Chapter 17
Climate-Smart Forestry in Brazil

Marcos Giongo, Micael Moreira Santos, Damiana Beatriz da Silva, Jader Nunes Cachoeira, and Giovanni Santopuoli

Abstract Brazil is the second largest forested country in the world with a high level of naturalness and biodiversity richness, playing a significant role in the adoption of mitigation and adaptation strategies to climate change. Although the Brazilian federal government is mainly responsible for the protection of natural ecosystems, the decentralization process, which demands competences of the states and municipalities, allowed the establishment of several agencies and institutions dealing with monitoring, assessment, and management of forest ecosystems through a complex and interrelated number of forest policies. Nevertheless, the deforestation rate, with a consequent loss of biodiversity and ecosystem services, represents critical challenges, attracting worldwide attention. The variety of mitigation and adaptation measures adopted over the years represents viable tools to face climate change and to promote climate-smart forestry in Brazil. Notwithstanding the positive effects achieved in the last decade, a better coordination and practical implementation of climate-smart forestry strategies is required to reach nationally and internationally agreed objectives.

This chapter aims to depict the Brazilian forestry sector, highlighting the management strategies adopted overtime to counteract climate change.

M. Giongo (✉) · M. M. Santos · D. B. da Silva · J. N. Cachoeira
Environmental Monitoring and Fire Management Center, University of Tocantins, Gurupi, Brazil
e-mail: giongo@uft.edu.br; damisb@uft.edu.br; jadernunes@mail.uft.edu.br

G. Santopuoli
Dipartimento Agricoltura, Ambiente e Alimenti, Università degli Studi del Molise, Campobasso, Italy

Centro di Ricerca per le Aree Interne e gli Appennini (ArIA), Università degli Studi del Molise, Campobasso, Italy
e-mail: giovanni.santopuoli@unimol.it

R. Tognetti et al. (eds.), *Climate-Smart Forestry in Mountain Regions*, Managing Forest Ecosystems 40, https://doi.org/10.1007/978-3-030-80767-2_17

17.1 Introduction

Climate change currently represents one of the main themes in global political agendas and presents crucial challenges for the world, requiring coordinated actions at all scales and contexts. Brazil presents a high value of natural and biodiversity richness, including the world's largest tropical forest. Balancing urbanization exploitation, continuous demand for ecosystem services by society, and promoting sustainable use of natural resources is very challenging, particularly in the developing countries. The implicit factors that determine vulnerability to the impacts of climate change are complex and closely related to the level of development of a given community (Parikh 2000). For this reason, Brazil, as a developing country, is more vulnerable to climate change because of less capacity for adaptation, technological enhancement, and financial and institutional structures to further development (Silva 2010).

Mitigation and adaptation measures are required to reduce the country's vulnerability to climate change. These measures aim to reduce (mitigation) and tackle (adaptation) the impacts of climate change. In other words, mitigation actions aim to avoid the uncontrollable, while adaptation actions aim to manage the inevitable (Laukkonen et al. 2009). As recently highlighted by Verkerk et al. (2020), a successful mitigation strategy must take adaptation measures into account to ensure the resilience of forest ecosystems. This assumption is the core of the emerging concept of climate-smart forestry (CSF) that deals with the enhancement of forests' resilience and the delivering of ecosystem services while connecting mitigation, adaptation, and societal demands (Verkerk et al., 2020; Bowditch et al., 2020). In Brazil, mitigation actions have historically been prioritized compared to the adaptation actions, which have been included more effectively in the Brazilian agenda to face climate change in the last decades (Rodrigues Filho et al. 2016).

The United Nations Framework Convention on Climate Change (UNFCCC) recognizes adaptation strategies as an important measure to respond to the adverse effects of climate change and to prepare for future impacts. According to the Intergovernmental Panel on Climate Change (IPCC), adaptation is the process of adjusting to the current and expected climate and to impacts (IPCC 2014). In human systems, adaptation actions aim to reduce or avoid damages to natural resources, exploring beneficial opportunities, through accurate interventions by facilitating adjustment to the expected impacts of climate change (Scarano and Ceotto 2015).

The need for mitigation and adaptation measures in Brazil is crucial, with consequences at a global scale due to the extensive forest cover, the high value of forest biodiversity, the significant exploitation of water resources, and the huge pool of carbon stored in the forest ecosystems and other natural resources. For these reasons, efforts to develop new actions and strategies to tackle climate change are strongly recommended and encouraged by the current socioeconomic development conditions.

Brazil is the seventh largest emitter of greenhouse gases (GHG) in the world, representing 3.4% of global emissions, following China, the United States, the

European Union, India, Indonesia, and Russia. According to the National Inventory of Greenhouse Gas Emissions, "energy," "industrial processes," "agriculture and livestock," "land-use changes and forestry," and "waste treatment" are the most important sources of GHG emissions in Brazil. Though most of the developing countries highlight a general increment of emissions caused by the energy sector, Brazil's emission trend is strongly dependent on deforestation activities, increasing and decreasing with the deforestation rate (Claudio Angelo and Rittl 2019). The contribution to the GHG emissions from the Brazilian energy sector (i.e., burning fuels and fugitive emissions) is lower than other developing countries (e.g., Russian Federation, India, and China), representing 27% of the gross emissions. On the contrary, land-use change and forestry is the most impactful sector with 38% of the total CO_2 emissions in 2015 (Pao and Tsai 2011). Agriculture represents 25% of gross CO_2 emissions, caused mainly by cattle enteric fermentation and by the use of both animal manure and synthetic fertilizers. Of the industrial processes, the production of steel and cement contributes the most, registering about 6% of the CO_2 emissions in 2015. Disposal of solid waste and treatment of domestic and industrial sewage are the main impacting factors of waste treatment, with 4% of CO_2 emissions (MCTIC 2017).

Regarding land-use change, the conversion from forest area to agricultural and livestock lands is the primary source of GHG in terms of gross emissions. The sector had a significant peak of emissions in 1995, related to the intense conversion of forest areas to pasture areas in the Amazon biome. In the period 1995 and 2004, the conversion rate increased significantly, requiring the implementation of the Action Plan for Prevention and Control of the Legal Deforestation in the Amazon (PPCDAm), which resulted in an evident reduction of deforestation in the Amazon biome. In addition, looking at the net emissions, which consider the carbon stored due to the growing stock within forests and natural resources, the land-use change contributed to more than 60% of total emissions in the period 1990–2009, representing the main source of GHG in Brazil. However, it decreased to 27% for the period 2005–2010, following the agriculture and energy sectors with 32% and 30% of emissions, respectively (MCTIC 2017).

Looking at the biome level, according to the inventory carried out in 2015, the emissions caused by land-use change in the Amazon biome represent about 47% of the total CO_2 gross emissions, followed by Atlantic Forest and Cerrado biomes with 25% and 21%, respectively. Nevertheless, it is important to highlight that in the previous inventories, particularly for the period 1990–2002, the Cerrado biome was the most exploited biome and the highest source of CO_2, while, subsequently, the deforestation focused on the Atlantic forest biome. The emissions caused by land-use change of Caatinga, Pampas, and Pantanal biomes were slightly lower, with 4%, 3%, and 0.6%, respectively (MCTIC 2017).

Considering the important role that Brazilian's forest ecosystems play in counteracting global climate change, this chapter aims to describe the climate change policies and actions adopted by Brazilian governments over time through five sections, including the present introduction. Section 17.2 will introduce the Brazilian forest ecosystems, highlighting the main aspects of forest degradation and the forestry sector, including timber market and commercialization. Section 17.3 will focus on the forest monitoring programs, particularly focused on deforestation and forest fire, adopted by federal governments and municipalities and their interconnections. Section 17.4 will describe the mitigation and adaptation strategies adopted in Brazilian's forest ecosystems to face climate change, while Sect. 17.5 will conclude with final considerations.

17.2 Forest Ecosystems and Forestry

17.2.1 Forest Area, Changes, and Trend

Brazil is the second largest forest country (the first one is the Russian Federation), with about 500 million hectares of both natural forests and forest plantations, representing 59% of its territory (FAO and UNEP 2020; MAPA 2019). If correctly managed, these forests can strongly support climate change mitigation, reducing the negative impacts caused by society. Nevertheless, deforestation is the leading cause of loss of forest cover in Brazil and represents a critical threat to forest biodiversity, with a consequent loss of 7.6% of forest species and 10% of the native vegetation species between 2000 and 2018. According to the IBGE (2020) report, between 2016 and 2018, the replacement of forest areas with agriculture, pasture, and urban sprawl consumed about 1% of Brazilian territory. Similarly, between 1985 and 2017, native vegetation decreased by 9%, while agricultural lands increased by 37% (Souza et al. 2020).

Brazilian's forest ecosystems present a complex forest structure defined in six biomes: *Amazon*, *Caatinga*, *Cerrado*, *Atlantic Forest*, *Pampa*, and *Pantanal*, with distinctive characteristics and types of vegetation and fauna. The Amazon biome is particularly important, being the largest biome in Brazil and South America, covering eight countries beyond Brazil for a total extension of about 6.4 million km^2 (Lentini et al. 2005). In Brazil, it covers approximately 4.2 million km^2, equal to 63% of Amazon biome and 49% of country area (MMA 2006a). The loss of natural vegetation within the Amazon biome in Brazil was c.440,000 km^2 (11.1%) between 1985 and 2019, mostly due to the conversion into agricultural and livestock lands (Souza et al. 2020). However, in 2019, native vegetation (forest and non-forest) covered approximately 3.5 million km^2 (83% of the total area of the Amazon biome).

More precisely, 1995 and 2004 were the years with the highest deforestation rate of Amazon biome of the last 30 years, with a loss of 29,100 km^2 and 27,800 km^2, respectively, and an average value of about 20,629 km^2 year^{-1}. The annual rate of deforestation was lower in the period 2005–2012, with values of 4600 km^2 in 2012, 5900 km^2 in 2013, and 10,100 km^2 in 2019, which resulted in the highest value in the last 10 years (Assis et al. 2019). Moreover, forest fires, which are very frequent in Brazil (Santopuoli et al., 2016a; Assis et al. 2019), continuously contribute to the deforestation rate (Fig. 17.1).

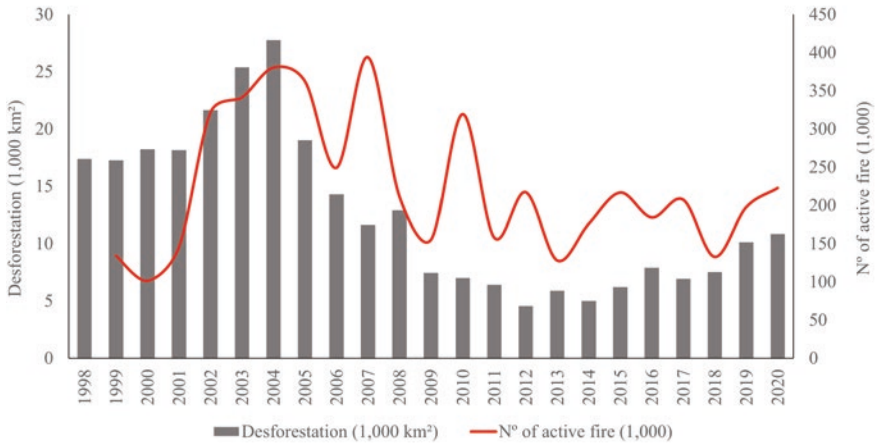

Fig. 17.1 Annual deforestation rates and outbreaks of active fire between 1998 and 2020. (Source Assis et al. 2019)

The Cerrado is the second largest biome in Brazil covering about 25% of the national territory and presenting a high level of endemism, with native vegetation covering 1 million km^2, more than 50% of the biome in 2010 (MMA and IBAMA 2011) and even more in 2002 which was equal to 60.4% (FAGRO 2007). According to the data carried out by TerraClass Cerrado Project, in 2013, the natural vegetation area was about 54% of the total Cerrado. The different values are associated with the methods adopted, such as the different scales and the minimum mapping size rather than differences in the biome area (MMA 2015). The Cerrado biome reached higher values of deforestation rate between 2001 and 2004 with a loss of about 29,000 km^2 of native vegetation areas per year, as reported in the PRODES system. Deforestation in the Cerrado has been gradually decreasing, in 2019 reaching the lowest value in terms of deforested areas, with 6483 km^2 deforested. The deforestation rate decreased by 33% compared to 2010, corresponding with the year in which the federal government adopted the Action Plan for Preservation and Control of Deforestation and Burnings in the Cerrado (PPCerrado).

The Atlantic Forest is extended in the south, southeast, midwest, and northeast regions, covering 15 Brazilian states. It represents the biome with the smallest natural vegetation area and with the highest human population, about 70% of the Brazilian inhabitants. From 2002 to 2009, about 2990 km^2 (0.27% of the biome) of natural vegetation were lost.

Though the Pantanal is a floodplain recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a Natural Heritage and World Biosphere Reserve, the annual rate of deforestation for the Pantanal biome was 638 km^2, with a total loss of natural vegetation equal to 4467 km^2 (2.9% of the biome) between 2002 and 2009.

The Caatinga, an exclusively Brazilian biome, lost 16,035 km^2 (1.9% of the biome) between 2002 and 2009. Slightly lower, about 2514 km^2 (1.4% of the biome) was the loss of natural vegetation within the Pampa biome (MMA and IBAMA 2011).

The drivers of land-use change in the Amazon rainforest are mainly related to economic opportunities. In some regions, particularly those with indigenous communities, the need for fertile soils and agricultural lands is still significant, often representing a traditional custom of such communities (Santopuoli et al. 2016a; Ometto et al. 2011). The paths of change in land use and land cover in the Amazon, in space and time, are shaped by different actors and institutional arrangements, which in different socioeconomic, biophysical, and political contexts characterize the patterns of deforestation and land use (Ometto et al. 2011).

The heterogeneity among Brazilian regions, not only in the Amazon, characterizes the different patterns of land use and land cover and, consequently, impacts on the deforestation rate in the whole country. Among some factors that promote deforestation, the most impacting are the interaction between agricultural expansion, timber trade, population growth, and the construction of roads and public governance, all of which can interact in different ways, depending on the temporal and spatial dynamics of each region (Arraes et al. 2012).

Half a century ago, occupation and, consequently, deforestation, mainly in the Amazon region, were the result of a developmental and integrationist model based on occupation policies founded on geopolitics (Alencar et al. 2004). Such a model can be summarized as integrationist aimed at the rapid opening and expansion of agricultural frontier areas and road construction, such as Transamazônica and Belém-Brasília, which connects the southern part with the northern part of Brazil (Martins et al. 2009). The great challenge that has been faced by Brazil, mainly in the Amazon region, is the maintenance of ecosystem services offered by the forest and its complex ecological processes, with the evident need for the growth and development of populations and communities (Davidson and Artaxo 2004).

17.2.2 Forestry Sector: Products and Market

In Brazil, forestry-based industries comprise several segments, such as cellulose and paper, corrugated cardboard, charcoal, furniture, and mechanically processed wood (i.e., sawn wood, reconstituted, plywood, and laminated panels) and higher-value aggregate products, in addition to several non-timber products (SBS 2008).

According to the national report of forest products (IBGE 2019), the products related to silviculture (i.e., forest exploitation of forest plantations) and timber extractivism (i.e., the harvesting of timber from natural resources) between 2016 and 2019 provided an average value of about R$ 20.6 billion. The silvicultural activities only registered a value of R$ 15.5 billion in 2019. The income derived from cellulose production was the highest among the silvicultural products, with 29.3% of total silvicultural income, occupying the fourth place in the ranking of the country's total exports. Wood for other purposes (e.g., furniture industry, shipbuilding, civil construction, manufacture of pallets, wooden panels, laminate floors, posts) represented 28.9% of the total forestry sector, being in the second position regarding the generation of value of the sector. The production of charcoal is the third largest generator of value in silviculture, representing 25.2%, followed by firewood with 13.9% and non-wood products with 2.7% (IBGE 2019). The income provided by timber extractivism reached a value of R $ 4.4 billion in 2019 and was mainly focused to store roundwood (IBGE 2019).

Though Brazil was the world's second largest cellulose producer in 2018, following the United States, it was the first in cellulose and timber exports. The export to China and Europe was 55% of the total exports (IBÁ 2019). Regarding paper production, Brazil ranks eighth in the world, with 10.4 million tons in 2018 (IBÁ 2019). At the global level, Brazil is eighth regarding the production of wood panels and sawn wood with 0.2 million m^3 and 9.1 million m^3, respectively. Regarding the production of charcoal, Brazil is the world leader, accounting for 11% of all charcoal produced globally (IBÁ 2019).

17.3 Forest Monitoring Programs

17.3.1 Monitoring of Deforestation and Forest Fires

Since the 1970s, through the establishment and strengthening of strategic partnerships, the National Institute for Space Research (INPE), the Brazilian Agricultural Research Corporation (Embrapa), and the Brazilian Institute of Geography and Statistics (IBGE), and all federal agencies of the indirect administration, have been developing technologies and methodologies for monitoring Brazilian natural resources. These assist inspection and monitoring in areas threatened by deforestation, as well as actions to prevent and fight fire (MMA 2017a). In the last decades, several efforts were made to develop and define new methodologies and techniques for mapping and monitoring Brazilian biomes to support policy- and decision-makers, providing timely and reliable information.

In an attempt to reverse the dependence on obtaining satellite images provided by equipment from other nations, on July 6, 1988, the governments of Brazil and China signed a partnership agreement involving INPE and CAST (Chinese Academy of Space Technology) for the development of a program to build two advanced remote sensing satellites, called CBERS Program (cbers.inpe.br). This program made Brazil the pioneer in providing free images from medium spatial resolution sensors, thus becoming a global example of the scope of Earth observation, by making remote sensing an easily accessible tool. The CBERS Program satellites are essential for major strategic national projects, such as PRODES, for assessing deforestation in the Amazon, and DETER, for assessing deforestation in real time, among other systems. Currently, the CBERS Program presents its sixth satellite launched into orbit, CBERS 04A.

Currently, there are four monitoring systems (i.e., PRODES, DETER, TerraClass, and Queimadas) to assess deforestation and forest fire in the Amazon biome. Moreover, INPE developed a further system called DEGRAD, which was replaced by DETER in December 2016. INPE has been monitoring the rate of clear-cut deforestation in the Amazon since 1988 through the Brazilian Satellite Forest Monitoring Project (PRODES), providing one of the most consistent maps of deforestation in tropical forest regions in the world (Ometto et al. 2011). PRODES system focuses on monitoring clear-cut deforestation in the Legal Amazon, providing crucial information for assessing the yearly regional deforestation rate and supporting the government to develop forest policies (INPE 2020). PRODES provides high-quality data supporting the assessment of the GHG emissions of the forestry sector, which are necessary to obtain funding according to the UNFCCC, based on the reduced deforestation rate.

Since 2004, DETER (Real-Time Deforestation Detection system) deals with the real-time detection of land-use changes in the Amazon biome. More precisely, DETER is an alert system aimed to support IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources) in the detection and control of deforestation and forest degradation, as well as other national and local governments about the use of natural resources. TerraClass system was developed through the collaboration between INPE and Embrapa, with the aims to provide maps of land use and land cover of deforested areas belonging to the Legal Amazon in 2004, 2008, 2010, 2012, and 2014 (Almeida et al. 2016). Furthermore, in 2008, the Institute of Man and Environment of the Amazon (Imazon) developed a further monitoring system, the Deforestation Alert System (SAD), to assess deforestation in Amazon. Imazon is a nonprofit Brazilian research organization, which, among other tasks, reports monthly the rates of deforestation and forest degradation of the Amazon biome. The integration of SAD and DETER products allows an accurate temporal and spatial evaluation of the deforestation rate in Amazon because they use different monitoring methods (Fig. 17.2).

Caatinga, Cerrado, Atlantic Forest, Pampa, and Pantanal are part of the monitoring programs started in 2002, through the Project for Conservation and Sustainable Use of Biological Diversity (PROBIO). Moreover, in 2008, the Ministry of the Environment (MMA) and the Brazilian Institute for the Environment and Renewable Resources (IBAMA) signed an agreement to carry out the Project for Monitoring Deforestation in Brazilian Biomes by Satellite (PMDBBS), with the support of the United Nations Development Programme (UNDP). These monitoring activities aimed to assess the loss of native vegetation of the abovementioned biomes to counteract illegal deforestation actions integrating data from different projects between 2002 and 2011. In 2013, the Ministry of the Environment (MMA) promoted the union of different public institutions to develop the first version of Mapping of Use and Vegetation Coverage of the Cerrado: TerraClass Cerrado, based on the methods defined through the TerraClass Amazon project (MMA 2013).

Recognizing the importance of having periodic information about the forest cover changes, the Ministry of the Environment established the permanent Environmental Monitoring Program for Brazilian Biomes (PMABB), through the Ordinance No. 365 on November 27, 2015. The program involved different agencies of the federal government, dealing with monitoring activities through remote sensing to promote the harmonization of the monitoring products. This step was

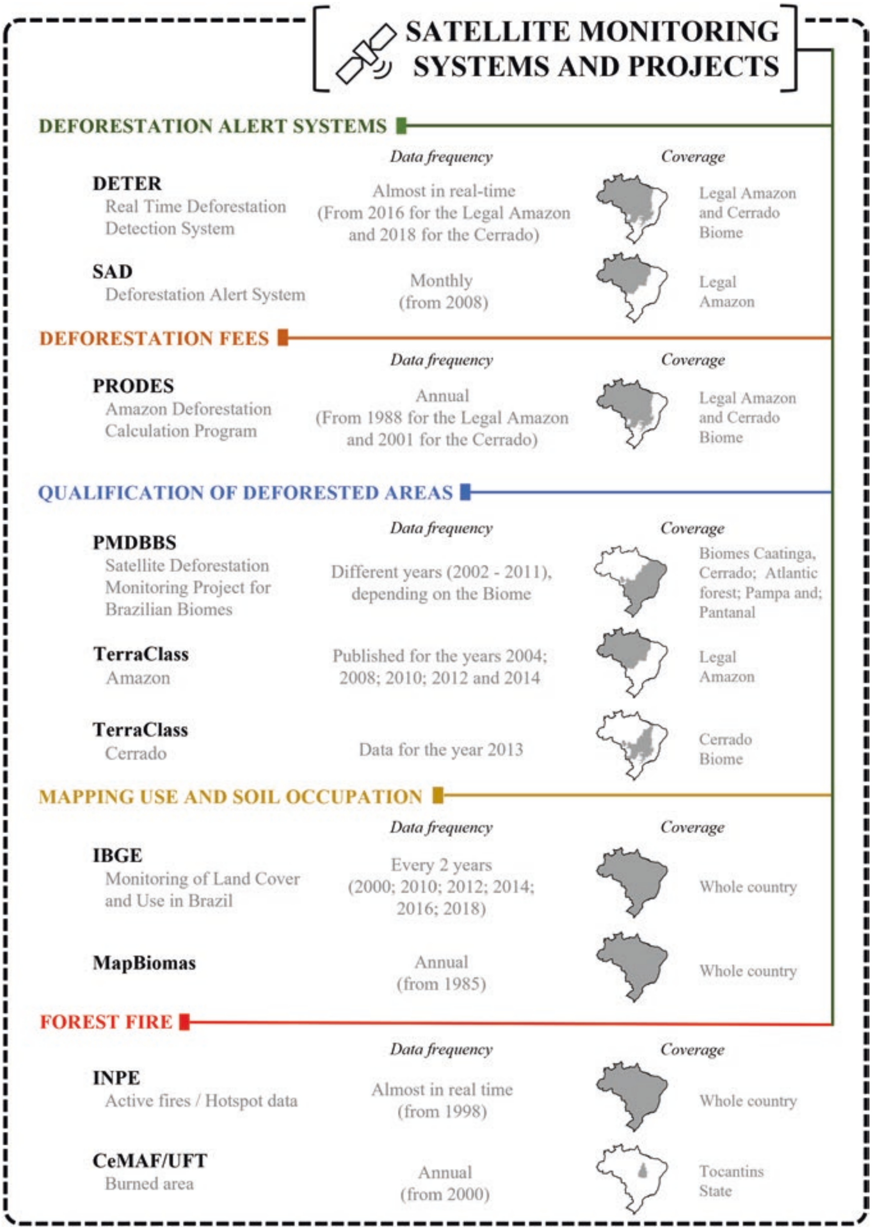

Fig. 17.2 Land-use cover monitoring systems in Brazil

very important, allowing comparison of maps from different programs and with different spatial and temporal scales developing official monitoring data on different forest biomes (MMA 2017a). The program implementation followed three steps: (1) implementation and monitoring of the Amazon and Cerrado (period 2016–2017),

(2) implementation and monitoring of the Atlantic Forest (period 2016–2017), and (3) implementation and monitoring of the Caatinga, Pampa, and Pantanal (2017–2018). However, there is no record of the progress of the Program, nor the achievement of the expected results outlined in the second edition of the *Strategy for the Environmental Monitoring Program for Brazilian Biomes* published in 2017.

A further important step of monitoring systems is the detection of active fires by satellite imagery. The monitoring activities aimed to detect the active spot within the forest fire, to calculate the fire risk, and to map burnt area scars. The platform, developed and operated by INPE, provides data from several satellites in quasi-real time, where outbreaks of at least 30 m long and 1 m wide are detected (burned.dgi.inpe.br).

Land-use and land cover changes in Brazil were monitored by the Brazilian Institute of Geography and Statistics (IBGE) and by the Annual Mapping of Land Cover and Use in Brazil project (MapBiomas). However, INGE aims to spatialize and quantify the land use and land cover of the entire Brazilian territory every 2 years and presents data for the years 2000, 2010, 2012, 2014, 2016, and 2018 (ibge.gov.br). Moreover, in 2015, a new project called MapBiomas was launched through an initiative of SEEG/OC (System of Estimates of Greenhouse Gas Emissions from the Climate Observatory), in collaboration with universities, NGOs, and technology companies, to produce annual maps of land use and land cover in Brazil since 1985 (mapbiomas.org). The project is implemented by the Google Earth Engine platform, which offers a wide processing capacity in the cloud, through extensive machine learning algorithms (Fig. 17.2).

17.4 Mitigation and Adaptation Measures

17.4.1 Preservation and Restoration of Native Forests

In order to promote sustainable forest development by reconciling the use of natural resources with the protection of ecosystems and to make forest policy compatible with other public government policies, the National Forest Program (PNF) was created, instituted by Decree No. 3420 of April 20, 2000 (MMA 2000). The program has broad objectives that range, for example, from encouraging the sustainable use of native and planted forests, recovering permanently preserved forests, supporting economic and social initiatives by populations that live and depend on forests, supporting the development of grassroots industries, and even expanding the domestic and foreign markets for forest products and by-products. The NPF was based on the participative and integrated processes involving federal, state, district, and municipal governments, as well as organized civil society (Brazil 2020). For this reason, the National Plan for the Recovery of Native Vegetation (PLANAVEG) was created as the main instrument for applying the National Policy for the Recovery of Native Vegetation (PROVEG), instituted by Decree No. 8972 of January 23, 2017. As reported in PLANAVEG, implementation, monitoring, and evaluation are carried out by the National Commission for the Recovery of Native Vegetation (CONAVEG) and aim to expand and strengthen public policies, financial incentives, markets, recovery technologies, good agricultural practices, and other measures necessary for the recovery of native vegetation of at least 12 million hectares (Mha) by the year 2030, mainly in permanent preservation areas (APPs) and legal reserve areas (RL), as well as in degraded areas with low agricultural productivity. PLANAVEG is based on eight strategic initiatives: (i) sensitization, (ii) seeds and seedlings, (iii) markets, (iv) institutions, (v) financial mechanisms, (vi) rural extension, (vii) spatial planning and monitoring, and (viii) research and development, designed to motivate, facilitate, and implement the recovery of native vegetation (MMA 2017b). Most of the 12 million hectares mentioned in the PLANAVEG are concentrated in the Amazon and Atlantic Forest biomes with about 76%, while the Cerrado biome represents 17% and the Caatinga, Pantanal, and Pampa biomes together represent 5% of the total goal. Funding to support PLANAVEG came from different sources, such as the government's budget, national and multilateral financial institutions, funds such as the Global Environment Facility (GEF), bilateral government agreements, donations, the private sector, and foundations (MMA 2017b). Established in 2017, CONAVEG was responsible for implementing the plan through two thematic advisory groups: one for the practical implementation of PLANAVEG and one for monitoring vegetation recovery. However, after a few meetings, the groups were deactivated due to the process of implementing the new structure of the Ministry of the Environment (MMA) and the process of extinguishing the federal collegiate bodies. Subsequently, CONAVEG was ended, hindering the implementation of PLANAVEG, due to the loss of the forum for discussion and coordination of actions and standards related to the different strategies adopted by the plan (Crouzeilles et al. 2019).

17.4.2 Financial Incentive Programs for Forest Conservation in Brazil

17.4.2.1 REDD+ in Brazil

The REDD+ (Reducing Emissions from Deforestation and Forest Degradation) program is the most important funding source for promoting the development of strategies for mitigating climate change and protecting tropical forests. In Brazil, the inter-ministerial working group on REDD + works to negotiate and build a national strategy based on discussions on four main points: financial architecture, technical aspects, governance and investment arrangements, and positive economic incentives (Toni 2011).

The Forest Code (Law No. 12.654/2012) became the main tool for implementing REDD+ in Brazil (Euler 2016), as it provides (i) the mandatory Rural Environmental Registry (CAR) for all rural properties in order to monitor the conservation status of forests; (ii) the institution of the Environmental Reserve Quota (CRA), a mechanism for offsetting the mandatory maintenance of forest cover required by law (art. 44, Law No. 12,651/2012); and (iii) the possibility of payment or incentives for environmental service, in order to present additionally for national and international greenhouse gas reduction markets (Art. 41, II, § 4 and § 5, Law No. 12,651/2012).

In Brazil, the national REDD+ strategy (ENREDD +) was developed between 2010 and 2016 to accomplish the rules established in the Warsaw Framework (MMA 2016a). The strategy should have met its objectives within 2020, and thereafter it will be reassessed for the next period of implementation. The general objective is to contribute to the mitigation of climate change through the elimination of illegal deforestation, conservation and the recovery of forest ecosystems, and the development of a sustainable low-carbon forest economy, to generate economic, social, and environmental benefits. The implementation of ENREDD+ should support the decentralization of funding derived by the payments for REDD+ results, promoting the development of a national REDD+ system that acts in an integrated manner at the federal and state levels (May et al. 2011). Moreover, the National Commission for REDD+ (CONAREDD+) was established by Decree No. 10,144 of November 28, 2019, to support coordination and monitoring, to improve the effectiveness of the REDD+ National Strategy, and to prepare the requirements for accessing to the payments for the achievement of REDD+ results. Resolution No. 6, of July 6, 2017, of CONAFREDD+, defines the allocation of payments for emission reductions within the Amazon biome, highlighting that most of the payments (60%) were assigned to the states of Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and the Tocantins. However, two criteria were considered for funding allocation: (i) the area of native forests, conservation units, and indigenous lands and (ii) the deforestation reduction rate. The remaining 40% of payments were for the federal government, for its efforts to conserve native forests in conservation units and indigenous lands and the reduction of deforestation. Funding can be directly allocated to the Amazonian states, or through the Amazon fund of the federal government. For direct funding, each state can define its own REDD+ results-based payment initiatives, beyond the REDD+ resources that they already receive through projects supported by the Amazon Fund. The Amazon Fund, launched in 2009, supports governmental and non-governmental projects in a diversified manner and aims to promote a sharing of the benefits of REDD+ received by the federal government at different scales and to promote the continuous reduction of deforestation (May et al. 2011). The management of the Amazon Fund is carried out by the National Bank of Economic and Social Development (BNDES), which also raises funds in coordination with the Ministry of the Environment, as well as contracting and monitoring the projects and sustained actions. Most of the funding came from Norway (the largest contribution) and Germany. Though to a lesser extent, Petrobrás (Petróleo Brasileiro S.A.) contributes to implementing projects financed by the Amazon Fund. From the beginning to 2017, the amount of funding received exceeded 1.2 billion dollars (MMA 2019).

For the first time in 2012, the Forest Code highlighted the importance of payments for ecosystem services (PES) to implement REDD+ in Brazil. Several federation units approved specific rules, to date, and any progresses about their implementation were reported at the federal level. However, in January 2021, Law 14119 established the National Policy for PES, aimed at contributing to climate regulation and the reduction of emissions from deforestation and forest degradation. Besides, it will support and promote the conservation and recovery of native vegetation, wildlife, and the natural environment in rural areas, forests, and forests located in urban areas, as well as water resources mainly located in hydrographic basins with critical plant coverage.

17.4.2.2 Financing Climate Change Adaptation

The Forest Code contains principles that detail incentives to promote the protection and the preservation of native vegetation, which are essential to the restoration and conservation of the environment (Costa 2016). The National Plan for the Recovery of Native Vegetation (PLANAVEG) aims to strengthen public policies and financial incentives and presents, among its eight strategic initiatives, the development of financial mechanisms to encourage the recovery of native vegetation (MMA 2017b).

One of the main instruments for balancing the sustainable use of forest resources and the mitigation of climate change is credit for financing forest activities. In Brazil, to meet the demands of companies, cooperatives, communities, family farmers, peoples, and traditional communities, financial instruments should support forest management, recovery of native vegetation in permanently preserved areas (APP) and legal reserves, forest plantations for industrial use, forest products, marketing, and working capital (MMA 2016b).

According to the information contained in the Forest Financing Guide concerning the lines in force in the second half of 2016, about 32 lines were available for funding among programs and subprograms, such as the National Program for the Strengthening of Family Farming (PRONAF), the National Program for Supporting the Medium Rural Producer (PRONAMP), the Program for Reducing Greenhouse Gas Emissions in Agriculture (ABC Program), the financing programs offered by the National Development Bank (BNDES), and the Constitutional Funds. Different financial instruments are available to cover wide situations and objectives, depending on the size and type of interested organizations or companies.

17.4.3 Forestry Production

17.4.3.1 Forestry and Production Incentive Policies

According to Antonangelo and Bacha (1998), the development of Brazilian silviculture can be split into three periods: (i) 1500–1965 before the definition of reforestation incentives, (ii) 1966–1988 testing and validity of reforestation incentives, and (iii) 1989 to nowadays use of reforestation incentives. Forestry activity in Brazil began shortly after its discovery, through the exploitation of pau-brasil, which became the main economic activity carried out in the country (Siqueira 1990). At the end of the first period, numerous efforts for planting and restoring forest ecosystems started to support forestry activities, even if these efforts were insignificant compared to the damages that occurred due to the deforestation rate. The few plantations aimed to supply the demand for sleepers and energy for rail transport demand rubber for the pneumatic industry and tannins for tanneries (Valverde et al. 2012). Despite this, in the period 1500–1965, there were mainly pioneering efforts to introduce plantations of eucalyptus and pine species (Antonangelo and Bacha 1998; Santopuoli et al. 2016b).

In the second period, there was a significant development of forestry due to the growth of forest science, the increasing number of forest professionals, the expansion of forest plantations, and the increased interest in the forestry business (Antonangelo and Bacha 1998). In 1966, Law No. 5106 of 1966 was established to support forestry companies, deducting up to 50% of the income tax amount, as they proved investments in afforestation or reforestation (minimum 10,000 trees per year), previously approved by the Ministry of Agriculture. The forest plantations area increased rapidly at the beginning of the second period (1966–1969) with about 310,000 hectares of forest plantations (Hora 2015), which further increased until 1979. Thereafter, there was a slight decrease in the annual average forest plantation area, as incentives were focused on non-timber species with a consistent reduction in tree species (Bacha 2008).

The incentive policies were the starting point and one of the main factors for the expansion of reforestation in Brazil. In the beginning, tax incentives were aimed at the development of reforestation to supply the already existing industries, consumers of paper and cellulose, and the charcoal steel industry, since, close to these units, the natural forest reserves threatened the future supply of the industries (Bacha 1991). The policy incentives represented the starting point for the development of forest plantations in Brazil. They were one of the main factors fostering the expansion of reforestation in Brazil. However, Bacha (1991) highlights that in the long term, incentives can reduce the companies' investments with negative impacts on the forestry and forest ecosystems, and thus it can't be an isolated factor for economic and industrial policies.

As Hora (2015) points out, the establishment of the Forest Code of 1965 (Law 4771, repealed by Law No. 12,651), the Tax Incentives Law (Law No. 5106 of September 2, 1966), the creation of the Brazilian Institute of Forestry Development

(IBDF) in 1967, and the creation of higher education courses focused on forestry in the 1960s opened a new vision of the Brazilian forest policy.

Currently, the forestry sector in Brazil drives the national economy with a sectorial gross domestic product (GDP) of R$ 86.6 billion, which represents 1.3% of Brazilian GDP and 6.9% of industrial GDP. These values grew by 13.1% in 2018 when compared to 2017, while the national average represented an increase in the national GDP of 1.1%, of agriculture and livestock involving only 0.1%, the service sector 1.3%, and the industry in general by 0.6%. In addition, since 2012, exports of forest products have grown by 12.3%, and in 2018, the Brazilian forestry sector was responsible for generating R$ 12.8 billion in federal taxes, corresponding to 0.9% of the entire collection of Brazil (IBÁ 2019).

The most planted forest genera in Brazil are *Pinus* and *Eucalyptus*, being the best adapted to the edaphoclimatic characteristics, having the highest levels of productivity. In the case of eucalyptus, the first studies were carried out at the beginning of the twentieth century, when Edmundo Navarro de Andrade started comparative tests between the genus *Eucalyptus* and native species (Valverde et al. 2012). In recent years, forest masses of this kind have been used to produce charcoal for the steel industry and for the production of cellulose, paper, panels, cleaning products, flavorings, and medicines, in addition to the use of eucalyptus lumber to grow each day (Valverde et al. 2012).

Between 2000 and 2018, there was an expansion (about 70%) of productive forests (IBGE 2020). In 2018, the total area of planted forests in Brazil reached 7.83 million hectares, of which 5.7 million hectares were occupied by eucalyptus (72.8% of the total planted areas), 1.6 million hectares (20.4%) by pine, while other species, including rubber, acacia, teak, and paricá, covered approximately 590 thousand hectares (7.5%). In the period 2009–2018, the surface of the eucalypt plantations increased by 1,013,507 hectares, going from 4.7 to 5.7 million hectares, while pine plantations decreased by 225,415 hectares, from 1.8 million hectares to 1.6 million hectares (IBÁ 2019). In terms of productivity, Brazil has the most productive eucalyptus and pine forests in the world, with an average of 35 m^3 ha $year^{-1}$ and 29 m^3 ha $year^{-1}$ for eucalyptus and pine, respectively. In addition to productivity, Brazil has one of the shortest rotations in the world, when it comes to the time between planting and harvesting trees, both for eucalyptus and pine (FAO 2001). Figure 17.3 shows a graph of Brazil's average productivity and rotation in relation to other important players in the world.

According to the report of the Brazilian Tree Industry (IBÁ 2019), in 2018, there were 7.83 million hectares of planted forests in Brazil, within which 36% for the production of pulp and paper, 29% for round wood, 12% for charcoal steel segment, 10% for financial investments, 6% for wood panels and laminate flooring, and the remaining for other timber products.

The expectations of the forestry sector are to increase the production of planted forests to supply the forest products and services market. In addition to the increase in pulp exports, making Brazil the largest player in the world market, new wood-based products have emerged, such as immunized wood artifacts, chips, and new panels (MDF, MDP, OSB) (Valverde et al. 2012).

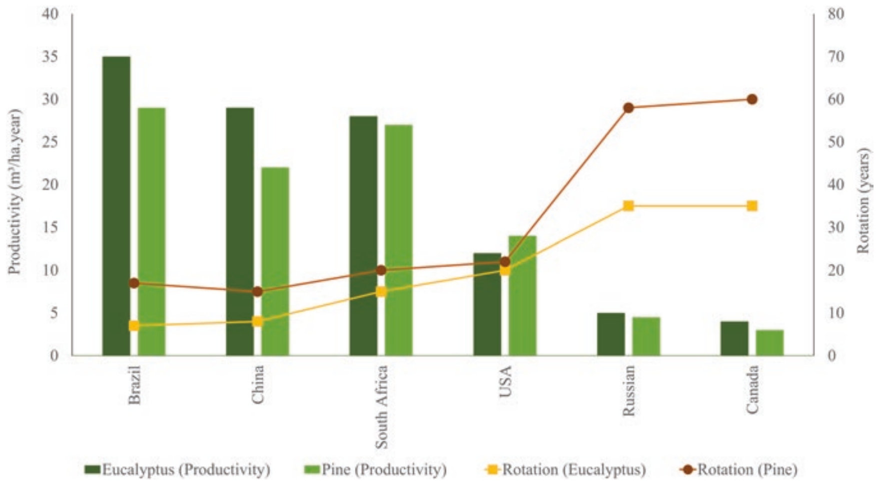

Fig. 17.3 Productivity and average rotation of different pine and eucalyptus producing countries (Source FAO 2001)

The Brazilian Tree Industry (IBÁ) in 2015 carried out a study with scenarios and trends for the planted forest sector (disregarding some factors), presented in the National Plan for the Development of Planted Forests (MAPA 2018), with the following projections until the year 2025: (i) the planted area should have an annual increment rate of 1.2%; (ii) the volume of wood produced would grow at an annual rate of 3.9%. The National Plan for the Development of Planted Forests presents the goal of more than two million hectares planted with commercial forests by the year 2030.

Despite the good expectations of the forestry sector, there are still several hindering factors to the expansion of forestry in Brazil: such as the empirical criticism without technical-scientific foundations of forest plantations; model of land-based forest production, concentrating and under extensive monoculture resulting from the Policy of Tax Incentives for Reforestation (in force from 1965 to 1988) that still persists; environmental management policies with complex legislation that are difficult to apply; the land policy that inhibits foreign investment in Brazilian land; precarious and deficient basic infrastructures for the production; legal regarding constitutional guarantees of property rights and free enterprise; and the scarce resources and policies aimed at research and development, among other obstacles (Valverde et al. 2012; Mendes et al. 2016).

17.4.3.2 Agroforestry Systems

In 2012, the Ministry of Agriculture and Supply launched the Low-Carbon Agriculture Program (Plano ABC) to promote the reduction of GHG in agriculture, to improve the efficiency in the use of natural resources, and to improve the resilience of productive systems and rural communities, including the agricultural sector in the practices of adaptation to climate change. Among other specific objectives, the ABC Plan reports the expansion of technologies: recovery of degraded pastures, crop-livestock-forest integration (iLPF) and agroforestry systems (SAFs), no-till system, biological nitrogen fixation, and planted forests (MAPA 2012).

In the last years, both the agroforestry systems (SAFs) and the crop-livestock-forest integration (iLPF) reached great evidence for their efforts to develop scientific research and projects to promote local development and environmental conservation. Despite SAFs being one of the oldest land-use techniques, currently it represents a recent frontier in the advancement of research and agriculture (Brant 2015). SAFs are gaining more space every day among agricultural enterprises, in view of their economic and environmental heterogeneity and for allowing the exploitation of finite resources in the long term (Steenbock and Vezzani 2013).

The abovementioned Forest Code established general guidelines for the restoration and exploration of legal reserve (RL) areas through SAFs, without distinguishing different SAF types and achievable objectives. In this case, the competent environmental agency is responsible for establishing acceptable criteria and standards for the restoration, exploration, and management of the RL areas (Martins and Ranieri 2014). In this context, Miccolis et al. (2019) highlighted that these knowledge and policy gaps, therefore, leave a wide margin for interpretation, leading to many uncertainties that discourage technicians from making recommendations and farmers to adopt SAFs in these areas. It is important to highlight that the Forest Code promotes the use of SAFs for the restoration of permanent preservation areas (APPs) using exotic species up to 50%, ensuring the maintenance of the ecological functions of native species.

In 2006, the National Forestry Plan with Native Species and Agroforestry Systems (PENSAF) was presented as part of the priorities of the National Forest Program. It established the basic conditions for the development of silviculture with native species and SAFs, directly providing financial income for rural owners and generating economic, social, and environmental benefits for Brazil (MMA 2006b). PENSAF was valid for 10 years with a budget estimated at approximately R$ 90 million distributed among information systems, science and technology, inputs, technical assistance and rural extension, credit, market and trade in forest products, legislation, monitoring, and control. Despite the existence of a program, presented as the first federal public policy for SAFs, its practical implementation is less known, with a lack of documents about the use of financial resources and achieved results, also because of the changes in the technical staff of government agencies.

17.4.4 National Policy on Climate Change

The National Policy on Climate Change (PNMC), instituted by Law No. 12187/2009, appears to formalize Brazil's voluntary commitment to the UNFCCC to reduce GHG emissions between 36.1% and 38.9% of projected emissions by 2020, ensuring that economic and social development contributes to the protection of the global climate. Considering the Brazilian GDP growth (5% or year until 2020) and the additional renewable energy demand, the emission of 3236 million tons CO_2_eq within 2020 was estimated.

Subsequently, Decree No. 9578/2018, which regulates Law No. 12187/2009, fixed the target of the emissions between 1168 and 1259 million tons CO_2_eq within 2020. Moreover, the PNMC established sectoral targets for meeting the aggregate target, the most relevant of which is the 80% reduction in emissions from deforestation in the Amazon, compared to the average verified between 1996 and 2005. At the time of its approval, in 2009, the PNMC Law represented an enormous role for Brazil, since few countries had legal instruments to establish their strategies to face the problem of climate change. In the same year, the National Fund for Climate Change (FNMC) was created, presenting itself as an unprecedented initiative for a developing country, idealized to become one of the most important instruments of politics (Senate Federal 2019).

As one of the instruments of the National Policy on Climate Change, in 2016, the Federal Government's National Plan for Adaptation to Climate Change was proposed to support initiatives for the management and reduction of climate risk in the long term, as established in the Ministerial Ordinance No. 150 of May 10, 2016. The plan was prepared between 2013 and 2016 by the Executive Group of the Interministerial Committee on Climate Change (GEx-CIM), as highlighted in the National Policy on Climate Change (Law No. 12,187/09) and its regulatory decree (Decree No. 7390/10).

Furthermore, Brazilian governments fixed a new target for the year 2025 according to the Paris Agreement signed at the COP21, established in the Intended Nationally Determined Contribution (iNDC). At the end of 2015, Brazil submitted its iNDC proposal and was unique among developing countries in presenting an absolute target (Brandão Jr. et al. 2018), highlighting reductions in GHG emissions by 33% within 2025 and by 43% within 2030, compared with emissions in 2005. Such contributions consist of achieving emission levels of 1.3 GtCO2-eq in 2025 and 1.2 GtCO2-eq in 2030. Between 2004 and 2012, Brazil's GDP increased by 32%, while emissions decreased by 52% (GWP-100; IPCC AR5), breaking the trend between economic growth and increased emissions during this period, reducing the per capita emissions from 14.4 tCO2-eq (GWP-100; IPCC AR5) in 2004 to 6.5 tCO2-eq (GWP-100; IPCC AR5) in 2012. The efforts to reduce emissions were visible with per capita values comparable to those that some developed countries have considered equitable and ambitious for their average emissions per capita in 2030. However, the per capita values should further decrease to 6.2 tCO2-eq (GWP-100; IPCC AR5) in 2025 and 5.4 tCO2-eq (GWP100; IPCC AR5) in 2030.

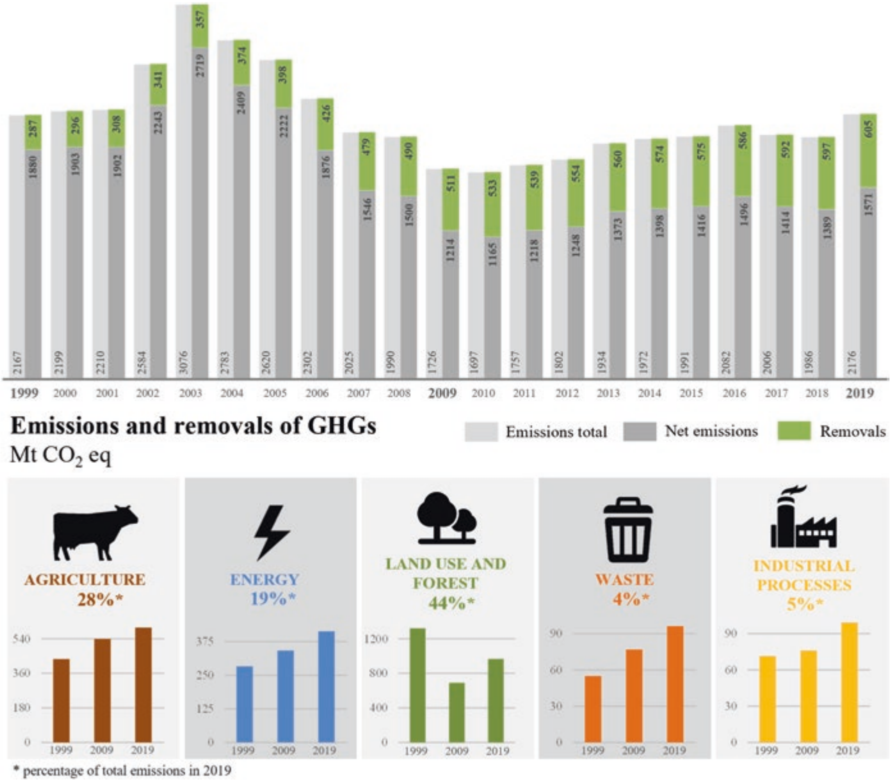

Fig. 17.4 Net GHG emissions from Brazil in $MtCO_2$-eq between 1999 and 2019. (Source SEEG 2020)

Figure 17.4 shows the graph with data on sectoral emissions of greenhouse gases in Brazil between 1999 and 2019 (in millions of tons of CO_2 equivalent, $MtCO_2$-eq), referring to the analysis of Brazilian emissions of Greenhouse Gases and their implications for Brazil's climate goals (SEEG 2020).

17.4.5 Forestry Practices for Adapting to Climate Change

Actions and strategies for climate change adaptation can be effectively implemented if poverty is reduced. According to the definition of IPCC, vulnerability to climate change is the propensity or predisposition of a given system to be adversely affected by climate change, including climate variability, extremes, and dangers. To reduce forest vulnerability and minimize the negative impacts caused by climate change, adaptation strategies are necessary. To increase resilience and reduce vulnerability, poverty must be reduced, and nature must be protected and restored (Scarano and

Ceotto 2015). While adaptation policies primarily address vulnerability and risks, sustainable development policies aim to reduce poverty through economic growth, address inequality through the redistribution of wealth, and prevent environmental degradation using resources sustainably (Agrawal and Carmen We read 2015).

In recent years, ecosystem-based adaptation (EbA), which is based on the use of ecosystem services to reduce human vulnerability to climate change, has gained space between managers and researchers as a new approach to tackling climate change. The benefits of EbA strategies include reducing vulnerability to gradual and extreme events, maintaining the ecological integrity of ecosystems, carbon sequestration, greater food security, sustainable management of water resources, and an integrated approach to territorial management, all of which generate multiple economic, social, environmental, and cultural benefits for society (MMA 2016c). In 2016, Brazil launched the National Adaptation Plan, where EbA is the fundamental part of the plan, even if no spatially explicit subnational priorities were defined in the plan (Kasecker et al. 2018).

Brazil's commitment to the iNDC is explicit in its propensity for EbA, as it states: "The implementation of climate change adaptation policies and measures contributes to building the resilience of populations, ecosystems, infrastructure and production systems, by reducing vulnerabilities or providing ecosystem services." Though there are still few experiences about the EbA implementation, the few applications implemented demonstrated the power of this tool due to the great richness and biological diversity of Brazil and the fact that Brazil has a tradition of community involvement (ICLEI 2014). EbA experiences in Brazil were funded by the International Climate Initiative (Internationale Klimaschutzinitiative, IKI), the World Bank, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the World Wildlife Fund (WWF), and FGV/GVces (ICLEI 2014).

Sustainable forest management of public Brazilian forests is based on mechanisms to promote forest management through (i) the creation and direct management of national, state, and district forests, (ii) the non-contributory allocation of forest management rights to local communities, and (iii) contributory forestry concessions in which the right to manage the forest is defined before the bidding process (SFB 2006).

17.4.6 Integrated Fire Management

Fire plays an important role as a tool for agricultural and landscape management and contributes significantly to the emission of GHG. Historically, fire was used as a tool for several traditional events in Brazil. Over the years, fire control activities have become extremely important on a global scale, and the increasing investments in research, as well as the intensification of fight actions, resulted, for a long time, in the prioritization of interventions aimed at fire-use restrictions (Toni and Pereira 2015). In Brazil, such as at the global level, for a long time, fire is conceived as a threat to the human population and natural resources. For this reason, most of the fire policies aimed to avoid the use of fire and to promote inspection, suppression, and prevention actions through restrictive laws (Falleiro et al. 2016). Nevertheless, the so-called "zero fire" policies commonly led to extensive forest fires, with duration ranging from a few hours to several days, particularly in the protected areas of Cerrado biome (Mistry et al. 2019).

By contrast, in the last decade, the use of Integrated Fire Management (IFM) gained great attention and application in Brazil. Officially, in 2014, the Brazilian government focused to adopt the concept of IFM, mainly in conservation units and indigenous lands, to reintroduce fire as a management tool in the Cerrado biome (Eloy et al. 2019). In particular, to explore and maintain the traditional knowledge about the use of fire, the first experiences with MIF were implemented in the state of Mato Grosso, in 2007, focused on the ecological aspects, such as the effects of fire on animals and fruit plants (Falleiro 2011). The IFM principles consider the use of fire by local communities to promote, as one of the tools, controlled burning in the beginning of the dry season for productive and conservation purposes in fire-resistant vegetation, to create mosaics with different burning periods, and to protect fire-sensitive vegetation from forest fires (Schmidt and Eloy 2020). The IFM consists of training residents of local communities as fire management agents to carry out controlled burning and incorporating ecological knowledge and practices within fire management (Falleiro et al. 2016). Controlled burning in the protected areas can be implemented according to the fire management plan, and it is also regulated by the national forest code. The National Integrated Fire Management Policy (PNMIF) was developed to reduce the occurrence of forest fires and damages caused by fire and to fulfill the need to establish a national policy as highlighted by the Forest Code. PNMIF provides a series of management measures to gradually replace the use of fire in rural areas, promoting the use of fire in a controlled manner, especially among traditional and indigenous communities, and increasing their capacity to cope with forest fires. Nevertheless, the process for PNMIF adoption is still at the initial stages. In the context of the IFM, tools and methodologies have been developed to assist management actions in conservation units and indigenous lands.

The tools that have made a considerable contribution come from remote sensing data, through methodologies that use spectral mixture analysis (SMA) to map vegetation conditions (green and dry vegetation) and soil detection. This methodology is very useful in planning IFM actions, as it provides data that is easy to interpret and apply, which can be assessed by indigenous and local inhabitants through smartphones and generates information on priority areas for the realization of FIM. Despite recent advances in fire management policies and practices in protected areas and indigenous lands in the Cerrado and the consequent results in the reduction of large forest fires, IFM programs are still in an initial stage, therefore requiring new studies and experiences for the improvement of the IFM in Brazil.

In the Brazilian context, IFM plays a crucial role and is strongly recommended to integrate, into the management actions, the local know-how for improving the positive effects of MIF on conservation and resilience of natural ecosystems (Schmidt et al. 2018).

17.5 Final Considerations

Despite the numerous environmental legal institutions, with detailed and complex legislation, the various policies to encourage reforestation and restoration of degraded areas, the extensive protected areas, the technologies of monitoring systems, and the large database of data obtained over decades, among other mechanisms, related to mitigation and adaptation to climate change, more practical actions are strongly necessary to adopt strategies and techniques for the climate-smart forestry. Despite all the positive factors listed above, especially when referring to Brazilian environmental legislation, there is still a great difficulty for public authorities to put into practice the actions to reach the policy objectives. These challenges are exacerbated by complex political frameworks and by continuous changes of structure and competences of environmental agencies belonging to the federal jurisdiction (IBAMA and ICMBio).

As a consequence, a decentralized setting of responsibility was developed, within which the federal government distributed the responsibilities to the states and municipalities regarding monitoring, conservation, and restoration of natural ecosystems and degraded areas through decentralized policies and tools. However, the federal governments remain mainly responsible for the management of natural resources, particularly for public lands, which are very large.

In addition, non-governmental organizations (NGOs) operating in Brazil act in a complementary manner to the actions of the federal government and have thus been playing an important role in mitigating and adapting to climate change in the country. The actions carried out by NGOs put pressure on the federal public authorities to improve their transparency mechanisms and improve the quality of results obtained.

Despite the conflicts that still exist, Brazil is a protagonist and one of the world's pioneers in signing international commitments to reduce GHG emissions, such as the Paris Agreement and the iNDC. This aspect highlights the interest of Brazil to improve the development and future implementation of mitigation and adaptation measures. Moreover, Brazil plays an important role at the global level to face climate change, due to the large forest area, the complex forest structure, and richness of forest biodiversity, across the different biomes, as well as the amount of forest carbon stock.

The abundance of natural resources, and the interest in more effective management of natural resources, including the restoration efforts of degraded natural resources, requires the integration of policies, actions, and tools that support timely monitoring on a large scale. Promoting the use of remote sensing can represent a viable strategy to support researchers and policy- and decision-makers in limiting forest damages, improving resilience, mitigation, and adaptation actions. The harmonization of a large quantity of information, derived from the different databases and platforms, is a crucial point to address in the future to support the development of climate-smart forestry.

References

Agrawal A, Carmen Lemos M (2015) Adaptive development. Nat Clim Chang 5:185–187. https://doi.org/10.1038/nclimate2501

Alencar A, Nepstad D, McGrath D, Moutinho P, Pacheco P, Diaz MDCV, Soares Filho B (2004) Desmatamento na Amazônia: indo além da "emergência crônica", vol 90. Ipam, Belém

Angelo C, Rittl C (2019) Análise das Emissões Brasileiras de Gases de Efeito Estufa e suas implicações para as metas do Brasil, 1970 - 2018. Sist. Estim. Emiss. Gases Efeito Estufa 1–33

Antonangelo A, Bacha CJC (1998) As fases da silvicultura no Brasil. Rev Bras Econ 52:207–238

Assis LFFG, Ferreira KR, Vinhas L et al (2019) TerraBrasilis: a spatial data analytics infrastructure for large-scale thematic mapping. ISPRS Int J Geo-Inf 8:513. https://doi.org/10.3390/ijgi8110513

Bacha CJC (1991) A expansão da silvicultura no Brasil. Rev Bras Econ 45:145–168

Bacha JCC (2008) Análise da evolução do reflorestamento no Brasil. Rev Econ Agric 55:5–24

Bowditch E, Santopuoli G, Binder F, del Río M, La Porta N, Kluvankova T et al (2020) What is Climate-Smart Forestry? A definition from a multinational collaborative process focused on mountain regions of Europe. Ecosyst Serv 43:101113. https://doi.org/10.1016/j.ecoser.2020.101113

Brandão Jr. A, Barreto P, Lenti F, et al (2018) Emissões do setor mudança do uso da terra

Brant HSC (2015) Os Sistemas Agroflorestais com funções ecológicas ressaltadas em áreas de conservação no Brasil. Cadernos da Disciplina Sistemas Agroflorestais 7

Brasil (2016) Pretendida contribuição nacionalmente determinada. 9:10

Brasil (2020) Decreto no 3.420, de 20 de abril de 2000

Costa MM (2016) Financiamento para a restauração ecológica no Brasil. In: da Silva APM, Marques HR, Sambuichi RHR (eds) Mudanças no Código Florestal Brasileiro: desafios para a implementação da nova lei. IPEA, Rio de Janeiro, p 359

Crouzeilles R, Rodrigues RR, Strassburg BBN et al (2019) Relatório Temático sobre Restauração de Paisagens e Ecossistemas, São Carlos

da Hora AB (2015) Análise da formação da base florestal plantada para fins industriais no Brasil sob uma perspectiva histórica

Davidson EA, Artaxo P (2004) Globally significant changes in biological processes of the Amazon Basin: results of the large-scale biosphere-atmosphere experiment. Glob Chang Biol 10:519–529. https://doi.org/10.1111/j.1529-8817.2003.00779.x

de Almeida CA, Coutinho AC, Esquerdo JC, Dalla M et al (2016) High spatial resolution land use and land cover mapping of the Brazilian legal Amazon in 2008 using Landsat-5/TM and MODIS data. Acta Amaz 46:291–302. https://doi.org/10.1590/1809-4392201505504

de Arraes RA, Mariano FZ, Simonassi AG (2012) Causas do desmatamento no Brasil e seu ordenamento no contexto mundial. Rev Econ e Sociol Rural 50:119–140. https://doi.org/10.1590/S0103-20032012000100007

de Falleiro RM, Santana MT, Berni CR (2016) As contribuições do Manejo Integrado do Fogo para o controle dos incêndios florestais nas Terras Indígenas do Brasil. Biodivers Bras – BioBrasil 6:88–105

Eloy LA, Bilbao B, Mistry J, Schmidt IB (2019) From fire suppression to fire management: advances and resistances to changes in fire policy in the savannas of Brazil and Venezuela. Geogr J 185:10–22. https://doi.org/10.1111/geoj.12245

Euler AMC (2016) O acordo de Paris e o futuro do redd+ no Brasil. Cad Adenauer XVII 2:85–104

FAGRO (2007) Mapeamento de Cobertura Vegetal do Bioma Cerrado, Brasília

Falleiro RDM (2011) Resgate do Manejo Tradicional do Cerrado com Fogo para Proteção das Terras Indígenas do Oeste do Mato Grosso: um Estudo de Caso. Biodivers Bras 2:86–96

FAO (2001) Mean annual volume increment of selected industrial forest plantation species. 1–27

FAO and UNEP (2020) The state of the world's forests 2020: forests, biodiversity and people

IBÁ (2019) Relatório 2019 Report 2019, Brasília

IBGE (2019) Produção da extração vegetal e da silvicultura 2019. Produção da extração Veg e da Silvic 8
IBGE (2020) Monitoramento da Cobertura e Uso da Terra 2016–2018, Rio de Janeiro
ICLEI (2014) Adaptação Baseada em Ecossistemas: Oportunidades para políticas públicas em mudanças climáticas. Fundação Grupo Boticário, Curitiba
INPE (2020) Monitoramento do Desmatamento da Floresta Amazônica Brasileira por Satélite
IPCC (2014) Summary for policy makers. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge/New York, pp 1–32
Kasecker TP, Ramos-Neto MB, da Silva JMC, Scarano FR (2018) Ecosystem-based adaptation to climate change: defining hotspot municipalities for policy design and implementation in Brazil. Mitig Adapt Strateg Glob Chang 23:981–993. https://doi.org/10.1007/s11027-017-9768-6
Laukkonen J, Blanco PK, Lenhart J et al (2009) Combining climate change adaptation and mitigation measures at the local level. Habitat Int 33:287–292. https://doi.org/10.1016/j.habitatint.2008.10.003
Lentini M, Pereira D, Celentano D, Pereira R (2005) Fatos Florestais da Amazônia 2005. Instituto do Homem e Meio Ambiente da Amazônia, Belém
MAPA (2012) Plano Setorial de Mitigação e Adaptação às Mudanças Climáticas para Consolidação da Economia de Baixa Emissão de Carbono na Agricultura – PLANO ABC, 1st edn, Brasília
MAPA (2018) Plano nacional de desenvolvimento de florestas plantadas, Brasília
MAPA (2019) Florestas do Brasil em resumo 2019, Brasília
Martins TP, Ranieri VEL (2014) Agroforestry as an alternative to legal reserves. Ambient Soc 17:79–96. https://doi.org/10.1590/S1414-753X2014000300006
Martins OS, Rettmann R, Pinto EDPP et al (2009) Redd – summary of the Brazil case, Brasília
May PH, Millikan B, Gebara M (2011) The context of REDD+ in Brazil: drivers, agents and institutions, 2nd edn. CIFOR, Bogor
MCTIC (2017) Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil, 3o. Ministèrio de Ciência, Tecnologia, Inovações e Comunicações
MCTIC (2019) Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil. Ministério da Ciência, Tecnologia, Inovações e Comunicações. Secretaria de Políticas para a Formação e Ações Estratégicas. Coordenação-Geral do Clima, Brasília
Mendes L, Treichel M, Beling RR (2016) Anuário Brasileiro da Silvicultura Brazilian forestry and timber yearbook 2016, Santa Cruz do Sul
Miccolis A, Peneireiro FM, Marques HR (2019) Restoration through agroforestry in Brazil: options for reconciling livelihoods with conservation. In: van Noordwijk M (ed) Sustainable development through trees on farms: agroforestry in its fifth decade. World Agroforestry (ICRAF) Southeast Asia Regional Program, Bogor, pp 205–227
Mistry J, Schmidt IB, Eloy L, Bilbao B (2019) New perspectives in fire management in South American savannas: the importance of intercultural governance. Ambio 48:172–179. https://doi.org/10.1007/s13280-018-1054-7
MMA (2000) Programa Nacional de Florestas, Brasília
MMA (2006a) Uso e Cobertura da Terra na Floresta Amazônica, Brasília
MMA (2006b) Plano Nacional de Silvicultura com Espécies Nativas e Sistemas Agroflorestais – PENSAF, Brasília
MMA (2013) Projeto TERRACLASS Cerrado, Brasília
MMA (2015) Mapeamento do uso e cobertura do Cerrado, Brasília
MMA (2016a) ENREDD+: estratégia nacional para redução das emissões provenientes do desmatamento e da degradação florestal, conservação dos estoques de carbono florestal, manejo sustentável de florestas e aumento de estoques de carbono florestal. Ministério do Meio

Ambiente. Secretaria de Mudanças Climáticas e Qualidade Ambiental. Departamento de Políticas de Combate ao Desmatamento, Brasília

MMA (2016b) Guia de Financiamento Florestal: 2016. Ministério do Meio Ambiente, Brasília

MMA (2016c) National adaptation plan. Ministry of Environment, Brasília

MMA (2017a) Estratégia do Programa Nacional de Monitoramento Ambiental dos Biomas Brasileiros, Brasília

MMA (2017b) Plano Nacional de Recuperação da Vegetação Nativa, Brasília

MMA (2019) Fundo Amazônia: Relatório de atividades 2019, Brasília

MMA, IBAMA (2011) Monitoramento do desmatamento nos biomas brasileiros por satélite, Brasília

Ometto JP, Aguiar APD, Martinelli LA (2011) Amazon deforestation in Brazil: effects, drivers and challenges. Carbon Manag 2:575–585. https://doi.org/10.4155/cmt.11.48

Pao HT, Tsai CM (2011) Modeling and forecasting the CO2 emissions, energy consumption, and economic growth in Brazil. Energy 36:2450–2458. https://doi.org/10.1016/j.energy.2011.01.032

Parikh J (2000) Inequity: a root cause of climate change. IHDP Updat Mag Int Hum Dimens Progr Glob Environ Change 3:2–3

Rodrigues Filho S, Lindoso DP, Bursztyn M, Nascimento CG (2016) Climate in trance: mitigation and adaptation policies in Brazil. Rev Bras Climatol 19:74–90. https://doi.org/10.5380/abclima.v19i0.48874

Santopuoli G, Cachoeira JN, Marchetti M, Viola MR, Giongo M (2016a) Network analysis to support environmental resources management. A case study in the Cerrado, Brazil. Land Use Policy 59:217–226

Santopuoli G, Marchetti M, Giongo M (2016b) Supporting policy decision makers in the establishment of forest plantations, using SWOT analysis and AHPs analysis. A case study in Tocantins (Brazil). Land Use Policy 54:549–558. https://doi.org/10.1016/j.landusepol.2016.03.013

SBS (2008) Fatos e números do Brasil florestal, São Paulo

Scarano FR, Ceotto P (2015) Brazilian Atlantic forest: impact, vulnerability, and adaptation to climate change. Biodivers Conserv 24:2319–2331. https://doi.org/10.1007/s10531-015-0972-y

Schmidt IB, Eloy L (2020) Fire regime in the Brazilian Savanna: recent changes, policy and management. Flora Morphol Distrib Funct Ecol Plants 268:151613. https://doi.org/10.1016/j.flora.2020.151613

Schmidt IB, Moura LC, Ferreira MC et al (2018) Fire management in the Brazilian savanna: first steps and the way forward. J Appl Ecol 55:2094–2101. https://doi.org/10.1111/1365-2664.13118

Senado Federal (2019) Avaliação da Política Nacional sobre Mudança do Clima, Brasília

SEEG (2020) Seeg 8 - Análise das emissões Brasileiras de gases de efeito estufa e suas implicações para as metas de clima do Brasil 1970-2019. Renew. Sustain. Energy Rev. 3:1–41

SFB (2006) Forest management for sustainable production of goods and services in Brazil, Brasília

Silva CHRT (2010) Cop16, Metas Voluntárias E Reforma Do Código Florestal: O Desmatamento No Brasil E a Mitigação Da Mudança Global Do Clima, Brasília

Siqueira JDP (1990) A atividade florestal como um dos instrumentos de desenvolvimento do Brasil. Congr Florest Bras 6:8–15

Souza CM, Shimbo JZ, Rosa MR et al (2020) Reconstructing three decades of land use and land cover changes in brazilian biomes with landsat archive and earth engine. Remote Sens 12. https://doi.org/10.3390/RS12172735

Steenbock W, Vezzani FM (2013) Agrofloresta – Aprendendo a Produção com a Natureza

Toni F (2011) Decentralization and REDD+ in Brazil. Forests 2:66–85. https://doi.org/10.3390/f2010066

Toni F, Pereira LEC (2015) Fogo nas savanas tropicais da América Latina: entre a criminalização e o manejo. 1–5

Valverde SR, Mafra JWA, da Miranda MA et al (2012) Silvicultura Brasileira – Oportunidades e desafios da economia verde. Coleção Estud sobre diretrizes para uma Econ verde no Bras 39

Verkerk PJ, Costanza R, Hetemäki L et al (2020) Climate-smart forestry: the missing link. For Policy Econ 115. https://doi.org/10.1016/j.forpol.2020.102164