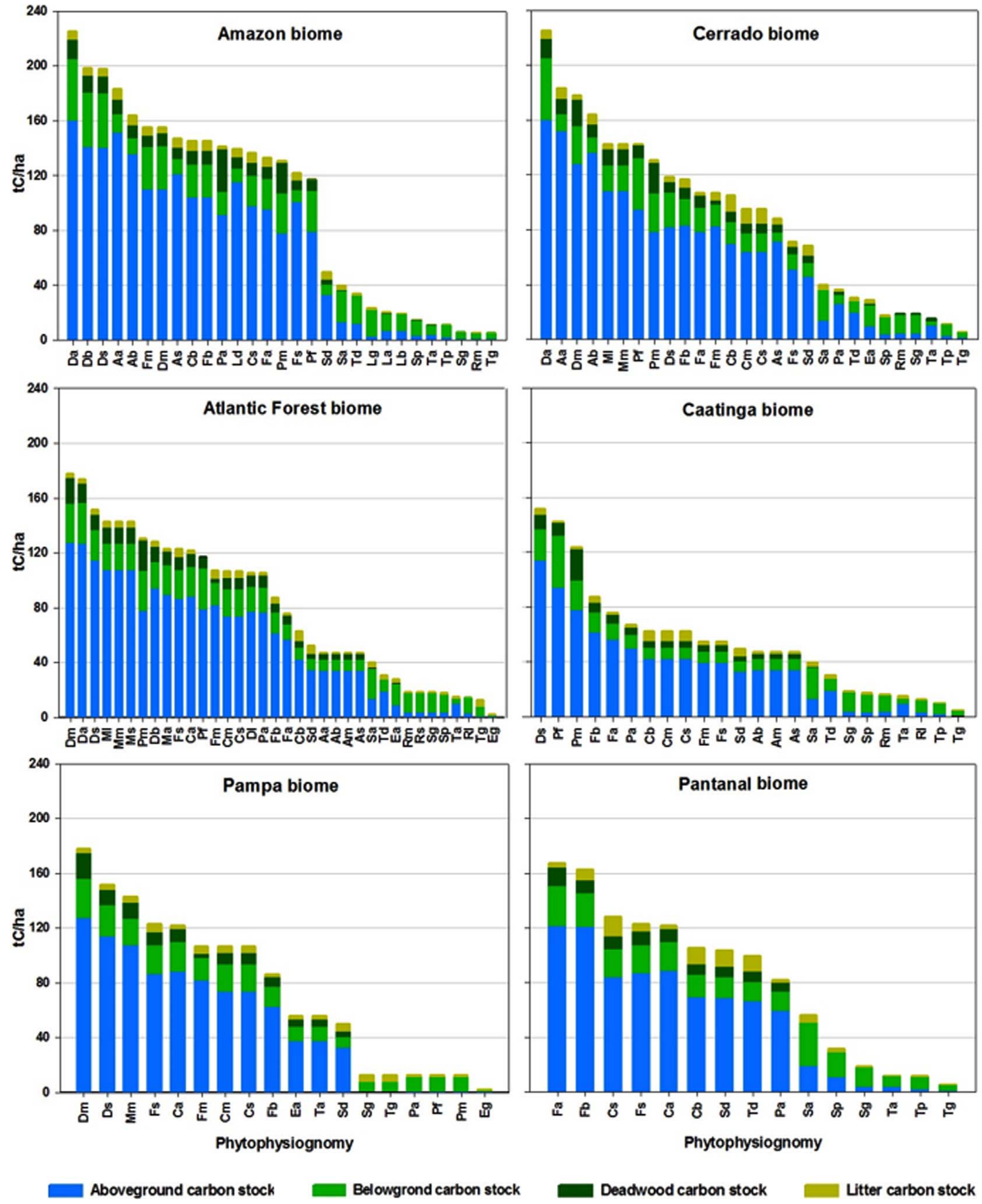

Figure 2. Carbon stocks in different compartments (tC ha^{-1}) in the biomass and necromass of different plant physiognomies of Brazilian biomes. Keys for plant physiognomies are presented in the supplementary material. Original data extracted from MCTI (2016b).

*Plant physiognomies correspond to: *Humid Forests* (Aa, Ab, Am and As), *Deciduous Seasonal Forests* (Ca, Cb, Cm and Cs), *Dense Humid Forests* (Da, Db, Dl, Dm and Ds), *Steppe* (Ea and Eg), *Semi Deciduous Seasonal Forest* (Fa, Fb, Fm and Fs), *Campinarana* (La, Lb, Ld and Lg), *Mixed High Humid Forest* (Ma, Ml, Mn and Ms), *Pioneer formation* (Pa, Pf and Pm), *Refuge* (Rl, Rm and Rs), *Savanna* (Sa, Sd, Sg and Sp) and *Steppe Savanna* (Ta, Td, Tg and Tp). Name descriptions of each plant physiognomies are shown in the supplementary material.

The plant physiognomy classes were then grouped into 15 categories according to dominant vegetation and/or location (Bernoux *et al* 2002). Finally, according to the detailed calculations of Bernoux *et al* (2002), soil C stock values were assigned for each vegetation-soil association up to 30 cm deep (see supplementary material).

The Third National Inventory called attention to a decrease in emissions due to a reduction of deforestation rates over the evaluated periods (2002–2005, 2005–2010), particularly in the Amazon biome. In contrast, emissions related to land use changes increased in other biomes, such as the Cerrado biome (figure 5), highlighting the need to enforce public policies related to deforestation control beyond the Amazon biome. In the period from 1994–2012, partial net anthropogenic emissions totaled 6 958 430.5 Gg CO_2. From 2002–2005, emissions were 4 594 652.8 Gg CO_2, and from 2005–2010, emissions were 2262, 372.2 Gg CO_2 (MCTI 2015).

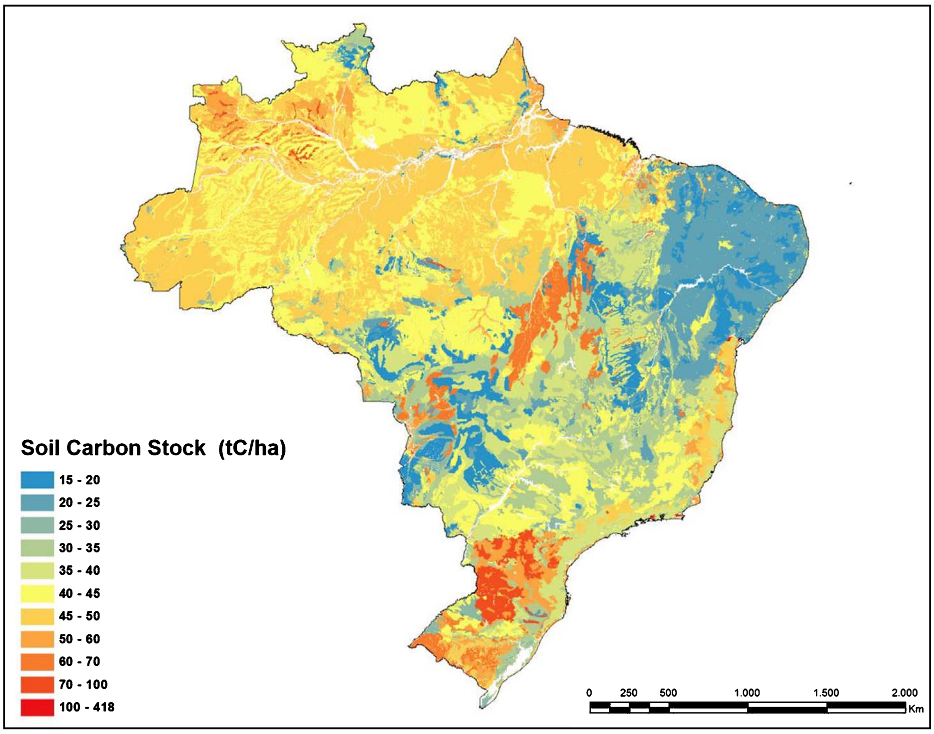

Figure 3. Soil Carbon Stock (tC ha^{-1}) in the Brazilian soils, reprinted from Bernoux *et al* Copyright © 2002. Soil Science Society.

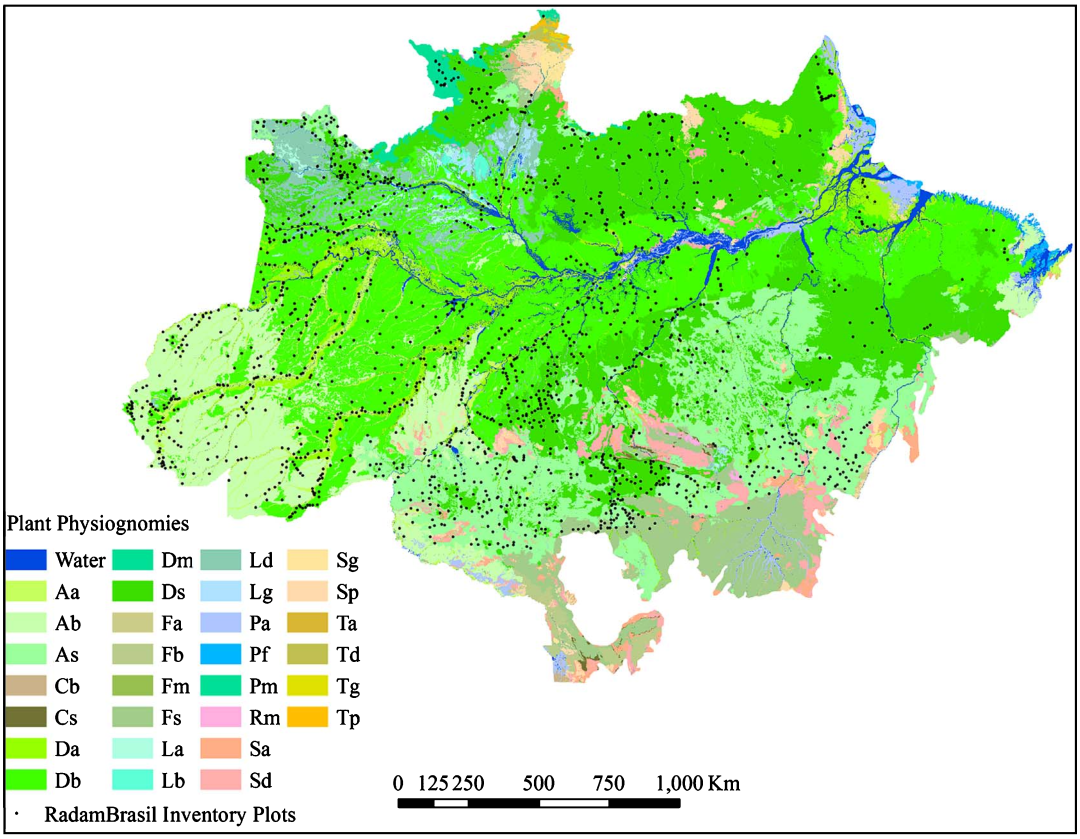

Figure 4. Plant physiognomies* from the IBGE previous vegetation map and RadamBrasil inventory plots across the Amazon biome (IBGE 2004).

*Plant physiognomies correspond to: *Humid Forests* (Aa, Ab and As), *Deciduous Seasonal Forests* (Cb and Cs), *Dense Humid Forests* (Da, Db, Dm and Ds), *Semi Deciduous Seasonal Forest* (Fa, Fb, Fm and Fs), *Campinarana* (La, Lb, Ld and Lg), *Pioneer formation* (Pa, Pf and Pm), *Montane Refuge* (Rm), *Savanna* (Sa, Sd, Sg and Sp) and *Steppe Savanna* (Ta, Td, Tg and Tp).

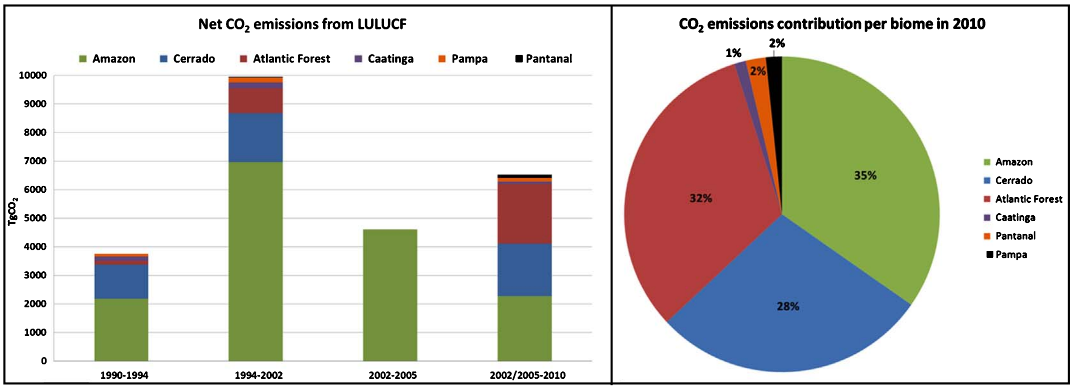

Figure 5. Net CO_2 emissions from LULUCF, and CO_2 emissions contribution per biome in 2010. Original data extracted from MCTI (2016b).

Scientific challenges for the LULUCF sector

Quantification of GHG emissions and removals considers a number of factors including changes in all C reservoirs, such as living biomass (above- and belowground), dead organic matter (litter and dead wood), and soil organic C (for more details see supplementary material). The inventory mapped the six categories of Land use and Land cover recommended by the IPCC. Forest and grassland categories were mapped in greater detail (table 1). It is important to note that transitions between Land use and Land cover categories and subcategories (MCTI 2015) were mapped, so that changes could be associated with different types of soil cover and C stocks. The estimation of these emissions followed the methods proposed in the Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003) and the National Greenhouse Gas Inventory Guidelines (IPCC 2006).

This concerted effort by the national inventory system made available carbon maps (above-, belowground and necromass) covering all Brazilian biomes with specific and regional values for the different plant physiognomies (figures 1 and 2). Involvement of Rede Clima and Brazilian experts enabled the construction of an extensive and detailed database of biomass and vegetation structure data for Brazilian biomes. In the database, (1) biomass values are assigned to all physiognomies of each biome for the different compartments (**aboveground**: herbaceous, lianas, palms, shrubs, trees; **belowground**: live roots; **necromass**: standing and lying deadwood and **litter** [fine to coarse]), with sources of the values and reasons for the choice; (2) methods were provided for estimating biomass (e.g. allometric equations, number and size of sampling plots) for all plant physiognomies and biomes; (3) reasons were clearly stated when using a value for a compartment that was obtained from another physiognomy in the same or different biome; (4) sources of expansion factors and allometric equations were cited when used; and (5) different values of biomass were used for different states when major biomass/structural variation was detected in the same physiognomy and biome between different regions (and the availability of data permitted). More than 400 scientific publications were surveyed for the elaboration of the Third National Inventory. Literature on vegetation (e.g. basal area and density of tree individuals) was also surveyed. Additionally, Brazilian researchers shared their plot data for diameter and number of trees, and in some cases height, to estimate biomass with the appropriate allometric equations, mainly for the Cerrado, Pantanal, and Caatinga biomes (especially for subregions and plant physiognomies where biomass data were scarce). This database is now providing subsidies for the implementation of the national reducing emissions from deforestation and degradation (REDD+) strategy, which is being developed in steps for the different biomes (e.g. MMA 2016).

The activity maps also provided estimates of land use changes for the whole territory, because not all Brazilian biomes are monitored as frequently as the Amazon (INPE 2017). In the last two decades, the Brazilian government has made efforts to reduce deforestation in the Amazon, which historically has had considerable conservation-oriented research and policy interventions (Nepstad *et al* 2014). As a result, the Amazon experienced a significant drop in deforestation rates, from 27 700 $km^2/year^{-1}$ in 2004 to 8000 $km^2/year^{-1}$ in 2016 (a reduction of 71%). The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), launched in March 2004, was a landmark that led to this reduction (INPE 2017). Other actions such as the Action Plan for the Prevention and Control of Deforestation and Burning in Cerrado (PPCerrado) and the Action Plan of Prevention and Control of Deforestation in Caatinga (PPCaatinga) were also proposed to reduce deforestation in these biomes. However, no significant results were achieved in terms of deforestation (legal or illegal). Desertification is a serious problem in the Caatinga, which has already lost more than 45% of its vegetation cover, making it highly vulnerable to climate change (Albuquerque *et al* 2012). Similarly, the Cerrado has lost 40%–55% of its original vegetation cover, with agricultural area doubling from 1.2–2.5 Mha between 2003 and 2013 (Klink and Machado 2005, Sano *et al* 2010, Spera *et al* 2016). The environmental risk in the Cerrado is of great concern, because it is an important biodiversity hotspot and important for the hydrological regime of three important Brazilian river basins: Paraná, Tocantins-Araguaia, and São Francisco (Silva *et al* 2011). The Atlantic Forest also harbors a significant portion of Brazilian biodiversity and high levels of endemism (Myers *et al* 2000). Covering only 5% of its original area (Ribeiro *et al* 2009), the Atlantic Forest has experienced an increase in deforestation rates in the past decade (SOS Mata Atlântica/INPE 2017). Approximately 3100 km^2 of natural vegetation (0.3% of the biome) were converted to other land uses from 2002–2010. The recently established PRODES-Cerrado monitors deforestation in the biome. MapBiomas, which brings together a network of universities, nongovernmental organizations, and technology companies to annually map land use and land cover changes in Brazil from 1985–2016, uses the Google Earth Engine platform and its cloud processing and automated classifier capabilities (www.mapbiomas.org).

These data reinforce the need for more ambitious initiatives to control deforestation and associated GHG emissions in all Brazilian biomes and for detailed reports that consider the complexity of plant physiognomies and land conversion patterns and uses. Also needed is funding for studies aiming to better understand the structure and biomass of different physiognomies of Brazilian biomes, as many knowledge gaps persist. Such efforts are needed to accomplish the nationally determined contribution of Brazil.

The Brazilian case also highlights the important role of GEF funds in supporting national capacities for reporting GHG emissions. Despite the established scientific capacity in Brazil and successful collaboration through the Rede Clima in the elaboration and improvement of the last national inventory, recent cuts in the national budget for science (Angelo 2017) are impacting further developments and increasing dependency on external funds.

Transparency to society—National emissions registry system—SIRENE

During the elaboration of the Third National Inventory, the National Emissions Registry System (SIRENE; http://sirene.mcti.gov.br) was created to comply with National Policy on Climate Change (PNMC in the Portuguese acronym) guidelines, which include the dissemination of information on climate change. This system consists of a web platform with the objective to confer permanence and accessibility to results of national inventories of anthropogenic emissions by sources and removals by sinks of GHGs not controlled by the Montreal Protocol (MCTI 2010). These GHGs include CO_2, CH_4, N_2O, CF_4, C_2F_6, HFC-23, HFC125, HFC134a, HFC143a, HFC152a, SF_6, CO, NO_x, and NMVOC for certain sectors of the Brazilian economy such as waste treatment; agricultural and livestock; land use, land-use change and forestry; and energy and industrial processes (MCTI 2016a).

Implementation of SIRENE seeks greater transparency in the national system of the GHG accounting and dissemination of its results. To support decision makers, the system makes available a wide range of information related to GHG emissions, climate change policies, and programs, especially on the generation of scientific knowledge, as well as the adoption of mitigation, adaptation, and sustainable development measures. Between October 2016 and October 2017, the system was accessed 4400 times, with 8000 work sections (e.g. activities as downloads, use of panels). User profiles indicate the interest of citizens from other regions, especially Europe and South America, which account for hundreds of new sessions. Based on the requests received, the largest stakeholder group (*ca.* 50%) consists of academics. The next largest stakeholder group consists of representatives of governmental or public institutions at the federal and state levels (*ca.* 45%) who use the data as a reference to analyze the implementation of policies and actions, or as guidance for the elaboration of subnational emission estimates. Other users and nongovernmental organizations account for approximately 5% of the requests. Typical requests include methodological clarifications, printed publications, LULUCF shapefiles, and other detailed data not yet available in the system (e.g. worksheets with activity data, emission factors, conversion, or results in disaggregated format), in this order of preference. Most users are under 45 years old (76%), and gender distribution is approximately 46% female and 54% male. These data are important to monitor participation of young scientists and women in climate change science and actions. In this regard, UNESCO during the 21st Conference of the Parties in Paris made recommendations and identified strategies to empower women in climate science, where they represent less than one-third of professionals in meteorology and hydrology globally.

To increase public awareness of Brazil's contribution to emissions and mitigation actions, the structure and methodology of the national inventory were also made available and mirrored in a system managed by nongovernmental and civil society organizations (System for Estimate Greenhouse Gas Emissions; http://seeg.eco.br). Wide dissemination of the national inventory system, including land use maps and databases on biomass and emission factors, can help address misconceptions about accounting issues reported in the scientific literature (e.g.

Richards *et al* 2017 and associated replies Rajão *et al* 2017 and Bustamante *et al* 2017).

Conclusions

Improving the quantification of anthropogenic GHG emissions will depend on an integrated governmental strategy at the federal, state, and municipal levels, in conjunction with scientific development. Although methodologies used in these quantifications follow IPCC guidelines recommendations, incorporation of local context is essential to reduce uncertainties and properly monitor the efforts that contribute to emission reduction targets. It is possible to verify that a robust system has been built to support climate change policies, either through an important legal apparatus or through actions that increase the access of emissions and deforestation data to society.

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