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Chair of Political Economy of Development

Impacts and challenges of reforestation in the Brazilian Amazon

Prof. Silvio Daidone

SUPERVISOR

Paolo Cultrera

CANDIDATE

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Table of Contents

1 Introduction

The Amazon Rainforest is a tropical jungle in the Amazon biome occupying most of the basin of the Amazon River and its tributaries. Home to 3,420 species of fresh water fishes, 687 of amphibia, 633 of reptiles, 1696 of aves, 541 of mammals (Lewinsohn and Prado 2005) and 14,003 species of seed plants, including 6,727 species of trees that can reach more than 10 cm of diameter at breast height and 7,276 species of smaller trees, lianas, vines, shrubs and herbs (Cardoso et al. 2017); the Amazon Rainforest is the most biodiverse environment and the single largest tropical rainforest in the world.

The Amazon is predominantly distributed in the Southern Hemisphere, stretching across the 15^{th} parallel South and the 5^{th} North and spans across 9 countries: Brazil, Bolivia, Colombia, Ecuador, French Guyana, Guyana, Peru, Suriname and Venezuela. The size of the rainforest is uncertain, ranging from 4.2 million (Salgado, Santos, and Paisani 2019) to 6.0 million square kilometres, according to Encyclopaedia Britannica ('Encyclopedia Britannica' 2023a). The reasons behind such discrepancies in the measurement are unclear, but may be due to different classification of forest types resulting from different identification methods.

As shown in Figure 1 the Amazon is composed of a tropical rainforest, characterized by an annual mean temperature of more than 25.2 ± 1.9 degrees and annual precipitation (mm) of 2404.6 ± 677, and a tropical moist forest, with temperatures averaging at 24.5 ± 2.0 degrees and annual precipitation (mm) of 1644.5 ± 512 (C. Xu et al. 2022).

Figure 1: Geographic distribution of forest types classified based on 8 km resolution monthly vegetation and climate data

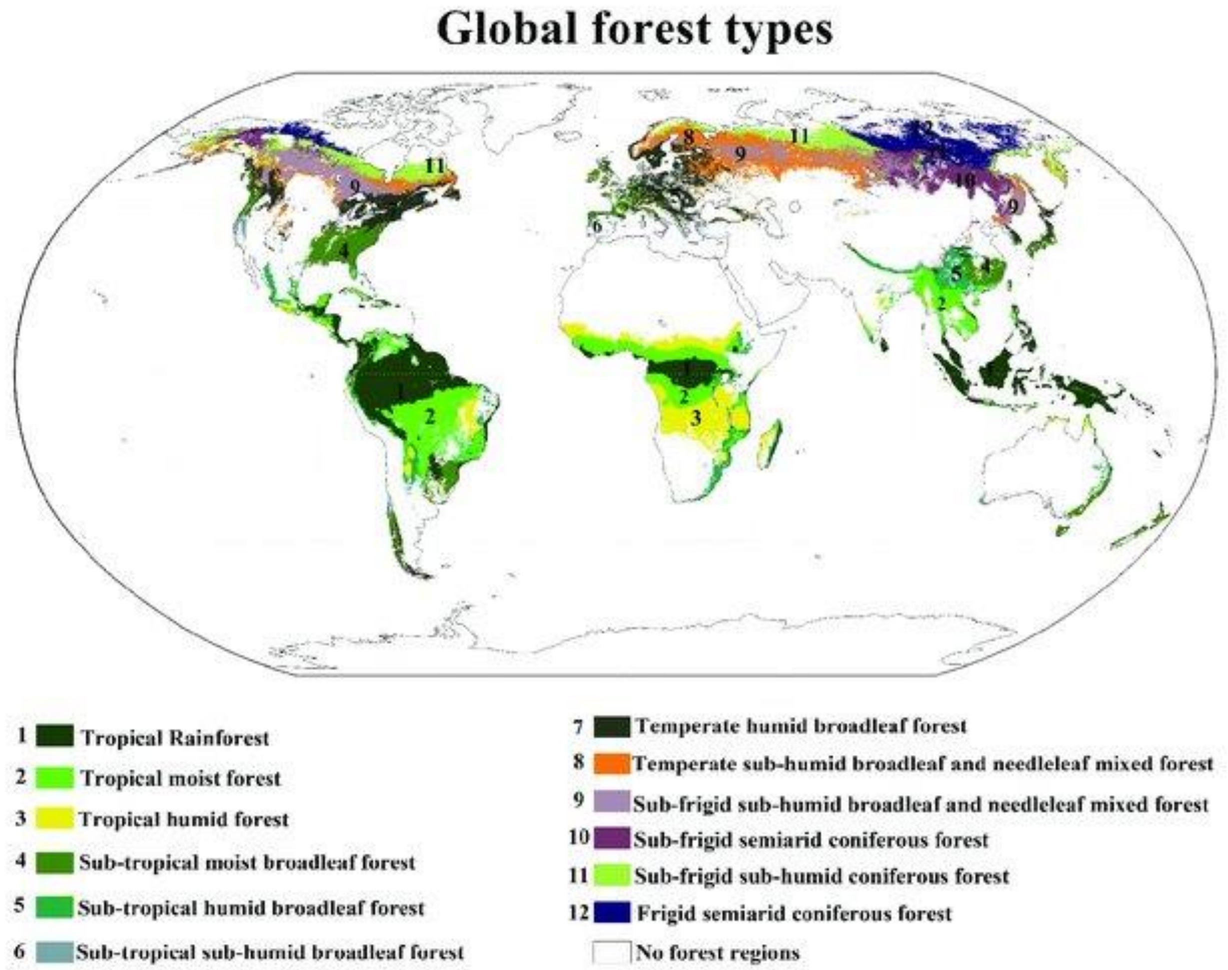

Figure 1

(C. Xu et al. 2022)

The structure of the Brazilian Rainforest consists of four vertical layers: the Overstory/Emergent layer, the Canopy layer, the Understory/Shrub layer, and the Forest Floor/Ground layer.

The Overstory, or Emergent layer, is characterized by trees standing over the neighbouring canopy. These trees evolved extremely light seeds, taking advantage of strong winds for seed dispersal. Amongst these colossal plants there is the Kapok tree, which releases its seeds attached to cotton-like material, drifting it miles away before touching the ground. This layer is inhabited by several aves species and other animals light enough to be supported by tree branches.

The Canopy Layer is characterized by a thick enough vegetation to limit the effects of atmospheric agents. This phenomenon is known as Canopy Cover, and it is essential for the protection of the underlying layers from rainfall and excessive wind force. Unable to reproduce otherwise, canopy plants encase their seeds in fruits. The availability of food and the protection from harsher environmental conditions makes of the Canopy the most densely populated layer of the rainforest.

The Understory, or Shrub layer, is a dark and humid environment. Here, plants developed large leaves to catch the little sunlight penetrating the layers above and large flowers to attract pollinators. The dim habitat thrive with animals which adapted to its features to camouflage efficiently.
The Forest Floor, or Ground layer, is populated by of decomposers and fungi. Their role is crucial since they break down decaying material in nutrients, feeding trees (H. J. Johnson 2023) (Butler 2014).

According to Survival International, the Amazon rainforest is also home to roughly 400 indigenous tribes. While few communities are nomadic and rely on hunting and gathering, most of them developed a sedentary lifestyle, living in villages nearby waterflows and engaging in agricultural activities. In countries like Suriname, the practice of indigenous tourism is seen as a potential source of economic growth. Their unique habitats, cultural heritage, history and handicrafts are the main tourists' attractions (Smith 1989), though, this rush to develop alternative source of income is causing the commodification of the indigenous culture (Whitford, Bell, and Watkins 2001)(Cappucci 2016)

In conclusion, the Amazon rainforest provides multiple Ecosystem Services, which are "the conditions and processes through which ecosystems, and the biodiversity that makes them up, sustain and fulfill human life". (Brauman and Daily 2014). It provides functional and structural environmental services (Cunningham et al. 2015), mitigates the impact of climate change and halts and reverse biodiversity loss. However, detrimental human activities are decreasing the rainforest ability to tackle the effects of global warming and threatening the survival of its flora and fauna.

This document is aimed at describing the environmental and socio-economic impacts of reforestation on the Amazon rainforest, the challenges and drivers of success of reforestation projects and advance key guidelines to implement them. It analyses the Brazilian legal framework to assess which rules and principles reforestation efforts are to comply with. It then proceeds to illustrate the relevant national and international restoration initiatives, and clarifies the meaning and practices associated with reforestation.
With regard to environmental benefits of reforestation, it describes the increase in the performance of the ecosystem services and how reforestation could help tackling the adverse effects of climate change.
As far as socio-economic benefits, it presents financial gains from restoration and carbon programmes, ecotourism and low-emissions development strategies. It then focusses on the underlying technical, cultural, institutional and policy challenges that actors should address throughout all project's stages. In conclusion, it summarizes its main findings and what can be usefully derived from them.

2 Brazilian legal framework and ecological restoration

2.1 Legal Framework

Deforestation, or forest clearance, could be defined as the “conversion of forest land to non-forest land” (Oral 2020). Multiple Non-Governmental Organizations provided different definitions for this practice, and depending on which parameters were considered divergences could arise. For example, in the Manual on Deforestation, Degradation and Fragmentation using remote sensing GIS (Tejaswi 2007) , FAO defines it as “the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold”. Similarly, the United Nations Framework Convention on Climate Change defines it as “the direct human-induced conversion of forested land to non-forested land” (‘Decision 11/CP.7 of the UNFCCC’ 2001). The definitions agree that deforestation is the changing in land-use from forest to non-forest uses, and that temporary tree cutting where forest could regenerate could not be considered as deforestation (Indarto and Mutaqin 2016); but they differ since while the latter considers solely directly human-induced forest clearance, the former addresses also forest losses due to changing climatic conditions.

Deforestation is the result of the combination and interaction among multiple factors. None of these causes could be addressed as the single dominant one, since they are all complementary (Scouvart et al. 2008). Roads, biophysical conditions, extractive cycles, densely populated frontiers, proximity to the market are addressed as the main sources of deforestation (Scouvart et al. 2008).

- Roads are necessary, but not sufficient conditions. They influence deforestation regardless of the economic conditions of the state it occurs.
- Biophysical conditions are crucial in the opening of new frontiers. For example, soil fertility is essential for agricultural activities. Biophysical conditions also influence the intensification of the road network since its complementary action favours a more efficient exploitation of resource-rich areas.
- Extractive cycles contribute to the enlargement of the secondary road system, improving accessibility and attracting new settlers looking for off-farm employment opportunities.
- Densely copulated frontiers are neither a necessary, nor a sufficient condition. Despite their minor role, densely populated frontiers need to be addressed.
- Proximity to the market is positively correlated with deforestation rates. This may be due to lower transportation costs and greater colonists’ propensity to intensify their agricultural production.

Due to its short-term profitability, deforestation is still practiced in the region. However, its implementation is putting under serious threat the fragile ecological balance which favoured the development of such a resource-rich and diverse environment. Defending this stability through the introduction of sustainable practices and regulations has become of paramount importance for the Brazilian government, which has been actively intervening on the matter since the second half of the previous century.

2.1.1 New Brazilian Forest Code (2012)

The New Brazilian Forest Code entered into force on 25th May 2012 through the Act n 12.651. The legislation establishes the general norms on vegetation protection, permanent preservation areas (APP), legal reserves (RL), forest and forest raw material exploitation, control of the origin of forest product, control and prevention of forest fires, and provides the economic and financial tools to achieve these objectives.

The piece of legislation is inspired by the conservation of the forest and its native vegetation, as well as its biodiversity, soil, water resources and integrity of the climate system. It reaffirms the need to ensure a sustainable use of natural resources and the joint responsibility of political actors and civil societies in the drafting of policy aimed at incentivizing sustainable economic practices.

In greater detail, the New Brazilian Forest Code focusses on two special status areas, PPA and RL.

PPA are protected rural or urban areas, covered or not by native vegetation, with the purpose of preserving water resources, landscape, geological stability, biodiversity and promoting the gene flow of flora and fauna. It includes the marginal strips of any natural perennial and intermittent stream, areas surrounding lakes and natural ponds, areas surrounding artificial reservoir resulting from the damming of natural watercourses, areas with a slope greater than 45 degrees, mangroves, sandbanks and the top of hills and mountain (all of them respecting specific standards).

RL are areas within a private rural property aimed at ensuring a sustainable economical use of natural resources of the rural heritage. Every rural property is required to maintain an area covered by native vegetation, with its surface determined by the one of the private property, and ranging from 80% for private properties located in wooded areas to 20% for those located Campos Gerais.
Legal Reserve must be surveyed at the competent environmental agency through the registration in the Environmental Rural Registry of a plan and a descriptive memorandum containing the indication of the geographical coordinates.

However, there are some exceptions.
For instance, public authorities can reduce the Legal Reserve up to 50% for the purpose of reconstruction, when a municipality has more than 50% of the area occupied by publicly owned nature conservation units and from approved indigenous lands. Additionally, public water supply and depuration companies and areas purchased for the exploitation of hydropower potential, in which electricity generation projects, substations or power transmission and distribution lines are installed, are not subject to the establishment of a Legal Reserve (*LEI Nº 12.651, DE 25 DE MAIO DE 2012.* 2012)

2.1.2 Sistema Nacional de Unidades de Conservação (SNUC)

The National System of Natural Conservation Units is the combination of federal, state and municipal conservation units. Its purposes are the conservation and restoration of biological and ecological diversity and genetic resources in the national territory and jurisdictional waters; the protection of endangered species; the promotion of sustainable development and environmental education; the protection of relevant geological, archaeological and cultural characteristics, water and soil resources; and the promotion of ecological tourism.

In the pursuit of these objectives, Article 5 of the 18^{th} July 2000 Act n 9.985 ensure the establishment of necessary mechanisms and procedures for the involvement of the society in the review of the national policy on conservation units and its effective participation in their establishment and management. Furthermore, it guarantees the economic sustainability of conservation units, where possible, and the allocation of financial resources to ensure their effective management. Lastly, it considers the needs of local populations in the development of methods and techniques for the sustainable use of natural resources.

Conservation Units are divided into Integral Protection Unit and Unit of Sustainable Use.

Integral Protection Units are responsible for the preservation of nature by means of indirect use of natural resources. It is composed of:

- an Ecological Station aimed at conducting scientific research and could grant changes in the ecosystem only if these measures are aimed at restoring damaged ecosystems, preserve biological diversity or collect sample for scientific purposes;
- a Biological Reserve aimed at ensuring the integral conservation of the biota without direct anthropic interference of environmental modifications, besides measures to restore altered ecosystems and actions to recover and preserve the natural balance and biological diversity;
- National Park aimed at preserving the natural ecosystem, allowing the conduct of scientific research and the development of educational activities;
- Natural Monument aimed at preserving rare and unique natural sites and sites of great scenic beauty
- Wildlife Refuge aimed at protecting natural environments which conditions ensure the existence and reproduction of species.

Units of Sustainable Use are responsible for the preservation of nature compatible with the sustainable use of part of its natural resources. It is composed of:

- Environmental protection areas. They are wide areas possessing abiotic, biotic, aesthetic or cultural characteristics relevant for the well-being of humans. Their purpose is the protection of biological diversity;

- Areas of Relevant Ecological Interest. They are small private areas with outstanding natural characteristics and hosting rare specimens of regional biota. Their purpose is the preservation of regional or local natural ecosystem;
- National Forests are wooded areas inhabited by native species. Its purpose is to manage the sustainable use of forest resources and scientific research;
- Extractive Reserves are areas inhabited by populations which subsistence is dependent on extractive practices. Their purpose is the protection of these means of subsistence;
- Wildlife Reserves are natural areas inhabited by native terrestrial and aquatic species. It is ideal for studies on sustainable economic management of wildlife resources;
- Reserves for sustainable development are areas inhabited by traditional population, living in the region by generations and which subsistence is dependent on the sustainable exploitation of natural resources;
- Private Nature Reserves are private areas responsible for the preservation of natural diversity.(*LEI No 9.985, DE 18 DE JULHO* 2000)

2.1.3 Treaty for Amazon Cooperation (1978)

The Treaty for Amazon Cooperation is an international agreement signed by 8 South American countries: The Republics of Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela. The treaty was aimed at promoting the harmonious development of the Amazon region and facilitating the fulfilment of the Contracting Parties socio-economic and ecological responsibility. Furthermore, the agreement ensures complete freedom of navigation of the Amazon and its tributaries and promote the harmonization of fiscal and police regulations to favour navigation and trade

Article VII states that the contracting parties will plan the exploitation of the Amazonian flora and fauna to preserve the ecological balance, as well as establish a system for exchange of information and technical personnel to promote scientific research and further their knowledge of the region.

The treaty was the beginning of a long-standing cooperation aimed at fostering the sustainable development of the contracting parties' respective Amazon territories and improving the living conditions of their population.
In February 1995 the *pro tempore* Secretariat of the Amazon Cooperation Treaty organized a regional workshop in the city of Tarapoto (Peru). Here, it was raised the issue of the adoption of a regional document on Criteria and Indicators for Sustainability of the Amazon Forest, it was recognized the value for the food, chemical and pharmaceutical industry of the Amazon rainforest, the need to develop a sustainable production system based on timber/non-timber forest resources and design soil and water conservation plans.

During the V meeting of Minister of Foreign Affairs, held in Lima in December 1995, the delegations agreed on adopting a regional document on criteria and indicators on sustainability of the Amazon rainforest (No.

RES/V MRETCA/6), on arranging further negotiations on measures to prevent the contamination of the Amazon water resources (No. RES/V MRETCA/7), on establishing an institute for research and protection of genetic resources (No. RES/V MRETCA/8), and on developing a joint programme to promote education and environmental awareness at school level (No. RES/V MRETCA/9) (*Amazon Cooperation Treaty* 1978).

2.2 National and Global Initiatives

2.2.1 Amazon Fund (2008)

The Amazon Fund is an early experiment and example of a developing model based on direct access to climate finance. Designed on the model of private and independent trust funds, the project is financed and managed by the National Development Bank (BNDES) and assisted by a steering committee involving federal and state officials, as well as civil society representatives.

The mechanism caught up quickly and implemented one of the first Reduction Emissions from Deforestation and Forest Degradation scheme (REDD). The fund was aimed at supporting and scaling up the implementation of the Brazilian National Strategy for Preventing Deforestation, and at enabling an economic transformation while strengthening the institutional forces responsible for the sustainable development of the Amazon.

The Amazon fund operate on a donation basis and retains only 3% of them for operational costs. Its steering committee establishes the guidelines and criteria for use of its resources and attests the annual report. In the pursuing of its objectives, the programme provided funds for law enforcement, environmental protection and payment for ecosystem services.

Several challenges needed to be addressed, starting off with the tackling of economic and political drivers of deforestation, educating stakeholders on the potentials of the programme, shifting the economy toward a model where low carbon industry could be competitive, and concluding with the development of national climate institutions able to cope with these issues.

The programme was extremely significant since it worked as a benchmark for the following ones. It highlighted the need for an ever-adapting and evolving institution and the need to adopt effective monitoring and evaluation processes to attract new donors (Marcovitch and Pinsky 2014) (Zadek, Forstater, and Polacow 2008)

2.2.2 Action Plan for Prevention and Control of Deforestation in the Amazon (PPCDAm)

The Action Plan for Prevention and Control of Deforestation in the Amazon *(PPCDAm)* is a multistep still-ongoing process started in 2004 and following multiyear plans, PPCDAm-I (2004–2008), II (2009–2011), III (2012–2015), and IV (2016–2020), aimed at preserving the Brazilian portion of the Amazon rainforest through the reduction of deforestation rates and the implementation of sustainable development practices (MINISTÉRIO DO MEIO AMBIENTE 2018). The decline in deforestation rates experience between 2004 and 2012 could be partly attributed by the implementation of said programme, alongside changes in the currency exchange rate and profitability of agricultural activities (West and Fearnside 2021).

The Plan introduced several changes in the Brazilian forestry and conservation policy, adapting pre-existing legislation and introducing new laws, depending on changing behavioural patterns of citizens, corporations and environment. For example, the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) raised the employment standards in its recruitment process, increasing both the number and quality of its personnel to face increasingly complex tasks.

PPCDAm-I prioritized land planning, expanding the network of protected areas and homologating indigenous lands and the development of sustainable infrastructures (West and Fearnside 2021). Furthermore, it improved monitoring capacity through the introduction of the Real Time System for Detection of Deforestation (DETER), a satellite-based system that captures images of the forest, and implemented the concession of rural credit in the Amazon Biome for those presenting proof of compliance with environmental legislation (CMN Resolution n 3.545) (Assunção, Gandour, and Rocha 2015).

PPCDAm-II addressed the major drivers of deforestation, including a) the lack of sustainable economic alternatives; b) the inefficient mutual cooperation among different governmental agencies, partly addressed through the creation of the Inter-ministerial Commission to Combat Environmental Crimes (CICCIA); c) the accessibility of credit for reforestation and recovery of degraded agricultural land (West and Fearnside 2021).

PPCDAm-III prioritized the intervention in blacklisted municipalities, regions with more intensive environmental surveillance, and others in the “Arc of Deforestation”; and the revision of the Brazilian Forest code (2012), which controversial legislation granted amnesty for illegal deforestation prior to 2008.

In conclusion, PPCDAm-IV focused on the elaboration of economic instruments aimed at preventing and controlling deforestation; stopping illegal logging; promoting sustainable agriculture and forest management; and prevent and combat the occurrence of forest fires (‘PLANO OPERATIVO DO PPCDAm’ 2016).

The results of the programme were extremely positive already in the first years of the implementation of the programme. As a matter of fact, conservation policies avoided over 73,000 square kilometres of deforestation between 2005 and 2009, increasing the stocking of carbon dioxide by 2.7 billion tons, valued at USD 13.2 billion (Assunção, Gandour, and Rocha 2015)

2.2.3 National Green Growth Programme (2021)

On October 25th, 2021, the Brazilian Federal government published the Federal Decree n 10,846, which established the National Green Growth Programme (PVNC). The programme is aimed at fostering economic growth through the promotion of sustainable initiatives and at improving the management of natural resources through the creation green jobs. Others objectives include the conservation of the rainforest, the protection of biodiversity, the reduction of greenhouse gas emission, and the facilitation of the transition to a low carbon economy.

Article 5 describes the general guidelines of the programme. It is aimed at encouraging public and private institutions on matters concerning the adoption of initiatives consistent with public policy on the environment and innovation; as well as developing and improving products, methodologies and standards in light of environmental and climatic aspects. It also focussed on the implementation of market instruments and financial mechanisms for climate change mitigation. Other guidelines include the development of sustainable and smart cities, the increase in the use of renewable energies and the improvement of communication and sharing of practices and knowledge related to sustainable economic development.

In the pursuit of these objectives, institutions will be supported by the Interministerial Committee on Climate Change and Green Growth (CIMV), established by the decree n 10,845, responsible for providing technical and administrative assistance to further the PVNC (*DECRETO Nº 10.845* 2021).(FAO 2020b)

2.3 Ecological Restoration

The conversion of natural ecosystem into agricultural, industrial and urban land threatened or seriously damaged the structure and the function of the environment (X. Wang et al. 2004). The adoption of said detrimental practices resulted in the manifestation of phenomena such as pollution, desertification, soil erosion and shortage of freshwater. To face these environmental issues, in the 1980s a new science emerged: Restoration Ecology (X. Wang et al. 2004).

The subject of the discipline is Ecological Restoration, which was defined by the Society for Ecological Development as “an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability.” (University of Wisconsin, Madison and Zedler 2005)
Our planet is extremely biodiverse. It is composed of terrestrial ecosystems, distinguished among rainforest, forest, desert, grassland, tundra, savanna and mountain; and aquatic ecosystems, divided into freshwater (rivers, lakes and ponds) and marine ecosystems. Clearly, a one-size-fit-all solution could not be adopted, and each type require its specific method of recovery and reconstruction. (Peng et al. 2015)

Ecological restoration is often associated with multiple practices, such as:

- Reforestation, which is defined as the “Re-establishment of forest through planting and/or deliberate seeding on land classified as forest.”
- Afforestation, which is a sub-category of Forest Expansion, and consist in the “Establishment of forest through planting and/or deliberate seeding on land that, until then, was under a different land use, implies a transformation of land use form non-forest to forest” (FAO 2020b)

- Invasive species eradication, which refers to the elimination of the entire population of a species. It is a cost-effective solution adopted whenever less radical preventive measures fails. To be successful it needs to be scientifically based, to be supported by relevant stakeholders, to have access to sufficient funding, as well as other conditions. (FAO 2008)
- Urban green space creation, which is an architectural nature-based solution to enhance local resilience while improving the quality of urban settings, citizens' health and well-being and promoting sustainable lifestyles. (WHO 2017)

2.4 Reforestation

According to FAO, reforestation is defined as the "Re-establishment of forest through planting and/or deliberate seeding on land classified as forest." (FAO 2020b). Analysing this statement, a few characteristics of the process and difference with afforestation can be outlined. To begin with, reforestation project occurs on "land classified as forests", meaning that the in the specific area there has never been any change of land use. Therefore, reforestation differ from afforestation since the latter establishes a forest "on land that […] was under a different land use". Moreover, as specified in section 1d of the assessment, reforestation includes planting/seeding "of temporarily unstocked forest areas" and "with forest cover", while excluding natural regeneration. This means that the practice of passive restoration, forest recover occurring when impeding past land use ceases (Meli et al. 2017), must not be address as reforestation.

Similarly, the UN defines reforestation as the "direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land". (UNFCCC 2008)

Both definitions address the need for human intervention, yet the two differ since the former implies the immutability of land use, while the latter includes also "land that was forested but that has been converted to non-forested land".
This discrepancy raises an issue. Indeed, while in FAO's definition the discerning element between afforestation or reforestation was the land use, this criteria no longer apply for UN's interpretation. As a matter of fact, the UN describes as afforestation the "[…] human-induced conversion of land that has not been forested for a period of at least 50 years to forested land […]". Hence, the difference lies in the temporal criteria (UNFCCC 2008).

The following reforestation practices, however, fall within both definitions.

2.4.1 Agroforestry

Agroforestry is a sustainable land practice which integrates tree growing with agriculture and/or animal breeding on the same land (Mukhlis, Rizaludin, and Hidayah 2022). It is associated with several practices, including silvoarable systems (trees/shrubs + crops), silvopastural (trees + livestock), agro-silvopastural (trees + crops + livestock), multipurpose trees, riparian buffer (strips of vegetation aimed at protecting water quality) and improved fallow (fast growing woody species planted during the phase of shifting cultivation). (Rigueiro Rodríguez, McAdam, and Mosquera-Losada 2009)

Agroforestry dates back to the period between 100 B.C. and 450 A.D., when it was adopted by the ancient Mayan civilization alongside wetland management and the use of fertilizer (Fedick and Morrison 2004). Carbonized tree remains and small gravel piles, found in the archaeological site of T'isil, are evidence of the integration of tree cropping, selection of specific tree species while removing others, within home gardens. (Fedick and Morrison 2004)

Due to their small size, agroforests often resemble forest fragments and work as a refuge for tropical biodiversity, as proven by (Bhagwat et al. 2008) who found that on average their species richness represent 60% of that found in neighbouring forest reserves. Their study also suggests that biodiversity is negatively correlated to time from conversion, and positively correlated with less intensive management and the surface area of the canopy cover (Bhagwat et al. 2008).

Agroforestry provides additional beneficial impacts on the environment, including the prevention of soil erosion and landslides, the improvement of soil nutrient availability and soil fertility (Dollinger and Jose 2018), as well as the improvement of ecosystem services through practices like crop rotation, crop diversification and soil conservation (Mukhlis, Rizaludin, and Hidayah 2022). Additionally, it could improve soil water conservation increasing the efficiency of the system in utilizing off-season rainfall (Lott et al. 2003)

In conclusion, the adoption of tree-based farming reduces the risks associated with food insecurity, decreasing the odds by 14 times (Le, Smith, and Herbohn 2014), and improve economic resilience through product diversification, providing an alternative income, and an additional source of food during deficit periods (Mukhlis, Rizaludin, and Hidayah 2022).

2.4.2 Riparian Planting

Riparian planting is the restoration of riparian vegetation along fluvial systems. This practice takes place in the Riparian Zone, "transitional semiterrestrial/semiaquatic areas regularly influenced by fresh water, usually extending from the edges of water bodies to the edges of upland communities" (Likens 2009), which sizes could be determined either setting a distance from the channel or using functional and structural parameters (Dufour and Rodríguez-González 2019)

Riparian planting offer a broad range of ecological functions, which could be categorized in three groups: Energy, Nutrients and Habitats (Dufour and Piégay 2005). Examples are:

- Stream Shading (Energy), which is responsible for providing salmonoid habitat needs, reducing maximum water temperatures and leaving unchanged minimum and mean temperatures (S. L. Johnson 2004) by moderating increasing temperatures from direct exposure to the sun;
- The action of floodplain vegetation (habitat), which improves microclimates of riparian areas, its root strength contribute to bank stability, and its large woody debris generate hydraulic diversity (Dufour and Piégay 2005);
- Increase in litter inputs (Nutrients), which is expected to increase the quantity of particulate organic matter and the diversity of food resources, and hence sustaining biodiversity (Quinn et al. 1997). Of course, different tree species provide different nutrient types to the stream ecosystem, with conifer needles braking down more slowly than Deciduous trees, maples and willows, but providing a longer lasting source of nutrients (Cummins 1974)

2.4.3 Forest Plantation

Forest plantation is a sustainable forest management (SFM) practice consisting in the establishment of “forest stands […] by planting and/or seeding in the process of afforestation or reforestation” (Jørgensen and Fath 2008). Forest plantation strategies could be classified depending on the nature of the species used: either mixed introduced species, mixed native species, mixed species or monoculture species. Due to this extreme versatility of its implementation strategies, forest plantation could be used to satisfy a multitude of purposes.

First, it improves the connectivity among forest remnants (Cunningham et al. 2015) through the establishment of forest corridors. In this way, it is possible to address the phenomenon of forest fragmentation, which is concurrently reducing the total surface area of natural habitats and isolating those remaining, hence preventing the movement of organisms and threatening native biodiversity (Crooks and Sanjayan 2006).

Then, monoculture forest plantation could be used to produce timber, paper pulp, charcoal and fuel through large scale plantation systems. *Eucalyptus*, *Pinus* and *Acacia* are often preferred due to their short-ration period, their competitive advantages over native species (Liu, Kuchma, and Krutovsky 2018). In the tropical region, non-timber monoculture plantation are used for the production of raw materials like palm oil, rubber or bamboo (Chaudhary et al. 2016).

Despite these economic benefits, monocultures are often associated with multiple negative social and environmental impacts. As a matter of fact, the establishment of large scale plantations results in a loss of traditional goods and culture, and often leads to communities dislocation and inequality in the distribution and access to resources (Liu, Kuchma, and Krutovsky 2018). Furthermore, raising single crops increases the risks of diseases and pests, inducing the production of pesticides which might pollute water flows (BALOGH 2021) and alter soil structure, water and soil nutrient balance (Widyati et al. 2022).

3 Environmental Benefits

Reforestation provides a wide variety of services to our society and the environment, making it one of our most valuable assets in tackling climate change and in fixing the damages our planet has suffered because of anthropic detrimental activities. Protecting biodiversity, improving water and air quality and mitigating the effects of global warming are only few of the environmental benefits that stem from this practice, some of which I will outline herein.

3.1 Ecosystem Services

First theorized in the 1970s, Ecosystem Services (ES) could be defined as "the conditions and processes through which ecosystems, and the biodiversity that makes them up, sustain and fulfil human life" (Brauman and Daily 2014).

In 2021, the United Nation Statistical Commission adopted the System of Environmental and Economic Accounting (SEEA), a statistical tool providing multiple services including: a) the measuring of the Ecosystem Extent, surface area of each sorted ecosystem; b) the addressment of Ecosystem Conditions, providing information about the health of the ecosystem and its changes; c) the accounting of Ecosystem Services; and d) the assessment of Monetary Ecosystem Assets, an ever-changing record of ecosystem assets. (United Nations et al. 2021)

This system is revolutionary since it expresses in monetary terms the benefits provided by the environment to the society.

Mapping and classifying Ecosystem services was extremely challenging, and several institutions have attempted to do so. Two of the most important codification efforts were brought out by the United Nations, which financed the Millennium Ecosystem Assessment (MEA), and by the European Environment Agency (EEA), which developed the Common International Classification of Ecosystem Services (CICES).

Both the attempts categorize Ecosystem Service in three broad groups: Provisioning Services, Regulatory and Maintenance Services and Cultural Services (European Environment Agency 2023) (Millennium Ecosystem Assessment 2005a).

3.1.1 Provisioning Services

Provisioning Ecosystem services are "the products people obtain from the ecosystem" (Millennium Ecosystem Assessment 2005b) and are characterized by their tangibility (Layke et al. 2012). In the Millennium Ecosystem Assessment, Food and Fibres, Fresh Water, Fuelwood, Genetic resources, Biochemicals and natural medicines, and Ornamental resources are recognized as the 6 provisioning ecosystem services (Millennium Ecosystem Assessment 2005a). Half a generation later, the EEA will divide these services into biotic and abiotic, and will further categorize them in 15 groups, some of which overlapping with the previous assessment.

I will reorganize some of them in three boarder categories and describe how reforestation projects increase their performances.

3.1.1.1 Terrestrial, Aquatic and Aerial Fauna

Each species has adapted to survive in specific environments, and it is the combination of its characteristics which led to the establishment and prosperity of what became the local *fauna*. These habitats need to provide protection from weather and predators, nourishment and enough space to copulate and reproduce (Yarrow 2009). Therefore, depending on the reforestation project specific taxa will benefit.

A study carried out on the western slope of the Central Cordillera of Colombia on flying mammals shows that naturally regenerated forests can host bat communities, and that nearby *Aliso* plantations provide them additional seasonal resources (Roncancio and Estévez 2007). Human-planted forests may host thriving medium-sized mammals communities, such as coatis and squirrel (Sanchez, Sánchez-Palomino, and Cadena 2008), and present similar biodiversity richness of several non-volant mammals by reducing the Fragmentation effect (DA SILVA 2001). Similarly, also large and medium-size carnivores might benefit from forest corridors connecting isolated forest remnants (Lyra-Jorge, Ciocheti, and Pivello 2008).

Reforested areas bordering with forest fragments increase habitat availability, preventing species extinction (Brancalion et al. 2013). Even if they usually register a lower biodiversity, equal or higher bird richness could be found (Santos Junior et al. 2016), probably due to aves ability to colonize neighbouring hospital environments.
Reforested areas have the ability to host both native and exotic species, with the former thriving in plantation closer to mature forests, and the latter in more distant areas. Both native and exotic bird species prosper on remnant corridors within reforested areas (Pejchar et al. 2018).

In the previous chapter, I have described the role of Riparian planting, which through its shading effect, microclimate regulation and increase in litter input I expect to sustain and increase aquatic biodiversity. As a matter of fact, the population of aquatic detritivorous invertebrates peaks in wintertime, due to the increase availability of litter inputs (Muotka and Laasonen 2002), and the shade provided by riparian plants favour the development of macrophytes (Ceneviva-Bastos and Casatti 2014), which in turn provide feeding for several aquatic organisms, and function as a refuge and a nursery habitat for younger medium-large sized fish species (Sánchez-Botero et al. 2007).

3.1.1.2 Terrestrial and Aquatic Flora

Understorey biodiversity is determined by which species are planted (Cunningham et al. 2015). For example, monocultures do not sustain a significantly higher diversity or abundance of plants beneath the canopy layer than pasture land (Felton et al. 2010), but a mixed species reforestation project might sustain more diverse ecological niches and understorey plants (Larjavaara 2008).

Riparian plantings perform a wide range of services which might benefit aquatic vegetation. Improved disturbed forests along river banks increase and decrease by 3% the streamflow during dry and wet season respectively (Wangpimool et al. 2013), mitigating the effects otherwise drastic seasonal changes on local fauna. Furthermore, an appropriate management of tree vegetation might reduce the effects of thermal pollution, positively affecting submerged microphytes (Kałuża et al. 2020). In conclusion, an increase in forest land along the riverside reduce the sedimentation in waterflows (Ouyang, Leininger, and Moran 2013), improving water clarity and allowing more sunlight to reach out aquatic plants.

3.1.1.3 Pharmaceutical Resources

Medicine could be described as the "the relief of pain [...], or the repair of damage produced by injury or diseases". It first developed as instinctive, common also among other animal species, and then evolved into empirical medicine, developed through experience and aimed at curing "invisible" diseases (Castiglioni 2019). Quickly, sapiens acknowledged the curative power of plants, some which were, and still are, able to relieve pain and cure illness (Castiglioni 2019).

The first ever recorded use of plants for drugs production dates back to the Sumerian clay slab of Nagpur (circa 3.000 B.C) (Petrovska 2012), and few centuries later Emperor Shen Nung wrote the "Pen Ts'ao Ching", a book listing 365 drugs developed from roots and grass, many of which are still in use (U.S. National Library of Medicine 2000). Western civilizations kept on looking for pharmaceutical resources in nature, with Homer describing in his epics 63 plants used as pharmacotherapy, Dioscorides quoting 657 drugs of plant origin in "*De materia medica*" (Petrovska 2012), and middle ages physicians consulting Arabic works on medicinal planting.

Human interest toward plant-based drugs culminated in the 19th century with the beginning of scientific pharmacy (Petrovska 2012), when it experienced its first decline only to come back as a new discipline in the 1980s, plant Pharmacophylogeny (D. Hao and Xiao 2020). The subject was thought to inspire the research of more efficient and less toxic drugs from nature (D. C. Hao 2018). Today, many conventional drugs and antibiotics derive from plants or fungi: aspirin from willow bark, morphine from opium (Vickers 2001), and penicillin, the first antibiotic, produced by a mould (Dunning 2020).

Clearly, managing reforestation projects to protect plant biodiversity for medical purposes is of paramount importance to develop nature-based solutions and improving humans' health.

3.1.2 Regulatory and Maintenance Services

Regulatory and Maintenance Ecosystem services are "the benefits people obtain from the regulation of ecosystem processes" (Millennium Ecosystem Assessment 2005b) and are less tangible than the previous (Layke et al. 2012). In the Millennium Ecosystem Assessment, 9 regulatory services are described, some of which overlapping with the 12 described in the CICES.

I will reorganize some of them in four boarder categories and describe how reforestation projects increase their performances.

3.1.2.1 Air Quality Maintenance

In recent years, the growing frequency of wildfires across the Amazon rainforest has contributed to 95% of total Particle Pollution (PM) in the Brazilian Legal Amazon. Therefore, the population of South America has been exposed to worse air quality conditions, which negatively affected public health. It was estimated that wildfires caused 367,429 DALYs and 9,469 premature deaths in the region (Butt et al. 2021). Preventing all wildfires is unpracticable, but slowing down deforestation and tackling the effects of climate change through ecological restoration initiatives might be do the trick.

In the Air Quality Guidelines (2005), the World Health Organization described the origin and the adverse effects of air pollutants (World Health Organization 2006). The most important are: carbon monoxide (CO), Oxides of nitrogen, sulphur dioxide (SO2), carbonaceous/non-carbonaceous particles and Fine Particulate matter. Besides the latter, all of them form through the process of partial or complete combustion of fossil fuels.

Trees improve air quality by actively removing few of them (O_3, SO_2 and NO_2) through leaf stomata (Nowak et al. 2014), and by changing the airflow within street canyons, which may result in a decrease of fine particulate matter concentration (Gromke and Ruck 2012). Furthermore, an increase in the Leaf Area Density distribution index and deposition velocity result in an increase in the deposition rate of particle pollutant by 39-89%, hence having a positive impact on urban environments (Xue and Li 2017). In conclusion, trees in urban areas could improve air quality by 51% on an hourly basis, as long as it rains with a reasonable frequency and wind speed is weak enough not to resuspend PMs (Riondato et al. 2020).

3.1.2.2 Water Regulation

Plants are essential to regulate water cycle through the process of Evapotranspiration, the "Loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it" (Encyclopedia Britannica 2023b). The phenomenon was estimated to be responsible for reintroducing in the water cycle up to 1400 mm of vapour for regions with an average annual rainfall of 3000 mm (L. Zhang, Dawes, and Walker 2001). This means that in the Amazon rainforest, which yearly precipitation range from 1,132.5-3,081.6mm/yr (C. Xu et al. 2022), evapotranspiration is responsible for 800-1400mm/yr of water reintroduced in the cycle, 45-70% of the total.

Due to their extensive root systems, forests are more efficient in the performance of evapotranspiration than agricultural land, reducing the chances of water runoffs (Cunningham et al. 2015), which are sources of flooding and cause the erosion of streambanks. Evapotranspiration is also crucial to counter the loss of water yields in stream flows. Previous studies proved that plantations have a negative incidence on the intensity of stream flows, reducing it on average by 52% on a global scale (Jackson et al. 2005), and have a greater impact on regions experiencing moderate rainfalls than those with higher ones (Farley, Jobbagy, and Jackson 2005). However, evapotranspiration increases moisture vapor in the atmosphere, increasing the probability of rainfall and hence nourishing water yields (Ellison, N. Futter, and Bishop 2012). Therefore, large scale reforestation project might stimulate more than enough rainfall to outweigh the decrease of water yields.

Reforestation has also the potential to improve water quality reducing the input of sediments and nutrients in stream flows. A study carried out in the Upper Ohio River reported a 92-93% decrease in mean annual organic sediments, with peaks of 97% for phosphorus 96% for nitrogen (Keller and Fox 2019). Even if these results are promising, different reforestation efforts in different environments and biomes might not record similar ones.

In conclusion, reforestation was proven to reduce water salinity. Due to intensive deforestation practices, salt concentration in the Denmark River increased so much that the stream flow became unsuited to provide clean water supplies. In 7 years, reforestation efforts managed to cover ¾ of the previously deforested land. As a result, total dissolved solids dropped by 500mg/L, proving that water salinity could be sustainably managed by the implementation of the appropriate reforestation projects (Ruprecht et al. 2019)

3.1.2.3 Soil Protection and Nutrient Cycling

Soil composition and stability are essential to ensure that it properly perform its six functions: biomass production, water, carbon and nutrient conservation and recycling, habitat for all kingdoms of living things and physical stability (Rabot et al. 2018). Reforestation has the potential to prevent water erosion from impairing soil fertility and decreasing soil organic carbon (SOC) concentration (Lense et al. 2022). This is since plant litter increases the soil's organic material and covers the underlying ground, reducing the detrimental effects of erosion by atmospheric agents (Sakadzo 2021).

Reforestation projects positively influence ground bacterial communities, which in turn influence the biogeochemical cycling of soil nutrients (Hofmann et al. 2016). Microorganisms makes up 10% of the Soil

Organic Matter (SOM), and are mostly responsible for the decomposition and conversion of organic excess into simple inorganic minerals (Sahu et al. 2017). This process is known as "Mineralization of Organic Matter" and results in the production of humus and oxidation of nitrogen, sulphur and phosphorus (Gan et al. 2020), nutrients sustaining autotrophic organisms.

Though, reforestation is not completely harmless for the soil and nutrient cycling. Increase in forest cover, regardless of whether it was human-induced or not, has always been associated with a decrease in soil pH by a global mean of 0.23 units, with larger effects for neutral than acid or alkaline soils (Huang et al. 2022). Furthermore, reforestation could be associated with a reduced groundwater recharge and the phenomenon of salinization of the soil due to the exclusion of freshwater by tree roots (Jobbágy and Jackson 2004). However, these phenomena could be prevented by planting native species and reducing tree density (Cunningham et al. 2015).

3.1.2.4 Pest and Disease Control

Wild environments are often associated with breathtaking landscapes, vivid colours and relaxing sensorial stimuli. Yet, these sites could also be associated with multiple dangers. For example, certain insects thriving in these locations are vectors of infectious diseases (Karjalainen, Sarjala, and Raitio 2010). However, more than often the spreading of these epidemics is the result of unsustainable practices, such as deforestation (Patz et al. 2004). Therefore, engaging in SFM practices like forest plantation might decrease the need to undertake detrimental activities for timber and wood pulp extraction, resulting in a decreased chance of epidemic outbreak.

Forests are a source of several edible products, hence increasing food security and providing dietary diversity (FAO 2020a), which in turn positively effect human health decreasing the chances of developing diseases and other chronic deleterious conditions (Fanelli Kuczmarski et al. 2019). Furthermore, rural population relies on wood fuel for cooking food and purifying water, preventing the spreading of food- and water-related diseases, such as typhoid and dysentery (FAO 2020a).

Throughout the course of eons, forests and other biomes have found an ideal balance among predators and victims, making sure that organisms carrying pathogens harmful for humans and other animals are constantly checked and balanced by their natural enemies. As a matter of fact, the decrease in contact rates among hosts via predation is expected to reduce the chances of pathogen transmission; and infected vectors are often selectively chased down by some predators since more vulnerable (Gallagher et al. 2019).

3.1.3 Cultural services

Cultural Ecosystem services are "are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences" (Millennium Ecosystem

Assessment 2005b) and, same as the regulatory ones, are less tangible than provisioning ones (Layke et al. 2012). These services are beneficial to humankind since favour cognitive development and spiritual enrichment while allowing us to perform recreational activities.

3.1.3.1 Inspiration

Local *flora* and *fauna* have always been a source of inspiration for human beings. Since the last Ice Age, the Amazon rainforest has inspired the painting of our ancestors who just moved in the region, when the jungle was still taking the shapes we know nowadays (BBC 2020). More recently, a 200 photographs exhibition in the Italian National Museums of XXI Century Arts expose the beauty of the Amazon. The show fuse Salgado's impression of the rainforest fragility and its thriving biodiversity with the rustling of its foliage and the calls of its *fauna (Museo Nazionale delle arti del XXI secolo 2022)*

In an attempt to build smart, more resilient, and more sustainable cities, many European metropolis are financing nature-inspired buildings. Examples are the "Bosco Verticale" in Milan, one of the biggest European redevelopment project composed of two residential towers decorate with 800 trees and 5000 shrubs (Stefano Boeri Architetti 2015), and Villa M in Paris, a building with an Amazon-inspired façade representing the sustainable direction our society and our economy are willing to move (Cowan 2022).

3.1.3.2 Spiritual and Religious Interactions

Analysing the course of the relationship between nature/forest and religious beliefs, Jeanne-Lazya Roux and her team suggested that spirituality follows the evolution of the society and the landscape (Roux et al. 2022). The research describes four stages of this relationship:

- Omnipresent Forest Spirituality, typical of populations relying on forests for their survival, hence divine and natural overlap. In this first stage, animistic religions are predominant.
- Religion controlling Nature and Spirituality, typical of populations increasingly controlling the environment they live in. In this stage, humans feels above nature, but still serve pantheistic gods.
- Science and Technology replace religion, typical of societies dominating the environment they live in. Forests become sources of timber, while urbanisation and agricultural activities shift people attention away from nature.
- Immaterial Values driving Re-spiritualization, typical of fully developed societies concerned with human well-being. In this stage, people are inspired by post-materialist values and perceive nature as something offering spiritual and cultural services.

3.2 Economic value of ecosystem services

Assessing the value of ecosystem services is crucial to properly design the appropriate intervention policy in each target area. Their value is influenced by a multitude of factors, varying according to countries and region, evaluation method, type of forest management and forests' specific features. Moreover, the complexity of this task is increased by the fact that ecosystem services are often intangible and hence impossible to properly be economically measured.

First, country-specific factors like GDP pro-capita are positively correlated with the value of ecosystem services, since both extractive products and recreational activities are exchanged in higher quantities and prices in wealthier nations (Grammatikopoulou and Vačkářová 2021). Second, determining the value of ecosystem services all-together prevents the incomplete assessment of their effective value. For example, forest plantation managed for timber production has often been highly evaluated due to hasty market-oriented analysis, which disregarded the added value of externalities and underestimating the value of other ecosystem services (Taye et al. 2021). Then, unprotected forests provide on average 61% more valuable ecosystem services than their protected counterpart, since their easier accessibility eases their exploitation. In conclusion, there is a negative correlation between forest surface area and ES economic value, with the latter decreasing by a mean 18% per each 1% increase of the former (Taye et al. 2021).

Globally, the monetary value of provisional ecosystem services provided by tropical rainforests is around 1,828 Int.USD/ha/year, 2.65% of the total, with pharmaceutical resources being the most valuable at around 1,504 Int.USD/ha/year. The economic value of air quality regulations and water regulation are estimated to be respectively 12 and 342 Int.USD/ha/year, while surprisingly low values for erosion prevention (15 Int.USD/ha/year) and nutrient regulation (3 Int.USD/ha/year) were recorded. The most valuable regulatory ecosystem services provided by rainforests is climate regulation, accounting for roughly 81% of its total value. Rainforest are also the most relevant among all biomes for climate regulation (de Groot et al. 2012).

3.2.1 The economic value of the Amazon Rainforest

More in depth, the value of ecosystem services provided by the Amazon rainforest is extremely diverse. According to Jon Strand, senior economist at the World Bank, and his team, 65% of the Amazon is valued less than 17 ± 2 US dollars per hectare per year, while high value regions, accounting for 12% of the total and scattering across Southern and Eastern Amazon, are worth as much as 56.72 ± 10 USD/ha/yr to 737 ± 134 USD/ha/yr (Strand et al. 2018).

The research focusses on the value added of for ecosystem services: food production, raw materials, greenhouse gas mitigation and climate regulation, while also estimating the value of forest losses due to land degradation and forest fires.

About raw materials, the most profitable activity is timber extraction, especially in those regions characterized by efficient infrastructures and proximity to the market, as they ease the access to forest resources while decreasing transportation costs (Merry et al. 2009). Hardwood and softwood production account respectively for 11% and 89% of total timber production, and each represent 19% and 81% of the total gross revenues. Sustainable practices like reduced impact logging could positively impact the industry extracting raw materials

for an average value of US$20 ± 2.8, and up to US$320 ± 17 per hectare per year in Amapa, Para and Mato Grosso regions (Strand et al. 2018).
However, it must be said that timber extraction is currently negatively affected by EcoFire (economic costs of forest fires), which decreases the profitability of the practice by US$39 ± 2 ha/year on average, with areas suffering recurrently for wildfires paying prices as high as US$183 ± 30 ha/year (Oliveira et al. 2019). This means that forest fires result in a net production loss of 2.4 millions US dollars each year, highlighting the need to quickly shift toward sustainable forestry-associated practices.

Currently, the extraction of non-timber forest products (NTFPs) employs family members of 6,000,000+ households in Brazil, and it is mostly concerned with the production of Brazilian nuts and rubber. In highly productive areas like Calha Norte and southern Amazon, nuts yields could reach up to 30kg ha/yr, worth as much 46 US dollars per hectare per year, while rubber extraction average US$0.56 ± 0.7 ha/yr even in those regions receiving governmental subsidies such as minimum-price regulation. Both goods are recorded to experience an increase in production rates and price nearby residential areas due to the proximity to industries and increased job availability (Strand et al. 2018).
Even if rubber production boosted Brazilian economy in the two decades following the end of the global conflict, unfair competition with extra-national rubber plantation makes of NTFPs an economically unsustainable option for Brazilian households (Jaramillo-Giraldo et al. 2017). Furthermore, Brazil is still not self-sufficient in rubber production due to high consumptions and the spreading of plant diseases like South American Leaf Blight (Luiz Furtado et al. 2020), endangering rubber tappers' identity and preventing the industry from effectively scaling-up.

Through the process of evapotranspiration, forests regulate the water cycle increasing the moisture vapour in the atmosphere, increasing the probability of rainfall (Ellison, N. Futter, and Bishop 2012). Practices like soybeans cropping, beef production and hydroelectricity generation are strongly influenced by regulatory ecosystem services, especially water regulation. Yet, these activities are only viable because of deforestation practices, which result in a decrease performance of ecosystem services. Soybeans cropping and beef production are expected to suffer a slight decrease, respectively averaging 1.81 and 5.43 USD per hectare per year (Strand et al. 2018). Furthermore, depending on the degree of deforestation, negative effects of the water cycle could cause up to 1.84 USD/ha/yr economic losses for hydroelectricity generation. It was estimated that a 40% decrease of forest cover along the Xingu river, as expected by 2050, will lead to a decline in evapotranspiration resulting in a decrease in electricity production by 25% (Stickler et al. 2013).

In conclusion, the Amazon provides a multitude of biological resources, like pollination and bioprospecting. The measurement of their value is often too complex because of our lack of information of their proper functioning, effects on biodiversity and relation with human well-being (Strand et al. 2018). Globally, crop pollination services were evaluated as high as US$195 to US$387 billion per year (Porto et al. 2020).

Agriculture is extremely dependent on pollinator abundance, but it is also responsible for their decline because of agro-chemical use and the engagement in deforestation practices, causing geographic isolation of its population and limiting the flow of pollen (Porto et al. 2020).

3.3 Meeting Restoration Commitments

The increasing pressure of climate change has pushed several Nations to engage in reforestation practices to meet the restoration commitments needed to face the environmental crisis.
On December 17th 2016, during the thirteen annual Conference of the Parties (COP 13) to the Convention on Biological Diversity, the Brazilian Former Minister of the Environment and Climate Change José Sarney Filho declared its Nation's will to "reforest, restore forests and promote the regeneration of 12 million hectares of forested areas by 2030" under the Bonn Challenge, as well as restoring 10 additional millions according to the Low Carbon Agriculture Plan (Plan ABC) (IUCN 2016a).

3.3.1 Bonn Challenge

In 2011, the International Union for Conservation of Nature (IUNC) and the Global Partnership on Forest/Landscape Restoration inaugurated the Bonn Challenge, a programme supported by several governments across the globe, including Brazil, and committed to restore 150 million hectares of degraded land by 2020 (The Global Partnership on Forest and Landscape Restoration 2017). Three years later, the challenge was then extended to 2030 and its restoration targets increased to 350 million hectares under the New York Declaration on Forest, proposed by the UN Secretary General's during the 2014 Climate Summit (UNFCCC 2015).

The two institutions provide an all-level technical support required in the designing and implementation of forest and landscape restoration (FLR) projects, while being directly involved in the sensibilization of local communities on sustainable and environmental issues, as well as securing the interests of all the stakeholders. The IUNC has estimated that more than 2 billion hectares of degraded landscape could be revived through FLR practices, 75% of which could be restored through mosaic restoration, where forests could co-exist with confining agricultural land, and the rest requiring greater reforestation efforts and the engagement of SFM practices (IUCN 2016b).

Restoration is costly, since it requires buying raw materials like seedlings and fertilizers, as well as compensate those employed in the project, logistical expenditures and others. Furthermore, local morphology, the degree of degradation and the restoration models and strategies affect the inherent costs of restoration programmes governments must sustain (UNEP 2010). Unfortunately, the absence of global standards for reporting, and the unreliability of previous literature due to approximation based on mean reforestation costs, makes it harder to properly assess the economic burden of restoration efforts (Verdone and Seidl 2017), which is estimated to be on average 1,276$ per hectare.

Estimating the benefits of restoration is just as challenging. This activity is not profitable if considering only the financial value it produces (De Groot et al. 2013), but considering a broader range of non-market benefits the net balance turns positive. The benefit-cost analysis proves that through the creation of economic incentives, and when accounting for the value of public goods and services and different social discount regimes, achieving the Bonn challenge restoration targets could provide to the global society a net value between $595 billion and $9.25 trillion (Verdone and Seidl 2017).

As of 2020, 74 countries, conservation alliances and private entities have committed 210 million hectares of land under restoration, increasing the efficiency of ecosystem services, agricultural productivity, food and water security and other environmental benefits (Oberle, Flasbarth, and Jagger 2020). According to Restoration barometer, a tool tracking the progress of the project, Brazil has committed to restore 4,28 million hectares, most of which in the Mar Grosso region (BONN CHALLENGE 2023), while Countries like the United States of America have even exceeded their pledge by 2 million additional hectares and few months in advance (IUCN 2019).

3.3.2 Low Carbon Agriculture Plan

The Plan for Adaption and Low Carbon Emission in Agriculture (ABC+) consists in the adoption of new sustainable, science-based agricultural strategies, each one tailored for each Brazilian biome. The plan has begun in 2010, and it is currently in its second cycle (2020-2030), which is expected to outperform the previous one thanks to learning from past experiences and an increased institutional governance (Ministério da Agricultura, Pecuária e Abastecimento 2021)

The strategy will involve an Integrated Landscape Approach applied on a regional-level, while improving monitoring and communication methods, as well as introducing a more precise evaluation system to allow a transparent management of land resources. The whole plan is thought to efficiently and sustainably utilise those areas suitable for agriculture, in a way to preserve and recover degraded landscapes and soils, while improving water conditions and protecting biodiversity.

The adoption of sustainable farming, the control of GHG emissions and the increase of productivity and income are attainable through reforestation projects. Not surprisingly, the ABC+ plans to adopt multiple agroforestry practices, including Integrated Crop-Livestock-Forestry (ICLF), Integrated Crop-Livestock (ICL), Integrated Livestock-Forestry (ILF) and Biological Nitrogen Fixation (BNF), which is the process through which certain plant species (especially legumes) capture nitrogen in the atmosphere, convert it in ammonia and fix it in the ground fertilizing it (de Bruijn and Hungria 2022) (Ministério da Agricultura, Pecuária e Abastecimento 2021).

In the pursuant of its objective, the initiative is thought to provide technical assistance, necessary to ensure the successful adoption of recommended systems and a proper measurement of the results, and to encourage scientific research to widen our understanding of the environment. The programme provides also economic incentives and other market instruments to ensure an additional source of income for the rural population, and include mechanisms for trading carbon credits, so to increase public and private investors' participation (Ministério da Agricultura, Pecuária e Abastecimento 2021).

3.4 Climate Regulation

In the past few years, reforestation has been regarded as one of the most efficient methods to tackle the adverse effects of climate change, due to trees ability to sequester carbon dioxide from the atmosphere and compress it for long-term storage (Andres et al. 2023). This process is known as photosynthesis, and it is the behaviour of photoautotrophic plants to synthesize carbon dioxide and raw sap, while releasing oxygen through leaf stomata and producing glucose (Rodriguez HG 2015).

It was estimated that 4/5 of all global carbon dioxide stored within aboveground biomass is trapped within woodland biomass (Jobbágy and Jackson 2000), and that 70% of carbon dioxide stored within the soil is stockpiled within forests' soil (Batjes 1996). Therefore, forests behave like a "Carbon Sink", which are "Carbon reservoirs and conditions that take-in and store more carbon […] than they release" (UNFCCC 2005). Hence, their protection, growth and maintenance is a cost-effective solution to compensate for GHG emissions resulting from anthropogenic activities (Ciasullo, Simone, and Conti 2014). Its capacity to sequester carbon dioxide is influenced by a multitude of variables, including tree age, specie, climate, human intervention and other environmental aspects. The uncertainties deriving from the complexity of these calculations often makes it preferable for policy-makers and private actors to invest in monocultures (Ciasullo, Simone, and Conti 2014).

Forests' ability to capture carbon dioxide is determined by the "balance between the accumulation of biomass and litter, and the losses from respiration and decomposition of litter and soil" (Cunningham et al. 2015). In turn, this balance is influenced by the type of reforestation projects, since polycultures have the potential to produce greater biomass than monocultures due to a decreased competitiveness for resources (Ahmed, Smith, and Godbold 2019); and by previous land uses. As a matter of fact, the conversion of agricultural land lead to a mean increase of 26% of Soil Organic Carbon (SOC), while the conversion of pasture or grassland leads to a decrease (Laganiã̂ Re, Angers, and Parã 2010)

Tree species influence the forests' ability to sequester carbon dioxide in the soil. Broadleaf species increases the SOC stocks by 25%, while conifers only by 2% (Cunningham et al. 2015). In conclusion, even soil structure and composition determine forests ability to fix C in the soil. Soils with a composition of at least

33% of clay were measured to store more SOC than others, but a causal relationship between this two factors has not yet been found (Laganiãˆ Re, Angers, and Parã 2010).

It is possible to assess the value of climate regulation services (carbon sequestration) by estimating the value of potential payments under REDD+ schemes in those regions under threat of deforestation or degradation due to drought or wildfires. Historically, the emission of one ton of CO_2 has been valued at 5 USD. Therefore, if Brazil was to achieve its reduction targets by 2025, REDD+ programmes could result in 48 ± 9 billion dollars, with the Mato Grosso region and the eastern Amazon generating as much as 100 ± 20 USD/ha/yr (Strand et al. 2018).

4 Socioeconomic Benefits

Besides the economic value of ecosystem services, restoration has often been associated with a wide variety of social and economic benefits, including financial gains from restoration and carbon programmes (PES, REDD+, CDM), low emission development strategies and ecotourism.

4.1 Financial gains from restoration and carbon programmes

4.1.1 PES

Payment for ecosystem services (PES) is one of the most promising solution in tackling the adverse effects of human activity and climate change on the environment, while also addressing poverty and social justice. Consisting in the provision of positive incentives for providers of ES (Kaiser, Haase, and Krueger 2021), payments are often made if the providers' contribution could be proven, implying the need for setting standards for quantification and monitoring of their output.

PES programmes are more probable to achieve their targets when performed at a local or regional level, due to a deeper understanding of social and environmental circumstances arising from the combination of knowledge of local experts, population and indigenous tribes. This, ease also the process of identification of the stakeholders involved and the distribution of costs and benefits (Grima et al. 2016). Moreover, planning a programme at a local level reduces transaction and enforcement costs, while also increasing stakeholders' participation as their appreciation rate decreases the larger the distance from the site (Kaiser, Haase, and Krueger 2021).

Four additional factors influence the outcome of PES schemes. First, successful programmes always provide an additional critical resource to the local population since it increases people's livelihood and well-being. Then, mid- and long-term planning and engagement increases the probability of success (Corbera, Soberanis, and Brown 2009), since long-term commitments are required to establish functioning sustainable management regimes and educate local populations. Third, non-monetary contributions have proven to be more successful than other form of incentives, since it prevents corruption and other sources of unequal distribution of benefits (Jindal, Swallow, and Kerr 2008). In conclusion, PES schemes success is strongly influenced by the type of actors involved. As a matter of fact, private actors, the absence of intermediaries and the degree of trust the local population have for donors positively influence the outcome of PES schemes (Grima et al. 2016).

The determinants of PES schemes participation rate are landowners' eligibility, willingness and ability to participate (Jones et al. 2020). Eligibility is assessed by the possession of formal land titles, probability of future occurrence of deforestation and attended increase in the performance of ecosystem services. Indeed, these high eligibility criteria ensure higher success rates for PES schemes, but substantially decrease landowners' enrolment. Willingness to participate is influenced by both monetary and non-financial incentives. Besides the opportunity costs of conservation and the expected benefits, social perception strongly influence farmer’s participation will. It was found that the bandwagon effect was positively correlated with people’s participation rate. In conclusion, the ability to participate is ground in farmers’ ability to meet the investments required to achieve their restoration commitments. Examples are both human, social and financial capital.

The outcome of PES schemes is still highly debated. Despite the well-documented proofs of their positive effects on the environment, including an increase in forest cover, biodiversity and others, it is rather unclear whether the socio-economic impacts of these schemes on its participants is positive. Some have argued that their implementation has resulted in an increase in agricultural output and consumption and a reduction in labour input. These results are more probable to be achieved under governmentally funded low-rate loan regime (Moros, Vélez, and Corbera 2019).
However, a study conducted by Thang Quyet Nguyen and his team demonstrates a negative impact on participants’ livelihood. The study compared pre-PES and post-PES household income, income from agricultural practices and hired income, and estimated that non-participants had a higher income respect to their counterpart (Nguyen, Huynh, and Hsu 2021). Yet, it must be said that these negative results were found only in 1 out of 5 assessment techniques. Nonetheless, these findings are logically consistent when balancing the opportunity costs of engaging in detrimental practices with the insufficient payments received.

4.1.1.1 Conservador das Aguas

Throughout the course of the last two decades, Brazil has experienced a “PES boom” with more than 70 PES schemes taking place across the country. These projects pursued different implementation methodologies and ecological objectives. Some were funded by a mixture of local municipalities and private partnership with regional committees, such as *Conservador das Águas* in the municipality of Extrema in the state of Minas Gerais; while others were financed by states, like ProductorES by the State Fund for Water Resources (FUNDAGUA) of the Espirito Santo (Zanella, Schleyer, and Speelman 2014).

I will hereby focus on the *Conservador das Aguas* in the city of Extrema because of its long-term commitment, outstanding results and high participation rate. The still-ongoing pioneer project began in 2005. It was aimed at planting forest corridors and guarantee socio-economic sustainability for the rural population living along the river Piracicaba and Jaguari. Water courses have an overall drainage area of 1.165,88 km² (Cruz et al. 2020), a critical source of water supply for the 19 million inhabitants of the Sao Paulo metropolitan area (Bremer et al. 2020). The programme was funded by the municipality of Extrema and was supported by several institutions, including the Piracicaba-Capivari-Jundiaí (PCJ) Watershed Committee, Nature Conservancy and the National Water and Sanitation Agency (ANA).

Since its beginning, 53 of the 108 landowners joined the programme, accounting for 90% of the land area. Farmers’ decisions were influenced by legal concerns, the compliance of their neighbours and the additional income received for complying with the forest code. Each participant would have been given 95 USD/ha/yr, adjusted each year to the inflation and based upon the opportunity cost of producing beef and diary products. Payments were allocated monthly and were first financed by the municipality, but with the increase in the enrolment rate additional funds were provided by the Municipal Public and Private Fund for PES (FMPSA) (Richards et al. 2015).

The first part of the project effectively began in 2007 with the fencing of forest remnants with enough potential to sustain passive restoration and then active reforestation to reclaim degraded land. Furthermore, 30 biodigestors and 50 water reservoirs were built to monitor soil erosion and water resources. In this stage, the project was highly dependent on external technical support, but in only two years it quickly increased its capacities. By 2009, the new financial mechanism (FMPSA) was set up and the programme expanded concluding contracts with landowners in the Salto sub-basin, while also starting to sell carbon credits in collaboration with TNC to finance further expansions (Richards et al. 2015).

In 10 years, the project had already reforested 6,135 hectares, increasing groundcover, and hence securing direct soil protection, biodiversity, and quantity and quality of water in the region. Though, since 2006 the urban area of Extrema has increased by 4.6 times, reaching 2,815 hectares in 2018. This was due to the establishment of multinational industries attracted by a lower tax burden, increasing job availability and resulting in said rapid urbanization process, which ultimately led to the conversion of forest land for agricultural and other purposes. The programme successfully tackled the negative outcome of this rapid expansion, since overall there was an increase in regional forest cover of 1.597,56 hectares, or 6.53% of the county area (Cruz et al. 2020).

The PES scheme was so successful that by 2016 the Secretary of Environment of the Municipality of Extrema scaled it up instituting the Mantiqueira Conservation Plan, including 425 municipalities within the Mantiqueira region and pledging 1.5 million hectares by 2030 (‘Conservador Da Mantiqueira’ 2016).

4.1.2 REDD+

REDD+ is a further development of the UN Reducing Emissions from Deforestation and Degradation (REDD), which includes the “sustainable management of forests, and the conservation and enhancement of forest carbon stocks” (FAO 2023). REDD+ schemes were thought to be developed at a national level and are aimed at commodifying carbon dioxide stored in forest biomass to reduce GHG emissions and tackling the side effects of climate change (Pasgaard et al. 2016). Since the Paris Agreement were reached in 2015, more than 50 million hectares have been pledged through 416 REDD+ programmes (IDRECCO 2020) and were expected to positively impact forest-dependent communities.

Setting up successful REDD+ projects is extremely complex since it entails the coordination of several factors.

First, developing a REDD+ programme at a national level could reduce the implementation costs while also exponentially reduce carbon emission, but since poor forest-dependent communities are the most affected by these programmes it was argued that they should lead and implement them. Therefore, a nested approach starting at a subnational level and then flowing in a national one might be the solution.

It was proposed to finance REDD+ projects selling carbon credits on the voluntary carbon market, hence helping rural communities in diversifying their income, but these incentives might increase government intervention and leading to the displacement of indigenous tribes and local communities. Furthermore, REDD+ could have a negative impact on food security, reducing land availability, shifting the production to cash-crops and hurting the most vulnerable farmers engaging in subsistence farming.

In conclusion, if no monitoring mechanism is set up, REDD+ could pose a risk to biodiversity. Even if there are already positive reports, improper REDD+ projects implementation could lead to the development of forest plantation and monocultures, resulting in an increased forest ability to capture and store GHG, but endangering biodiversity (Bayrak and Marafa 2016).

An analysis of the cross-country outcomes of REDD+ projects suggests that local communities are rarely involved in the decision-making process, despite their substantial role in the implementation and success of said initiatives. Few cases reported limited sharing of knowledge with native populations, especially with women and low-income rural inhabitants; while others demonstrate how REDD+ projects have *de facto* reduced gender inequalities increasing women's participation in decision procedures (Duchelle et al. 2018). While few countries have experienced low participation rates, mostly because of a lack of education and trust and fear of land-grabbing; several others did not. This was mostly due to increased perception of projects' reliability, increased jobs availability, income diversification and increased food security.

Besides Uganda, all countries have experienced an increase in forest cover, boosted by a gradual decrease of self-reported forest clearing. Furthermore, most countries have measured a mean reduction in forest areas struck by wildfires and an increase in forests' performances of regulatory ecosystem services. Despite case reports from Nigeria and Vietnam demonstrated a negative impact on local livelihood, other countries have experienced a slight or concrete increase. However, the diverging outcome of these two cases could be explained by rigid restrictions on forest access. In conclusion, REDD+ projects seem to fail in properly addressing land tenure, arising from resource conflicts and the non-participation of local communities in the decision-making process (Duchelle et al. 2018).

4.1.2.1 Carbonext

In 2021, the Secretariat of the Amazon and Environmental Services of the Environmental Ministry enacted the technical note n.353/2021, which lays the foundation for the implementation of the *Floresta + Carbona* programme, previously developed by the *Resolução nº 03, de 22 de Julho de 2020* of the National Committee for REDD+ (CONAREDD+). The programme is aimed at stimulating the national voluntary market for carbon credits actively engaging private actors in the preservation of natural resources. Therefore, the resolution allows private companies to buy carbon credits from sellers who had produced mitigating effects on climate change.

Industry leader Carbonext quickly began developing and monitoring several REDD+ projects in the Amazon. The company generates and trades carbon credits globally on the voluntary market while conserving 1.6 million hectares of Amazon rainforest, protecting 1300+ animal and plant species and employing more than 900 households (‘Carbonext’ 2023). Carbonext directly manages the Fortaleza Ituxi REDD+ project, a 30-years project beginning in 2013 and currently preserving 46,592 hectares of rainforest in the municipality of Labrea, located nearby the Arc of Deforestation. The project is expected to capture 4.2 million tons of CO^2 from the atmosphere, as well as establish seedling nurseries, producing up to 50,000 native species per year, and improve socio-economic well-being of the inhabitants of the region by increasing job availability and promoting education (Carbon Neutral Pty Ltd 2021).

4.1.3 CDM

Clean Development Mechanism (CDM) is defined in Article 12 of the Kyoto protocol as the reciprocal assistance among states in achieving sustainable development, pursuing the objective of said international agreement, and meeting their emission reduction and limitation commitments (United Nations 1998).

The general guidelines of the mechanism are provided by the Conference of the Parties, while the activities are supervised by the CFM executive board (art 12.4). Participation to these projects is open for both public and private entities (art 12.9). Each of the emission reductions (CERs) are certified by operational entities designed by the Conference and need to prove their effective long-term effects in tackling climate change. The Conference was also responsible for the elaboration of standard procedures (art 12.7), as well as ensuring that part of the profits from certified projects will be devolved in the assistance of developing countries, especially those vulnerable to the adverse effect of climate change (art 12.8).

In the implementation of environmentally-friendly CDM projects, countries need to address a multitude of challenges and risks associated with either national cultural and political traditions or the gaps left by the Kyoto protocol itself. For starter, CDM project were approved solely on their potential to reach GHG emission reduction objectives, while neglecting their impact on local populations and other ecosystem services. As seen in previous chapters, forest plantation and monocultures are more efficient in capturing carbon dioxide and hence producing CERs, but negatively affect both biodiversity and nutrient cycling in the soil. Clearly, there is the need to complement CDM projects with others addressing environmental threats posed or omitted by their implementation. Few projects are unable to effectively finance alternative renewable sources of energy while also decreasing fossil fuel dependency in developing countries. This is since the evaluation procedure consider solely the reduction of GHG emission as the parameter, neglecting carbon leakages, the increasing emissions in other sectors. In conclusion, the lack of an appropriate legal, cultural and institutional framework at a national level could further endanger the successful development of CDM projects (Aigbokhaevbo 2022).

CDMs are mostly concerned with the reduction of GHG emissions and the sustainable development of global economies. Since their first theorization, China has been the leading economy in their development. Few studies have been conducted on their socio-economic and environmental effects, but most of them suggest promising results. A study over 30 cities in China have proven that CDMs do positively effect air quality conditions (L. Wang et al. 2019), improving public health and reducing the incidence of DALYs (Butt et al. 2021). Furthermore, the analysis of the effects of reforestation and afforestation (A/R) CDM projects implemented in several Chinese counties suggests that they have a prominent role in boosting the economic output of local communities (Hu et al. 2021). The study argue that CDMs' economic benefits are to be expected in the long-run. Indeed, while non-significant changes in economic growth occur in the first 6 years, from the 7th year onward participant communities outperform the control group. These positive economic outcomes derive from CDMs' ability to optimize the regional industrial structure, increasing the levels of fixed-asset investments, regional capital stock and indirectly raising government fiscal revenues and expenditures (Hu et al. 2021).

Clean Development Mechanisms are costly and require two or multiple sources of funding. However, more than 8 thousand project have been registered, with 28.54% of the already selling carbon credits. In south-eastern Europe, multiple countries have already implemented few energy-production-related CDMs and have proven to be extremely efficient in reducing GHG emissions. Italy- and UK-financed wind parks in Montenegro, Hydroelectric projects in Bosnia, Montenegro and Albania have recorded extremely promising results. More specifically, the HPP Ashta project in Albania had an outstanding outcome, with a ratio of investments/emission reduction of 3.106,27 (Cansino, Román-Collado, and Nassar 2022).

4.1.3.1 Vale Florestar

Latin America is the second most prolific continent in establishing CDMs, with Brazil alone authorizing 227 projects, or 2% of the total global initiatives. As of 2015, Brazil had issued 76 billion CERs (59.34% of the total South American output) and it was the fourth most copious country in the world (Watts, Albornoz, and Watson 2015). 88% of the 5,193 certified projects were either involved in the production of biofuels or renewable energy, with Brazil promoting respectively 92 and 116 projects.

In 2012, Brazil authorized the *Vale Florestar* CDM project, a subset of the larger Vale Florestar reforestation plan. The 15-years-long project was aimed at reclaiming degraded tropical land along the Deforestation Arch through the plantation of 7.124 hectares of *Eucalyptus urograndis*. The reforestation site would have been rented from local landowners and then given back after 15 years, leaving plantation in place and hence granting farmers harvesting opportunities at insignificant costs.

The project was thought to lead to the establishment of a local market for renewable timber products, reducing predatory logging and increasing carbon stocks, and the expansion of agroforestry practices in the region. The implementation followed a multistep procedures starting with planning and soil sampling, going through the steps of area preparation, planting and irrigation, and finishing with fertilization and maintenance. Only then, raw materials could have been extracted, transported and commodified (CDM Executive Board 2012).

Forest implementation costs were estimated to be around 3,884 Brazilian dollars per hectare, multiplied by the 7,124 hectares expected to be planted and by the 15 years period of the commitment. Additional costs included the land lease price per hectare (at around 200 R$/ha) multiplied by the lend lease period, as well as salary expenses, materials, infrastructures monitoring systems and taxes over profits and revenues. The result of the investment analysis resulted in a fixed price for CER at 4.5 USD, leading to an Internal Rate of Return of 1.61%, below the baselines scenario. Therefore, only 20% of the planned area was *de facto* reforested (CDM Executive Board 2012).

4.2 Low-Emission Development Strategies

Low-emission development strategies (LEDS) are described by the OECD as “forward-looking national development plans or strategies that encompass low-emission and/or climate-resilient economic growth” (Clapp, Briner, and Karousakis 2010). LEDS could be brought out and financed by national and local governments, private and public institutions and actors, and the international community. LEDS can identify and estimates challenges, costs and distributional impacts of mitigation actions, promote synergies between economic growth and sustainability, facilitate monitoring and control activities and build political and popular consensus through inter-ministerial coordination and education.

The drivers of LEDS are often economic development priorities, sources and sinks of GHG emissions and vulnerability to the adverse effects of climate change. Each priority is addressed by *ad-hoc* strategic plans assisting countries in pursuing a low-carbon economy and achieving sustainable development (Averchenkova, Christov, and Yessenova 2010). In the implementation process several technical, institutional or policy challenges could arise. Examples are data collection, handling and costs estimation (technical); lack of inter-ministerial coordination (institutional); and strategy elaboration and balancing between economic growth and sustainability (policy) (Clapp, Briner, and Karousakis 2010).

Sustainable agricultural practices, land-use planning and sustainable forestry management are few examples of these activities balancing the economic, social and environmental interests. These practices may be carried out under Nationally Appropriate Mitigation Actions (NAMAs), which are expected to foster low-carbon development in the forestry sector as well as in the energy and transportation one.

4.2.1 Brazilian Nationally Appropriate Mitigation Actions

The Brazilian Nationally Appropriate Mitigation Actions was first presented at the UNFCCC in 2011, and pointed out Brazil's willingness to anticipate its mitigation actions, leading to a 36.1% decrease in GHG emissions by 2020 (UNFCCC 2011). The national plan is extremely diverse, including energy-related solutions, deforestation reduction commitments and other ecological restoration projects.

Some of these mitigation plans embracing reforestation were already covered in the previous chapters: the Plan for Adaption and Low Carbon Emission in Agriculture (ABC+) and the Action Plan for Prevention and Control of Deforestation in the Amazon (PPCDAm). Therefore, this section will describe the attempts to replace charcoal from deforestation with the one from forest plantation, leading to substantial reduction in GHG emissions.

The Charcoal Sustainability Protocol (2012) is a joint initiative launched by the Brazil Steel Institute and other participating private companies aimed at increasing the sustainable production of charcoal. The protocol inspired its members to foster sustainable development in the respect of national environmental legislation, keep commercial relations only with parties complying with Brazilian legal and environmental standards and match the production demands through either privately owned or third party plantation (Instituto ACO Brazil 2015). Of course, the Sustainability Report control mechanism was set up forcing private companies to periodically report the progress.

In 2014, 11% of steel was produced by plants adopting charcoal as energy source. 85% of these charcoal was produced by privately owned plantations, 8% by those managed by third parties and the remaining from legal forest wastes. 842.200 hectares were actively reforested to produce sustainable charcoal, and those areas which protection and restoration projects were managed autonomously even surpassed legal requirements and expectation.
Half of the steel produced starting from sustainable charcoal (52%) was certified by Forest Stewardship Council International, an institution aimed at assessing that raw materials are not produced harming the environment, and 13% receive certification by the Brazilian Forest Certification Program.

Unfortunately, in the same year Brazil experienced a severe economic crisis due a decrease in external demands, and the subsequent fall of commodity prices, and a large scale corruption scheme of politicians and private corporations. Clearly, the steel industry was negatively affected, experiencing a 0.93% decrease in the employment rate in 2014 and then 4.04% in 2015. Therefore, it was impossible to assess the short-term socio-economic outcome of these manoeuvres, and their expected benefits in standard economic conditions.

4.3 Ecotourism

Ecotourism is “subset of the tourism industry that reflects an ethos of responsible involvement with the environment and with local cultures” (McKinney 2016). Ecotourism involves a multitude of activities, such as hiking, diving, wildlife viewing and others and it is the fastest growing business in the tourism industry. Service providers are often small local businesses, which minimize the detrimental effects of tourism on the environment while also generating an economic return and alternative job opportunities for local communities (UNWTO 2006).

Tourists are increasingly more concerned about the environment, and the rise in the demand of sustainable tourism experiences is proved by the growth of the ecotourism market, which has been growing thrice as fast as the conventional one. Examples are the Hol Chan marine reserve in Belize, which experienced a 49.7% increase in between 1991 and 1996, and the country of Costa Rica, where 53% of the national gross income derives from ecotourism and related activities (Das and Chatterjee 2015). In 2019, ecotourism was worth 181.1 billion USD and was expected to increase by 87% by the end of 2027 (Statista 2019b).

Ecotourism was thought as a strategy to preserve biodiversity, providing an alternative to natural resources exploitation and increase the livelihood and well-being of rural population and indigenous tribes through income diversification and micro-enterprises development. However, balancing biodiversity conservation and poverty reduction is an extremely challenging task, and ecotourism service providers failures in addressing this issue have risen multiple criticism to the practice (Das and Chatterjee 2015).

In the fulfilment of their promises, local business owner need to face several challenges. First, they need to develop an appropriate compensation mechanism for indigenous tribes, entailing an appropriate distribution of economic profits and addressing land insecurity. Second, an effective mechanism should be developed to prevent distorted competition from limiting the access to tourist resources to complementary sectors, such as those providing highly demanded tourist products and services. Third, uneven income distribution between stakeholders needs to be properly managed to prevent the ecotourism ecosystem to fail. High income job opportunities are often open exclusively for outsiders, threatening and limiting local populations rights. In conclusion, ecotourism has often been associated with compulsory displacement, leading to homelessness (Das and Chatterjee 2015).

It could be argued that Brazil is not the leading economy in the development of ecotourism associated with reforestation projects, however substantial funding and political incentives are expected to boost these initiatives.

A joint survey of the Brazilian ministry of tourism and the ministry of the environment estimated that in 2018 the total value of Brazilian ecotourism was worth as much as 8.6 billion R$ (3.1% of the national GDP)

(Statista 2019a). These results are the outcome of the extreme biodiversity characterizing the Amazon rainforest, as well as institutional incentives and International voluntary funding. An example is the *Fundo de Incentivo à Geração de Emprego no Setor de Ecoturismo*, a mechanism set-up in 2002 by deputy Miro Teixeira to generate job opportunities in the ecotourism sector and financed by sanctions of environmental crime law, the forest code and other international or domestic voluntary donations (CAMARA DOS DEPUTATOS 2002). By 2022, the National Bank for socio-economic development (BNDES) has even increased the fundings of the *Fundo Socioambiental*, by 50 million R$. The non-refundable credit is planned to be distributed among 13 initiatives, 2 of which related to ecological restoration and financed by a 12 million R$ (BNDES 2022).

5 Challenges and drivers of success

5.1 Addressing the Challenges

5.1.1 Plant species selection

Despite the increasing attention to reforestation projects, the scientific community is mostly concerned with their dependency on exotic species. This is due to their adaptability and tolerance, rapid growth, availability of information and excess of seedlings (Tolentino 2008). However, exotic species monocultures might endanger biodiversity of native species as they substantially change the performance of several ecosystem services, as well as competing for ground and water resources (Hooper, Condit, and Legendre 2002). On the contrary, planting native species is preferred as they best fit the restoration site conditions, enhance biodiversity and mitigate climate change. However, the absence of either ecological-silvicultural and nutritional demands knowledge (Nunes et al. 2020) or germplasms makes their seeding more challenging (Chechina and Hamann 2015).

Depending on site location and conditions, reforestation target and climate change scenarios, different tree species combinations must be adopted (Fremout et al. 2022).

Site location influences soil moisture, sunlight exposure, average temperatures, water availability, elevation and humidity. The greater the solar radiation, the lower the levels of soil moisture. Hence, these regions are best suited for growing xerophytes. Contrarily, higher levels of moisture are best suited for planting deciduous, coniferous, fruit and hardwood trees. The higher the site's elevation, the lower the tree species diversity (Song et al. 2021). Therefore, at higher altitudes only fast-growing and resilient trees with efficient seed dispersal mechanisms are expected to thrive. Tropical regions, characterized by warmer temperatures and high levels of precipitation, are best suited for teak, palm trees and tropical fruit trees. Mediterranean regions host drought-tolerant species, like olive trees and lavender; while boreal regions are best suited for evergreen conifers like pines and firs.

Site conditions include soil type, water availability, fragmentation, grazing pressure and wildfire occurrence. Fast-growing plants with deep fibrous roots or with resprouting abilities could withstand heavy grazing pressures. Planting forest shrubs is essential for the establishment of microhabitats and microclimates beneath the canopy layer (Cunningham et al. 2015). Shrubs like sagebrush and other browse plant are best suited for grazing-prone areas. Trees with thick bark, high moisture contents and low flammability foliage work as firebreaks and could prevent the spreading of wildfires. Other native fire-resistant species with high water-storing capabilities are best suited for areas struck by persistent wildfires.

Ultimately, no reforestation strategy could maximize the performance of ecosystem services altogether (Cunningham et al. 2015). Plantations of production species are best suited for carbon sequestration, but are less efficient than large, unharvested and densely distributed native species for biodiversity. Monocultures are best suited for wastewater treatment and the provisioning of timber and non-timber products, despite their limited social and environmental impacts (Liu, Kuchma, and Krutovsky 2018).

5.1.2 Soil management strategies

Population growth entails higher food demand, which is typically met employing intensive agriculture, which in turn brings about soil degradation. Reforestation initiatives and other sustainable land management strategies have the potential to address food insecurity, while also protecting biodiversity and increasing the performance of ecosystem services. Sustainable Land Management (SLM) refers to “the use of land resources, including soil, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions” (FAO 2013). Besides agroforestry, examples of SLM practices include conservation tillage, crop rotation, organic matter management, forest shelterbelts and other soil erosion control mechanisms.

Conservation tillage is “planting crops in the soil through a previous crop's residue” (South Carolina Department of Natural Resources 2020). This technique reduces labour inputs and is associated with several environmental benefits. Crop residues increase water availability as they reduce the chances of evaporation from the soil and build a thick layer of organic materials. In turn, the latter increases water filtration, and hence crop resilience during dry periods. This increased ground cover shields the soil from exogenous agents, reducing soil erosion by 90%, while also improving biodiversity providing a safe habitat for small invertebrates. The latter improve soil quality reducing soil compaction and structure (South Carolina Department of Natural Resources 2020).

Crop rotation is the “successive cultivation of different crops in a specified order on the same fields” (Encyclopedia Britannica 2018). This practice is essential to prevent the same crop from overexploiting nutrients stored in the rhizosphere, and hence improve soil fertility and productivity. Crop rotation is an affordable and sustainable alternative to chemical fertilizer, and outperform the latter since it prevents soil depletion. To be effective, this technique should be implemented sowing plants from different families, as well as alternating exhaustive and restoratives crops, shallow-rooted and deep-rooted ones, and disease-resistant and susceptible ones (Tanveer, Ikram, and Ali 2019).

A shelterbelt forest is a “barrier of trees and shrubs that provides protection […] from wind and storm and lessens erosion” (Merriam-Webster 2023). Because of their disposition, forest shelterbelt can protect farmlands, large areas, and the animals inhabiting them, from excessive wind speed. They have the potential to prevent soil erosion, improve water and air quality and mitigate climate extremes (Zhu 2008). Furthermore, shelterbelts are expected to increase underground soil organic carbon concentration by 15.8%, and hence improving the performance of regulatory ecosystem services (X. Zhang et al. 2022).

5.1.3 Seedlings availability

Tree seedlings availability reflects market demand, such as timber prices; the performances of the timber industry, like harvesting pressures; and cost-cutting national or federal initiatives (Fargione et al. 2021). Currently, seeds and seedlings production rates are lagging behind growing reforestation demand. To successfully provide enough supply there is the need to scale up the whole "pipeline", through the improvement of "seed collection and storage" facilities, "nursery production, out planting, and post-planting treatment and monitoring" (Fargione et al. 2021).

In Brazil, imbalances in native species production and consumption rates often favour the implementation of fast, cheap and exotic species-based forest initiatives. The country's commitment and reforestation strategies are putting under serious pressure nurseries, which are facing an ever-increasing demand of highly diverse species.

Private, public and NGOs-led nurseries mostly collect seedling from native forests in private lands, and work at only 43.2% of maximum capacity producing up to 142 million seeds/yr (Moreira da Silva et al. 2017).

Nurseries are mostly clumped alongside the Atlantic forest and nearby urban centres, while small-size, thinly distributed ones are scattered in other biomes. 80% of forest nurseries experience a lack of seed supply and more than 3/5 of them address commercialization resistance and lack of highly-skilled workers as the main sources of market failure. Furthermore, half of them found no difference in sales since the introduction of the new Forest Code in 2012 (Moreira da Silva et al. 2017).

Therefore, implementing national and federal supportive policies, and training highly-skilled professional, might drive the development of the seedlings market. Hence, nurseries could be expected to work at full capacity, and properly satisfying existing demand.

5.1.4 Competition between reforestation and agriculture

Population growth, urbanization and increased vulnerability of rural population are three factors positively correlated with food insecurity. Food demand is unlikely to be met locally in regions characterize by low-agricultural output, resulting in greater reliance on food import. However, increasing pressures from climate change are a fertile ground for large-scale reforestation initiatives. Despite their well-documented environmental benefits, ecological initiatives could be associated with the abandonment of previously cultivated croplands (Qiu et al. 2022)

Therefore, if combined with urban expansion and population growth, and assuming that regions with high potential risk of soil erosion must be reforested, engaging in ecological restoration practices might exacerbate food shortage. People dependent on subsistence farming and limited access to core markets might become extremely vulnerable to emergencies, leading to a re-conversion of reforested land for agricultural purposes (Qiu et al. 2022). Fortunately, there are multiple solutions.

Agroforestry, and other systems integrating tree growth and crop cultivation, have the potential to improve carbon sequestration, biodiversity and other regulatory ecosystem services, while also increasing yields productivity (Mukhlis, Rizaludin, and Hidayah 2022). For example, planting multipurpose trees could improve farmers' economic resilience providing an additional source of income. It could also minimize the production costs and increase food supply, reducing the chances of rural migrations. However, the success of this practice is strongly influenced by landowners' knowledge (Mukhlis, Rizaludin, and Hidayah 2022). In conclusion, the provisioning of substantial public fundings could improve small landowners' production capacities, shifting from a high-input, low efficiency agricultural techniques to modern and sustainable ones (Qiu et al. 2022).

5.1.5 Outweigh deforestation incentives and illegal timber extraction

As of 2020, Brazil have achieved an unprecedented reduction in deforestation rate since its peak in 2004. This is due to the successful implementation of national and federal preservation initiatives, as well as the establishment of APP and RL since the enter into force of the new Forest Code in 2012. However, since 2013 the trend has reversed and peaked in 2020, when there was a 9.5% increase in the deforestation rate respect to the previous year (Silva Junior et al. 2020).

Despite its well-documented negative effects on the environment, deforestation is still practised throughout the globe because of its short-term socio-economic value. As a matter of fact, deforestation is a highly profitable activity which works as a starting point for future human-induced land-use changes. Hectares of previously forested areas could then be exploited for agricultural activities, repurposed to address space deficiencies in urban environment, or to extract previously inaccessible resources (minerals and fossil fuels). Deforestation is also a critical source of raw materials, such as timber, wood pulp and rubber, and provides previously unavailable jobs opportunities for unskilled workers.

While legal deforestation is regulated by national legislation, Brazil and other tropical country are struggling against illegal timber extraction. It develops in three forms: informal logging, pursued by local communities; illegal logging, pursued for agricultural or commercial purposes; and criminal logging, the "unauthorised large-scale deforestation or the selective cutting of (high-value) timber" (Carry and Maihold 2022). It is a source of market prices distortion, and is often associated with tax evasion and increasing income disparities. This practice is so profitable that is currently the highest-value environmental crime, grossing as much as 152 billion dollars every year (Carry and Maihold 2022). Clearly, it is of paramount important to contain and prevent these detrimental activities, as well as outweighing their economic incentives through the implementation of remunerative ecological restoration programmes and national/regional control mechanism.

5.2 Drivers for success

Reforestation success is the "continuum from the successful establishment of the initial planting through to maturation and realisation of the full environmental and socio-economic benefits of the forest" (Le et al. 2012). The work of Hai Dinh Le, Carl Smith and John Herbohn is a pivotal hallmark in the assessment and evaluation of the reforestation projects success. Their analysis compared previous literature on reforestation initiatives in Leyte Island, in the Philippines, and properly synthesized their key drivers and indicators for success (Le, Smith, and Herbohn 2014).

The seven most important drivers for success are reforestation method, socio-economic incentives, forest protection mechanisms, sustainable livelihood, diversification of funds and partnership, provisioning of technical assistance and infrastructure development.

First, it was found that the adoption of mixed species reforestation strategies, especially when producing commercial and highly-valuable goods, are associated with increased economic resilience for local populations. The strategy increases also the performance of regulatory ecosystem services, especially soil protection and nutrient regulation, and enhance forest growth and biomass production.

Socio-economic incentives are just as important. Ensuring long-term involvement of native populations is essential to increase projects success. Providing a stable source of income through the implementation of PES and REDD+ schemes, as well as other mechanisms aimed at properly distributing costs and benefits, could increase the voluntary participation of local communities.

Implementing and Increasing forest protection mechanisms efficiency have the potential to reduce or eliminate the detrimental impacts of human-induced or natural processes. Besides grazing management and weed control, fire wise landscaping is a potent solution limiting the harmful effects of wildfires. It consists in the selection of low-flammable tree species and their spatial arrangement in irregular and distant clusters of vegetation, separated by fire breaks (Kays et al. 2020). Therefore, addressing these underlying drivers of forest degradation is essential to achieve reforestation objectives.

The implementation of agroforestry and other integrated production systems are likely to increase rural communities' livelihood through income diversification, deriving from the production of commercial products, and the provisioning of an additional food source (Mukhlis, Rizaludin, and Hidayah 2022). Ensuring funding's continuity is essential to encourage long-term planning and increase native populations' participation rate. In the event that national subsidies could not fully cover implementation costs, partnership diversification could provide critical assistance to the project.

Technical support and training from highly-skilled professionals is vital throughout all project's stages. Starting from its design, through plant selection, adoption and maintenance, and provisioning of market and legal information, technical assistance is strongly required achieve expected outcomes. In conclusion, infrastructure development is imperative to ease market access and inputs supply, as well as significantly diminish transportation costs.

5.3 Success indicators

5.3.1 Tree's survival rate

It was evaluated that to ensure at least an 80% survival rate of tree plantations three factors needs to be properly address. First, grazing management is essential to prevent ruminants from causing soil degradation. It was found that overgrazing increases soil compaction and soil bulk density by 11.3% respect to pre-grazing conditions, halves soil penetration resistance and significantly reduces soil organic carbon and nitrate (Lai and Kumar 2020). Then, weed control is the single most impacting variable in the determination of tree survival rate. Weeds compete with freshly planted seedlings for sunlight and nutrients. Furthermore, weeds have the ability to quickly repopulate the soil from dormant seeds. Therefore, for the first three years there is the recurrent need to apply herbicides (Neumann 2016). Ultimately, road conditions are to be properly address to ease transportation.

5.3.2 Planted area

To ensure that the target area is successfully planted, several variables need to be addressed. Again, road conditions is positively correlated with the chances of fulfilling reforestation commitments, as they ease the access, reduce transportation costs and prevent seedlings from being damaged. Government funded projects are more probable to achieve their objective as they restore larger areas at lower costs per hectare. Integrated production systems are positively correlated with restoration targets since they reduce the risks associated with food insecurity, as well as improving economic resilience through product and income diversification (Mukhlis, Rizaludin, and Hidayah 2022). In conclusion, site dimension is negatively correlated with the actual planted area.

5.3.3 Area remaining intact vs actual planted area

Distance between the site and the closest urban centre, profit sharing arrangements, and disparities between actual and target area are key determinants of forest resilience. The former is the single most impacting variable. Easier access to the reforestation site means greater maintenance, speed of action and monitoring. Therefore, the distance is negatively correlated with forest resilience. The two additional factors are both positively correlated with it, as the provision of socio-economic incentives, disposal of better equipment and increase local communities' commitment have the potential to increase the reforestation success rate.

5.3.4 Increase for total volume an above ground biomass

Revegetation method is the single most significant variable. On average, mixed exotic species outperformed other species combinations in restoring above ground biomass and forest growth. This might be explained by complementary and selection effects (Clark et al. 2019). Both excessive tree density and sparsity will inhibit forest growth, even if the latter has the potential to produce trees with larger diameters than the former. It was estimated that the maximum tree density for trees with a diameter ABT larger than 10 centimetres should not exceed 1740 stands per hectare (Le, Smith, and Herbohn 2014). Unsurprisingly, using seedlings respecting quality standards are more probable to enhance forest growth and above ground biomass. In conclusion, both altitude and slope negatively affect tree growth. As already seen in the previous paragraphs higher altitudes are associated with lower biodiversity and tree density (Song et al. 2021), while increases in slope decreases soil water retention abilities, creating a more inhospitable environment.

5.3.5 Tree species diversity

There is a spurious relation between rock type and tree species diversity. Planning preference for different reforestation sites might influence the revegetation method. Therefore, even if the two variables are correlated, no causality exist between them. Predictably, tree species and size diversity are mutually reinforcing. In conclusion, seedling sourcing strongly influence species diversity. Government nurseries are more probable to diversify their seeds stocks than private ones (Gregorio, Harrison, and Herbohn 2008). Clearly, reforestation initiatives sourced by government nurseries could be expected to have a more varied composition.

5.3.6 Soil erosion and landslide frequency

As already described in the previous chapters, reforestation programmes have significant positive impacts on soil fertility and have the potential to reclaim degraded land. Furthermore, due to their extensive root systems, forests can significantly reduce landslide occurrences, even if they are unlikely to prevent them in seismic regions.
Revegetation methods, protection mechanisms, education and effectively restored areas are expected to increase forest performances.

First, the increase in litter output and the diversity of root systems could explain why adopting mixed species plantings could result in an 81-fold increase in soil protection and a 15-fold decrease in avalanche occurrence. Then, the implementation of protection mechanisms, like fire breaks, decreased by 10 times the odds of soil erosion and by 34 those of landslide. It is still unclear whether there is a causal relationship between education and the improvement of forest performances, but it was reported a 16-fold increase in soil protection and a 34-fold decrease in landslide frequency. In conclusion, approaching restoration targets is the single most significant variable. Planting at least 50% of the committed area is expected to result in a 72-fold decrease in soil erosion and a 60-fold decrease in landslide occurrence (Le, Smith, and Herbohn 2014).

5.3.7 Jobs availability

Fencing and direct payments for planting are the two most significant complementary factors in the assessment of employment outcomes of reforestation initiatives. Fencing is a labour intensive practice, providing several job opportunities. However, they might not be met by increased participation unless sufficient economic incentives, like direct payment, are implemented as well. Once again, road conditions positively influence jobs availability since it prevent transportation-related issues and eases the access to the site.

5.3.8 Market access

Timber production and municipality class are the two driving factors for market access. While timber production increases market access by 8 times, any additional increase in municipality class double the market access. The municipality class is determined by the annual average income. From here, we could derive that in high-income regions there is an easier access to the marketplace. Lower-income municipalities are inhabited by forest-dependant rural populations. Therefore, reforestation projects have the potential to improve living standards, as well as increasing market access.

5.3.9 Cash income and Food security

Unsurprisingly, the involvement of forest-dependent communities, increased market access and job availability due to reforestation initiatives are all positively correlated with cash income. Similarly, high-income municipality and better road conditions seem to positively affect people's earning. Education is expected to increase income generation potentials due to highly-skilled professional contribution in the selection of proper species combination and market information.

Cash income is strongly related to food security. As a matter of fact, the former increases the latter by 61 times, as income diversification is expected to increase food consumption in harsher periods. Similarly, agroforestry and other integrated production systems might address income insecurity through product diversification, providing an alternative source of food in case of crop insufficiency.

6 Conclusions

Reforestation is an ecological restoration practice able to provide a multitude of environmental and socio-economic benefits to our global society and the surrounding ecosystem. It is a highly diverse process consisting in the re-establishment of forest cover through several methodologies and approaches, each one designed to achieve specific purposes. Throughout the course of the past decades, Brazilian governments built an extensive legislative network aimed at preserving the ecological balance of the Amazon rainforest and promoting scientific research, as well as establishing special status areas and proper mechanisms to foster sustainable economic development. In cooperation with several international, state and regional institutions, it had also financed and developed several initiatives complying with the objectives and principles described in the existing legislation.

The main findings of this paper argue that reforestation projects could effectively provide a plethora of environmental and socio-economic benefits. However, no reforestation strategy could maximize the performance of ecosystem services altogether (Cunningham et al. 2015). Therefore, different methodologies are to be applied depending on the scope of the project.

Agroforestry is a refuge for tropical biodiversity (Bhagwat et al. 2008), improves soil conditions, nutrients and water availability (Dollinger and Jose 2018)(Lott et al. 2003), and improves economic resilience through product and income diversification (Mukhlis, Rizaludin, and Hidayah 2022). Urban trees improve air quality by actively removing fine particulate matters through leaf stomata (Nowak et al. 2014) (Gromke and Ruck 2012). The larger the leaves area, the faster the deposition rate of particle pollutants, with consequent positive impacts on urban environments (Xue and Li 2017).

Riparian plantings moderate the temperatures from direct exposure to the sun (S. L. Johnson 2004), contribute to bank stability, generate hydraulic diversity (Dufour and Piégay 2005), and increase litter inputs, hence sustaining biodiversity of aquatic flora and fauna (Quinn et al. 1997) (Sánchez-Botero et al. 2007) (Ceneviva-Bastos and Casatti 2014) (Muotka and Laasonen 2002). They increase/decrease streamflow during dry/wet seasons (Wangpimool et al. 2013), mitigating the effects of seasonal changes on local fauna, while also reducing water salinity (Ruprecht et al. 2019). Deciduous trees are a more nutritious but short-lasting source of nutrients. The opposite is true for conifers (Cummins 1974). They reduce the chances of water run-offs and the intensity of the streamflow through the phenomenon of evapotranspiration, while also nourishing water yields increasing the probability of rainfall (Ellison, N. Futter, and Bishop 2012) (Cunningham et al. 2015) (Jackson et al. 2005). Therefore, riparian planting are best suited for preventing floodings and the erosion of streambanks (Jackson et al. 2005).

Forest plantations improve connectivity among previously isolated forest remnants (Cunningham et al. 2015), hence reducing the fragmentation effect (DA SILVA 2001) and preventing species extinction (Brancalion et al. 2013). It guarantees the movement of native organisms (Crooks and Sanjayan 2006) and sustain similar biodiversity and richness of medium-sized, volant and non-volant, mammal communities (Sanchez, Sánchez-Palomino, and Cadena 2008) (Lyra-Jorge, Ciocheti, and Pivello 2008). Forest plantation of single exotic species, monocultures, are best suited for the production of timber and non-timber forest products (Chaudhary et al. 2016) and are preferred because of their competitive advantage over native ones (Liu, Kuchma, and Krutovsky 2018) (Tolentino 2008). Despite their economic benefits, monocultures are often associated with multiple negative social and environmental impacts (Liu, Kuchma, and Krutovsky 2018) (Hooper, Condit, and Legendre 2002), are more vulnerable to diseases and pests (BALOGH 2021) and alter soil structure, water and nutrient balance (Widyati et al. 2022). Monocultures host a similar diversity and abundance of understory plants to pasture land (Felton et al. 2010), but lower than mixed-species reforestation initiatives (Larjavaara 2008).

Plantations of broadleaf production species could maximize carbon sequestration at medium densities (Cunningham et al. 2015) and are often preferred because a lower degree of uncertainty about their carbon-capturing capacity (Ciasullo, Simone, and Conti 2014). Hence, they are a cost-effective solution to compensate for GHG emissions. However, polycultures are as efficient since have the potential to produce greater biomass than monocultures (Ahmed, Smith, and Godbold 2019) (Cunningham et al. 2015).

Reforestation projects could be developed concurrently with financial initiatives like PES, REDD+ and CDM initiatives.

PES programmes are more probable to achieve their targets if properly distributing costs and benefits, performed at local or regional level, providing an additional critical resource, planned in the mid- and long-run, allocate non-monetary incentives and if trusted by the local population (Grima et al. 2016) (Kaiser, Haase, and Krueger 2021) (Corbera, Soberanis, and Brown 2009) (Jindal, Swallow, and Kerr 2008). They are more probable to increase the agricultural output and consumption, while also reducing the labour input. However, these results occur if PES are governmentally funded through low-interest rate loan regimes, or if outweighing deforestation incentives and the opportunity costs of engaging in other activities through the provision of other stable and recurrent economic incentives and the enforcement of legal constraints (Moros, Vélez, and Corbera 2019). To improve the outcome of reforestation efforts associated with PES schemes, it should be determined the balance between eligibility criteria and reforestation success rate, the need to educate and provide incentives to increase willingness to participate, and provide technical assistance to local farmers (Jones et al. 2020).

REDD+ and CDMs help rural communities in diversifying their income and help reaching the GHG emission reduction through the commodification of carbon dioxide through carbon credits and their sale on the voluntary carbon market (Pasgaard et al. 2016). The joint development of these programs between government and vulnerable local communities would ensure the benefits of having them implemented at a national level (Bayrak and Marafa 2016), while also preventing the displacement of indigenous tribes. As these programmes are mostly concerned with greenhouse gas emission reduction, they might neglect several other environmental and social opportunities. Developing a proper strategy addressing food insecurity, biodiversity protection, people's awareness and trust toward the project, jobs availability, income diversification and land tenure conflicts is crucial to maximize the benefits of these programmes (Duchelle et al. 2018) (Bayrak and Marafa 2016). The strategy should implement a monitoring mechanism to avoid the development of monocultures, improve evaluation procedures, share the knowledge with native populations and find the right balance between loose and strict restriction on forest access. It should also develop an appropriate legal, cultural and institutional framework, and ensure that the price of carbon emission reduction outweigh implementation costs. (Aigbokhaevbo 2022) (Duchelle et al. 2018).

To sum up, the parallel development of reforestation strategies and financial mechanisms is supposed to be developed through a highly-tailored evidence- and science-based strategy increasing institutional governance, improving monitoring and communication methods and introducing a more precise evaluation system. It should also include mechanisms for trading carbon credits and balance between economic growth and sustainability (Clapp, Briner, and Karousakis 2010) (Das and Chatterjee 2015).

The implementation of reforestation initiatives entails several challenges.
Each reforestation approach is to be developed following specific guidelines to ensure their highest possible beneficial effect on the environment. To effectively protect biodiversity, agroforestry should be immediately implemented after forest conversion, increase as much as possible canopy cover and remain unharvested (Bhagwat et al. 2008) (Cunningham et al. 2015). Reforested areas are more successful in protecting biodiversity if bordering forest fragments (Santos Junior et al. 2016). The closer the reforested area to mature forest, the higher the chances of protecting native species. The opposite is true for exotic ones (Pejchar et al. 2018).
Riparian plantings' tree vegetation should be managed to reduce the effects of thermal pollution (Kałuża et al. 2020). Urban trees are efficient only if it rains with a reasonable frequency and wind speed is weak enough not to resuspend PMs (Riondato et al. 2020).

It is vital to promote scientific research to address those uncertainties preventing the development of native species reforestation initiatives, to quantify the value of ecosystem services all-together, to properly assess the economic burden and profitability of restoration efforts and to set global standards for reporting (Ciasullo, Simone, and Conti 2014) (Taye et al 2021) (Verdone and Seidl 2017) (De Groot et al. 2013) (Nunes et al. 2020) (Chechina and Hamann 2015) (Luiz Furtado et al. 2020).

Technical expertise is crucial to determine the most appropriate solution for each specific social and environmental conditions. Plant species selection, choice of reforestation strategy and soil management are just few examples (Song et al. 2021) (Zhu 2008) (X. Zhang et al. 2022) (Cunningham et al. 2015) (Clark et al. 2019) (Le, Smith, and Herbohn 2014). Experts' participation is thought to address seed nurseries' inefficiency and commercialization resistance, as well train highly-skilled professionals, educate landowners on new techniques and protect the interests of all stakeholders involved (Moreira da Silva et al. 2017). Technical expertise is also required to advance a solution balancing the trade-off between reforestation outcomes and agricultural output, as well as developing a proper strategy to tackle the drivers of forest degradation and provide other market and legal information (Qiu et al. 2022) (Mukhlis, Rizaludin, and Hidayah 2022)(Kays et al. 2020)(Nunes et al. 2020) (Lai and Kumar 2020) (Neumann 2016).

Institutional support is just as important. Reforestation programmes are more successful if financed and implemented by the government (UNEP 2010). Government intervention is essential to establish public fundings to increase farmers' efficiency and outweigh deforestation incentives, and establish a local market for renewable timber products. It could develop a control mechanism to contain and prevent illegal and criminal logging, and develop a road system and other infrastructures (Carry and Maihold 2022) (Strand et al. 2018) (Qiu et al. 2022) (Karjalainen, Sarjala, and Raitio 2010) (Gallagher et al. 2019) (Scouvart et al. 2008) (West and Fearnside 2021). Public fundings also increase the chances of success as they ensure long-term involvement of native populations, increase jobs availability, restore larger areas at lower costs per hectare and finance nurseries with a more diverse seed stock (Mukhlis, Rizaludin, and Hidayah 2022) (Le, Smith, and Herbohn 2014) (Gregorio, Harrison, and Herbohn 2008).

Clearly, a lack of inter-ministerial coordination and support could threaten the positive socio-economic and environmental benefits deriving from reforestation initiatives.

I hope that the main findings of this paper, and those of previous literature, could inspire further research on the matter and support decision makers in including reforestation initiatives in their fight against climate change and in their efforts in shifting toward a sustainable economy.

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Summary

La foresta Amazzonica è una giungla tropicale sviluppatasi lungo il corso del Rio delle Amazzoni ed i suoi affluenti. L’Amazzonia è la più grande foresta tropicale contigua del mondo, si estende per 9 paesi, ed è caratterizzata da un’estrema biodiversità e frequenti piogge. Ospita oltre 400 tribù indigene e fornisce molteplici servizi ecoambientali. Peraltro, l’attività antropocenica sta danneggiando la foresta e minacciando la sopravvivenza della flora e fauna locale.

La tesi descrive gli effetti ambientali e socio-economici della riforestazione nella regione Amazzonica, le difficoltà, i determinanti del successo dei progetti ed evidenzia le linee guida nella loro implementazione. Il saggio analizza il quadro giuridico brasiliano per valutare quali regole e principi i programmi di riforestazione debbano rispettare. Procede poi ad illustrare le iniziative di restauro nazionali ed internazionali più rilevanti, e chiarisce il significato delle pratiche associate alla riforestazione.

Per quanto riguarda i benefici ambientali, descrive l’incremento delle prestazioni dei servizi ecosistemici e come la riforestazione può aiutare ad affrontare gli effetti negativi del cambiamento climatico. Riguardo gli aspetti socio-economici, presenta i benefici derivanti da “restoration and carbon programmes”, eco-turismo e strategie di sviluppo a basse emissioni. Si concentra quindi sulle sfide tecniche, culturali, istituzionali e politiche che dovrebbero essere affrontate nelle diverse fasi del progetto. In conclusione, sintetizza i suoi principali risultati e ciò che può essere derivato dagli stessi.

La riforestazione è una pratica di ripristino ecologico in grado di fornire una moltitudine di benefici ambientali e socio-economici alla nostra società e all'ecosistema circostante. Si tratta di un processo molto diversificato che consiste nel ristabilire la copertura forestale attraverso diverse metodologie e approcci, ognuno dei quali è stato progettato per raggiungere scopi specifici. Nel corso degli ultimi decenni, i governi brasiliani hanno costruito un'ampia rete legislativa volta a preservare l'equilibrio ecologico della foresta amazzonica e a promuovere la ricerca scientifica, oltre ad istituire aree a statuto speciale e meccanismi adeguati per favorire uno sviluppo economico sostenibile. Tra le più rilevanti vi sono Nuovo Codice Forestale Brasiliano (2012), il quale istituisce le suddette aree a statuto speciale (RL e APP), il Sistema Nazionale delle Unità di Conservazione (2000) ed il Trattato di Cooperazione Amazzonica (1978), volto a promuovere lo sviluppo armonico della regione.

In collaborazione con diverse istituzioni internazionali, statali e regionali, il governo ha inoltre finanziato e sviluppato diverse iniziative conformi agli obiettivi e ai principi descritti nella legislazione esistente. La tesi descrive il Fondo per l’Amazzonia (2008), uno dei primi REDD mai stabiliti e volto a finanziare la strategia nazionale brasiliana per la prevenzione della deforestazione, il PPCDam (2004), volto a migliorare i meccanismi di controllo e prevenzione della deforestazione, ed il Piano di Crescita Verde Nazionale (2021), volto a preservare ed utilizzare in maniera sostenibile le risorse della foresta.

La riforestazione fornisce un'ampia varietà di servizi alla nostra società e all'ambiente, il che la rende uno degli strumenti più preziosi per affrontare il cambiamento climatico e per rimediare ai danni che il nostro pianeta ha subito. Nessuna strategia di riforestazione può contemporaneamente massimizzare i benefici ambientali ed economici, perciò ciascuna è da applicare per far fronte ai diversi obiettivi.

L'agroforesteria è un rifugio per la biodiversità, migliora le condizioni del suolo, la disponibilità di nutrienti e acqua e la resilienza economica. Gli alberi urbani migliorano la qualità dell'aria rimuovendo attivamente le polveri sottili. Le piantumazioni ripariali moderano le temperature dovute all'esposizione diretta al sole, contribuiscono alla stabilità delle sponde, sostengono la biodiversità della flora e della fauna acquatica e diminuiscono la salinità dell’acqua. Inoltre, riducono le probabilità di deflusso dell'acqua e l'intensità del flusso del torrente attraverso il fenomeno dell'evapotraspirazione, aumentando la probabilità di precipitazioni.

Le piantagioni forestali prevengono l'estinzione delle specie, e promuovono la loro proliferazione tramite la riduzione dell'effetto di frammentazione. Le monocolture sono le più adatte per la produzione di legname e prodotti forestali non legnosi e sono preferite per i loro vantaggi competitivi rispetto alle specie autoctone. Nonostante i vantaggi economici, le monocolture sono spesso associate a molteplici impatti sociali e ambientali negativi.

I progetti di riforestazione potrebbero essere sviluppati in concomitanza con iniziative finanziarie come PES, REDD+ e CDM. Gli schemi PES consistono nella fornitura di incentivi positivi per i fornitori di servizi ecosistemici, ed hanno il potenziale di aumentare la produzione e il consumo agricolo, riducendo al contempo l'input di lavoro. Tuttavia, questi risultati si verificano se i PES sono finanziati dal governo attraverso regimi di prestito a basso tasso di interesse, o se si superano gli incentivi alla deforestazione e i costi-opportunità di impegnarsi in altre attività.

REDD+ e CDM aiutano le comunità rurali a diversificare il loro reddito e contribuiscono alla riduzione delle emissioni di gas serra attraverso la mercificazione dell'anidride carbonica. Purtroppo, poiché questi programmi si occupano principalmente della riduzione delle emissioni di gas serra, potrebbero trascurare altre opportunità ambientali e sociali. Sono perciò da sviluppare delle strategie adeguate ad affrontare l'insicurezza alimentare, la protezione della biodiversità e la disponibilità di posti di lavoro. Le iniziative dovrebbero inoltre implementare un meccanismo di monitoraggio per evitare lo sviluppo di monocolture, migliorare le procedure di valutazione, e condividere le conoscenze con le popolazioni autoctone.
Di conseguenza, lo sviluppo parallelo delle strategie di riforestazione e dei meccanismi finanziari dovrebbe avvenire attraverso una pianificazione altamente specifica basata su dati ed evidenze scientifiche.

L'attuazione delle iniziative di riforestazione comporta diverse sfide. Pertanto, ogni metodo di riforestazione deve essere sviluppato seguendo linee guida specifiche per garantire il massimo effetto benefico possibile sull'ambiente.

È fondamentale promuovere la ricerca scientifica per affrontare le incertezze che impediscono lo sviluppo di iniziative di riforestazione di specie autoctone, per quantificare il valore dei servizi ecosistemici nel loro complesso, per valutare correttamente l'onere economico e la redditività degli sforzi di ripristino e per stabilire standard globali per la rendicontazione.

La competenza tecnica è determinante nella identificazione della soluzione più appropriata per ogni specifica condizione sociale e ambientale. La selezione delle specie vegetali, la scelta della strategia di riforestazione e la gestione del suolo sono solo alcuni esempi . La partecipazione di esperti è utile per affrontare gli ostacoli alla commercializzazione, per formare professionisti altamente qualificati, oltre che per trovare una soluzione che bilanci i risultati della riforestazione e la produzione agricola.

Il sostegno istituzionale è altrettanto importante. Non a caso, i programmi di riforestazione hanno più successo se finanziati e attuati dal governo. L'intervento del governo è essenziale per stabilire finanziamenti pubblici che aumentino l'efficienza agricola e superino gli incentivi alla deforestazione, nonché per stabilire un mercato locale per i prodotti sostenibili. Esso dovrebbe inoltre mirare allo sviluppo di infrastrutture e garantire un maggiore coinvolgimento a lungo termine delle popolazioni autoctone.