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Review

Payment for ecosystem services: the economy that will save natural environments?

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ABSTRACT
Since the dawn of civilization, it has been understood what natural resources were and their importance for the survival and development of humanity. The environmental history, until payment for ecosystem services, was marked by conservationist and preservationist thoughts that took different directions regarding the "value of nature" and "payment for nature's services" but that consented to maintaining biodiversity. In the 20th century, after the publication of the first works on the categorization and valuation of ecosystem services, a certain consensus began to emerge regarding the commercialization of these services. Subsequently, several payment markets for ecosystem services emerged, such as the carbon market, which in 2021 reached the level of 2 billion dollars in transactions. Studies assessing the growth of the carbon market may provide relevant information for implementing payment projects for carbon credits, encouraging the maintenance of biodiversity and mitigation of climate change.

Keywords: biodiversity maintenance, carbon credits, carbon market, climate change mitigation, ecosystem services.

Introduction

Ecosystem services: emergence and first definitions

Since the dawn of civilization, even if they did not know what ecosystem services were, they already understood the importance of nature and the resources it provides, as well as the consequences of losing these resources (Chew, 2001; Gómez-Baggethun *et al*., 2010). Initially, the availability of nature's resources was so vast that it was believed to be inexhaustible, which allowed Egyptian, Greek, and Persian civilizations to take on grand proportions, becoming actual empires (Chew, 2001). However, faced with the scarcity of resources over the millennia due to their massive exploitation, the search for fertile land and raw materials began, leading to the formation of the first civilizations around the world (Chew, 2001; Ferro, 2017), which would later cause military and political conflicts, causing crises, such as the increase in hunger, due to the poor distribution of nature's resources and the search for absolute power over them (Arnson & Zartman, 2005).

One of the best examples is the colonization of South America by Europeans, as in Brazil from the year 1500 (Lang, 2013) with the arrival of the Portuguese, motivated by the natural riches of Brazilian lands, bringing with them several social, economic and environmental problems (Ferro, 2017). After many discussions about natural resources, their functions, benefits and consequences (Marques & Comune,

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1997), at the end of 1970, the debate reached an agreement, with the definition, conceptualization and categorization of "ecosystem functions" or "ecosystem services" drawn up by MEA (2005).

According to the Millennium Ecosystem Assessment (MEA, 2005), ecosystem services can be divided into four categories: support, provision, regulation, and cultural (Fig.1).

In this sense, each of these categories can be defined as:

- Support: responsible for maintaining soil fertility, nutrient cycling, and biogeochemical cycles.
- Provision: supplying food, raw materials, and drinking water.
- Regulation: regulation of temperature, precipitation, air quality, biological control, pollination, and seed dispersal.
- Cultural: providing human beings with leisure, scenic beauty, tourism, and recreation.

Ecosystem services are provided directly or indirectly by nature for human well-being, such as the provision of drinking water and food, food supply, climate regulation and carbon storage by plants (Costanza *et al*., 1997; MEA, 2005). Carbon sequestration by plants is a natural process in which plants absorb CO_2 from the atmosphere and, through a photochemical process, convert it into energy for their growth (Taiz *et al*., 2017; Eichhorn & Evert, 2019).

This ecosystem service has gained substantial importance in recent years, especially after the frequent climate changes resulting from rising levels of greenhouse gases (Wolff *et al*., 2015; Gatti *et al*., 2021). Through plant photosynthesis (Gurevitch *et al*., 2009), billions of tonnes of carbon dioxide (CO_2) are removed from the atmosphere every year (Pan *et al*., 2011). This plays a crucial role in slowing down global warming and therefore balancing climate change and the Cerrado biome plays a key role in providing these ecosystem services (Fernandes *et al.,* 2008; Lopes & Miola, 2010).

With a territorial extension of two million km² (IBGE, 2018), the Cerrado biome is characterised by diverse vegetation, subdivided into distinct phytophysiognomies that form a mosaic (Ribeiro & Walter, 2008). Due to its high vegetation diversity and climate resilience (Franco *et al*., 2014), the Cerrado is one of the world's main ecosystems, with a high potential for removing carbon dioxide from the atmosphere (Silva *et al*., 2013; Sawyer *et al*., 2017). As well as harbouring a vast diversity of native fauna and flora, the Cerrado also provides sustenance and refuge for Indigenous communities and families who depend on collecting native seeds for subsistence (Marimon & Lima, 2019).

International payment for ecosystem services initiatives have been implemented as an alternative to reduce environmental impacts (Milder *et al*., 2010) resulting from intensive land use in the Cerrado biome (Ronquim *et al*., 2008). Due to the high financial value attributed to carbon storage potential, the carbon market has attracted a lot of scientific and political attention, becoming one of the leading names in the field (Mattei & Rosso, 2014).

Opening up a market to commercialise ecosystem services, as in the carbon credit markets, means admitting that it is better to pay to maintain natural resources than

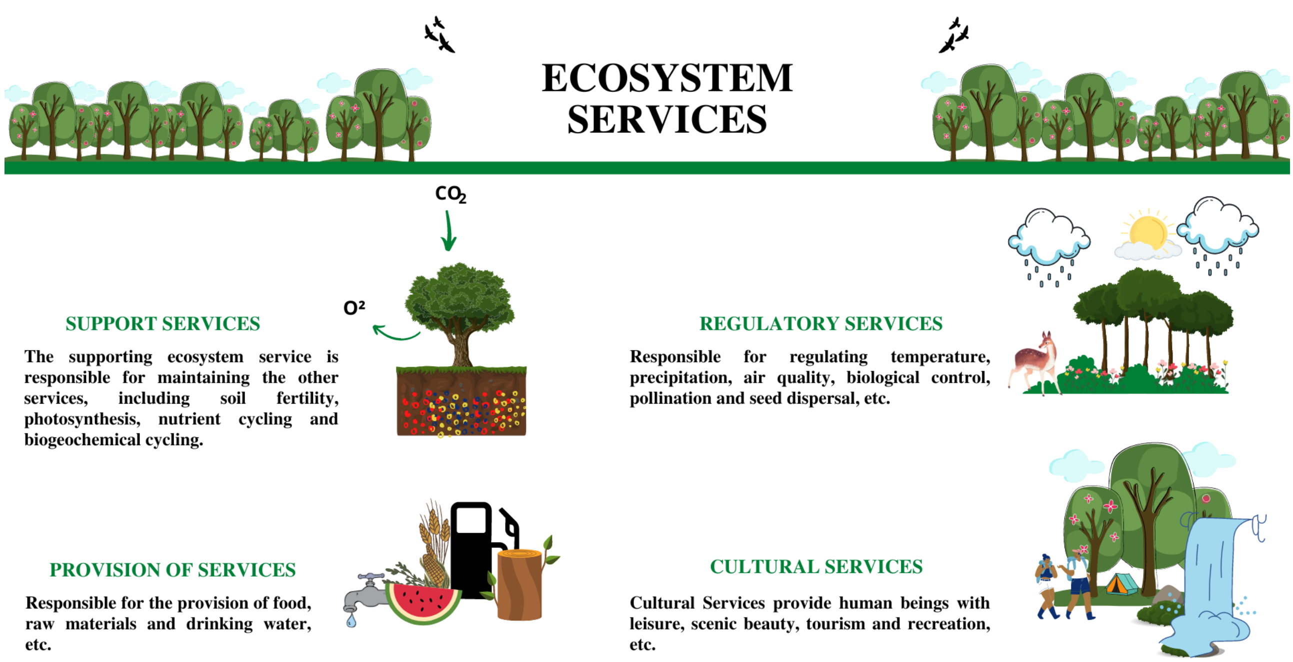

Figure 1. Categories of ecosystem services according to the Millennium Ecosystem Assessment (2005).

to pay the price for not having them. It also shows that more effort is needed than the consistent use of natural resources: suppliers must be paid to preserve ecosystem services. Based on the historical context and the current perspective of the payment for ecosystem services market, the questions that guided this research were: i) What are the prospects for the payment for carbon credits market in Brazil? ii) What are the main challenges of the payment for carbon credits market in Brazil? iii) Does the Cerrado biome have the potential to implement payment for ecosystem services projects?

Material and methods

We carried out a narrative literature review (Rother, 2007) which aims to provide information objectively. This approach punctuates a critical and personal analysis by the author on the payment of ecosystem services in the Cerrado biome. We also assessed the potential for implementing voluntary carbon credit payment projects (REDD+) in the Cerrado biome. In most reviews, we find a methodological approach that often makes it difficult for the reader to understand. The objective is to simplify access to information and the reader's understanding of the subject.

We used Connected Papers, Wiley, Researchgate, and Google Scholar as a base. We searched papers in English and Portuguese from a 40-year time frame, using the main keywords: history of ecosystem services, ecosystem services, environmental services, payment for ecosystem services, and ecosystem services in the Cerrado biome. We analysed the guidelines for capturing payments for REDD+ results in Brazil's ENREDD+. This document formalizes the United Nations Framework Convention on Climate Change (UNFCCC) signatory countries before the Brazilian Society (MMA, 2016).

In addition, we reviewed the principal payment for ecosystem services projects under development in the Cerrado biome and the criteria for implementation and methodologies present in the REDD+ BRAZIL and VERRA – Standards for Sustainable Future platforms, the main institution that regularizes and validates methodologies for quantifying ecosystem services in their different categories.

Results

Prospects of the payment for the carbon credits market in Brazil

Unlike the Kyoto Protocol, the Paris Agreement adopts the mechanism of incentivizing Reducing Emissions from Deforestation and Degradation (REDD+) through payments for ecosystem services (Fearnside *et al.* 2009; Börner *et al*., 2010).

Brazil, for its part, has committed to reducing its emission rates from deforestation and ecosystem degradation by 37 per cent below 2005 levels by 2025, through sustainable energy production projects, afforestation and reforestation of degraded areas (MMA, 2022). The country's active contribution to the influential Paris Agreement has had a positive impact on the emerging international carbon market, indicating a strong commitment to the environment. This has significantly increased the country's potential for carbon credit transactions, as well as strengthening its competitiveness in the search for funding for decarbonization initiatives.

REDD+ has been working through the commercialization of carbon credits, an essential initiative for conserving ecosystem services (ES) in areas threatened by agricultural expansion (Nepstad *et al*., 2013). However, during the 2016 United Nations Climate Change Conference (COP 16), it became clear that implementing such a mechanism would take a long time (Salles *et al*., 2017). Even in the face of so many impasses and delays in the implementation of the REDD+ mechanism, Brazil took its own "reins" with the creation of the Voluntary Carbon Market (MVC), which regulates and commercializes carbon credits in the country simply and objectively, in addition to the Amazon Fund (FA), which finances REDD+ projects (Ecosystem Marketplace, 2022; Salles *et al*., 2017).

The realization of the REDD+ mechanism in Brazil voluntarily reduced greenhouse gas emissions by about 41% in 2012 (Euler, 2016). The same author argues that Brazil has taken on the responsibility to zero its deforestation quota by 2030, primarily by achieving good results. Under an optimistic scenario of applying monetary incentives as an instrument for E.S. conservation, the country could achieve its objectives, but this requires studies that seek to calculate the value of ecosystem services to strengthen public and private policies to encourage and finance ecosystem conservation (Tosto *et al*., 2015).

The main challenges of the payment for carbon credits market in Brazil

Implementing payment for ecosystem services projects is a complex and time-consuming process with a high cost until its realization (Silveira & Oliveira, 2021; Vargas *et al.,* 2022). According to Article 8 of Law Nº. 14,119 of 13 January 2021 in Section III of the Application Criteria of the Federal programs for Payment for Environmental Services (PFPSA), the following may enter the Payment for Environmental Services market:

I. Areas covered in native vegetation;
II. Areas subject to ecosystem restoration, recovery of native vegetation cover, or agroforestry planting;
III. Complete protection of conservation units, extractive reserves, and sustainable development

reserves, under the terms of Law Nº. 9.985, of 18 July 2000;

IV. Indigenous lands, quilombola territories, and other areas legitimately occupied by traditional populations, through prior consultation, under the terms of the International Labour Organization (ILO) Convention 169 on Indigenous and Tribal Peoples;

V. Landscapes of great scenic beauty, primarily in particular areas of tourist interest;

VI. Fishing exclusion areas, considered to be those that are banned or in reserves, where the exercise of fishing activity is prohibited temporarily, periodically, or permanently by an act of the public authorities;

VII. Priority areas for biodiversity conservation, as defined by an act of the public authorities.

The implementation of payment for ecosystem services projects comprises three main phases, forest data collection, quantification of stored carbon, and analysis for validation and certification (Vargas *et al*., 2022).

Initially, in the case of carbon credit trading, stakeholders need to hire specialized companies for forest data collection, CO_2 quantification, and certification of carbon credits for trading on the global market (Ecosystem Marketplace, 2022).

Each company employs a specific methodology according to the vegetation structure and ecosystem resources to be quantified. Currently, there are two of the most widely used ways of quantifying the carbon stored in natural forests: direct destructive or indirect non-destructive methods (Arevalo *et al*., 2002; Barbosa & Fearnside, 2005; Silveira *et al*., 2008).

The destructive method consists of cutting the trees, where each compartment (stem, bark, branches, foliage, and roots) is separated and taken to a forced air circulation oven, then weighed and calculated to obtain the carbon stock (dry biomass) (Cotta *et al*., 2008). The non-destructive method is based on remote sensing from high-resolution satellite images (Watzlawick *et al*., 2009) or on allometric equations (Fig. 2), which generally use the parameters of diameter (cm), height (m), and wood density of living trees (D.M.) (Silveira *et al*., 2008).

In addition, other biomass estimation methods, widely used in national emissions inventories, are based on biomass conversion factors (*fcb*), biomass expansion (*Feb)* and root ratio (*r*) (IPCC, 2006; Sanquetta *et al*., 2019). Some of the most used equations for biomass quantification are the equations suggested by Rezende *et al*. (2006), Scolforo *et al*. (2008), Chave *et al*. (2014), and the compilation of equations and estimates suggested by Miranda *et al*. (2014).

Several equations for biomass estimation exist because they have been developed for specific vegetation (e.g., savannah or forest). Therefore, the non-destructive method

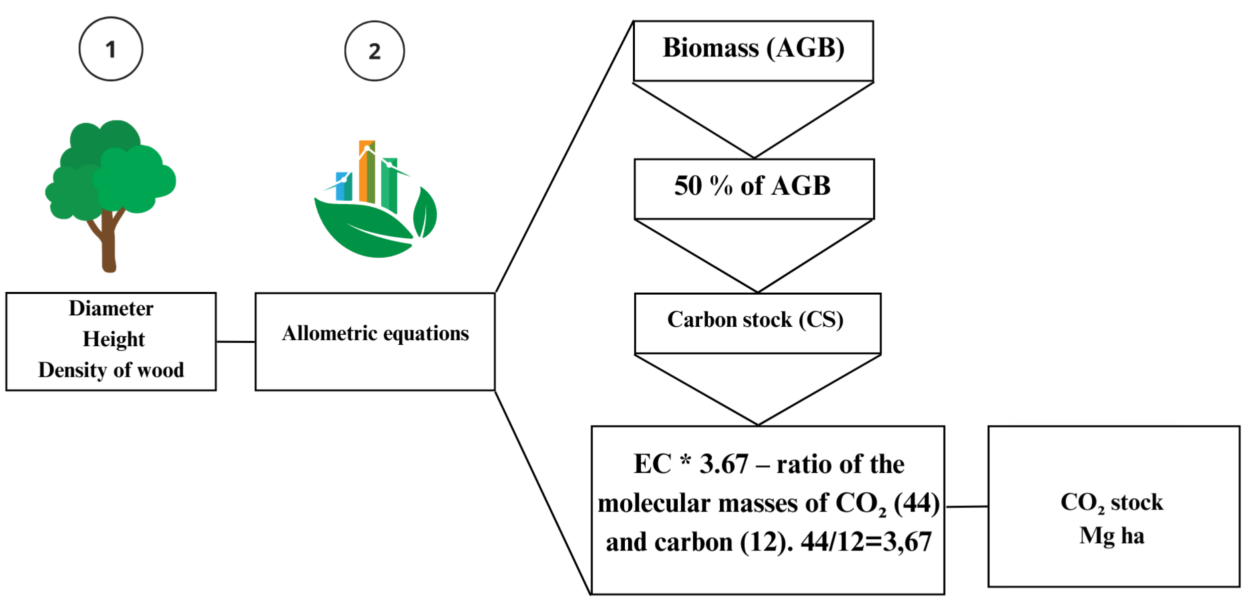

Figure 2. Process for quantifying vegetation carbon and CO_2 stocks from allometric equations.

must consider the "vegetation structure" factor for higher reliability in quantifying the CO_2 stored in the vegetation.

Carbon certification is the last step before trading and must be carried out by a recognized company or institution. VERRA – Standards for a Sustainable Future is a non-profit organization working since 2007 to verify greenhouse gas (GHG) reductions and mitigate climate change. Its primary function is to manage the certifications for obtaining carbon credits for commercialization in the global market through the Verified Carbon Standard program. The platform is widely known for its strong performance with rigorous methodologies (VM0006, VM0005 and VM0015) and records of large payments for ecosystem services projects.

Validation and certification to obtain carbon credits for commercialization is the most rigorous phase in implementing payment for ecosystem services projects (Vargas *et al*., 2022). In this phase, contracted companies audit and monitor the vegetation to be certified according to their certification standards, considering the rigour and reliability of the methodologies employed in quantifying the CO_2 stored in the vegetation (Paiva *et al*., 2015).

After obtaining the carbon credits, the third and final phase is pricing. Each tonne of carbon has a value that varies according to the market to which it is destined. For example, a carbon credit traded on the Voluntary Market (VM) is around US\$3.82/tCO_2E, which is much lower than the carbon credit traded on the Regulated Market (RM), which ranges from US\$50 to 100/tCO_2e (Fearnside, 2008; World Bank, 2022). These markets operate independently by stipulating rules (Reset, 2023). The Voluntary Market operates mainly in underdeveloped or developing countries such as Brazil, aiming at reducing emissions (GHG), co-benefits, and sustainability (Nepstad *et al*., 2013; Paiva *et al*., 2015).

The comprehensiveness of the MV and the addition of its own rules justifies the variations in prices. It is available in the World Bank's carbon pricing report (2022), which indicates the increase in the value per global average voluntary carbon credit in 2021 to US\$ 3.82/tCO_2. In addition to the variation between MV and MR, the price of a tonne of carbon can vary according to the type of vegetation and the sector in which the carbon credit was generated, as we can see in the Dashboard of the Observatory of Knowledge and Innovation in Bioeconomy (2023), where the tonne of carbon for Forests and Land Use is equivalent to R\$27.98 (US\$ 5.4), at the dollar rate of 01/02/2023.

In addition to the price of carbon credit by vegetation and sector, social and human aspects can influence carbon pricing (Nepstad *et al*., 2013). An example is the GOLD STANDAR platform (www.marketplace.gold standard.org), with 2,900 projects, where carbon credit values range from 17 to 45 US\$/tCO_2, according to the community to be benefited and the sustainable co-benefits to be achieved.

Potential for implementation of voluntary carbon credit payment projects in the Cerrado biome

According to the Ministério do Meio Ambiente (2022), the Cerrado is the second-largest Brazilian biome with about 2 million km², an area equivalent to Peru, an integral country of the South American continent (IBGE, 2018). With 11 phytophysiognomies described (Ribeiro & Walter, 2008), the Cerrado is the third-richest biome in vegetational biodiversity in Brazil, with 12829 species described by 2020 (Flora e Funga do Brasil, 2024).

Vegetation in the Cerrado is composed of forest ecosystems: riparian forest, gallery forest, dry forest, and cerradão; savanna ecosystems: dense Cerrado, typical Cerrado, sparse Cerrado, Cerrado park, palm grove, vereda, and rupestrian Cerrado; and grassland ecosystems: campo rupestre, campo sujo and campo limpo, in addition field of murundu and flooded areas that form a mosaic of vegetational ecosystems essential to harbour the high biodiversity of the biome (Ribeiro & Walter, 2008; Santos *et al*., 2020). In addition to all this complexity of phytophysiognomies and the high biodiversity, the Cerrado is a significant provider of ecosystem services, especially in maintaining the cycle of the carbon, since the high tree diversity is directly related to the potential to store and capture carbon dioxide from the atmosphere (Worm & Duff, 2003).

Another relevant piece of information that deserves to be highlighted is that Cerrado trees, mainly from savana formations, can grow in a hostile environment where the forest cannot survive, which is essential for carbon sequestration. In addition, the Cerrado biome is considered the "cradle of waters" for feeding the Amazon, Paraná-Paraguay, São Francisco, and Tocantins-Araguaia River basins with its springs and for harbouring the Guaraní, Bambuí and Urucuia aquifers. Despite its importance, the Cerrado is among the most threatened biomes in the world (National Geographic Brasil, 2023), with the lowest percentage of protected areas in the country (8%) and alarming annual rates of deforestation and fires (MMA, 2022).

In recent decades its vegetation has been converted into pastures and crops (FAO, 2020; Marques *et al*., 2020), and after long periods of use, many areas become unusable or are abandoned (Silva & Bassêto, 2012) (Fig. 3). However, vegetation recovery is gradually resumed in abandoned areas, called ecological succession (Miranda, 2009).

According to Lopes & Miola (2010), an area under regeneration has a high potential for carbon sequestration and storage due to its rapid growth. Thus, implementing payment for ecosystem services projects can be a fundamental instrument for reducing CO_2 in the atmosphere and maintaining biodiversity in the Cerrado biome.

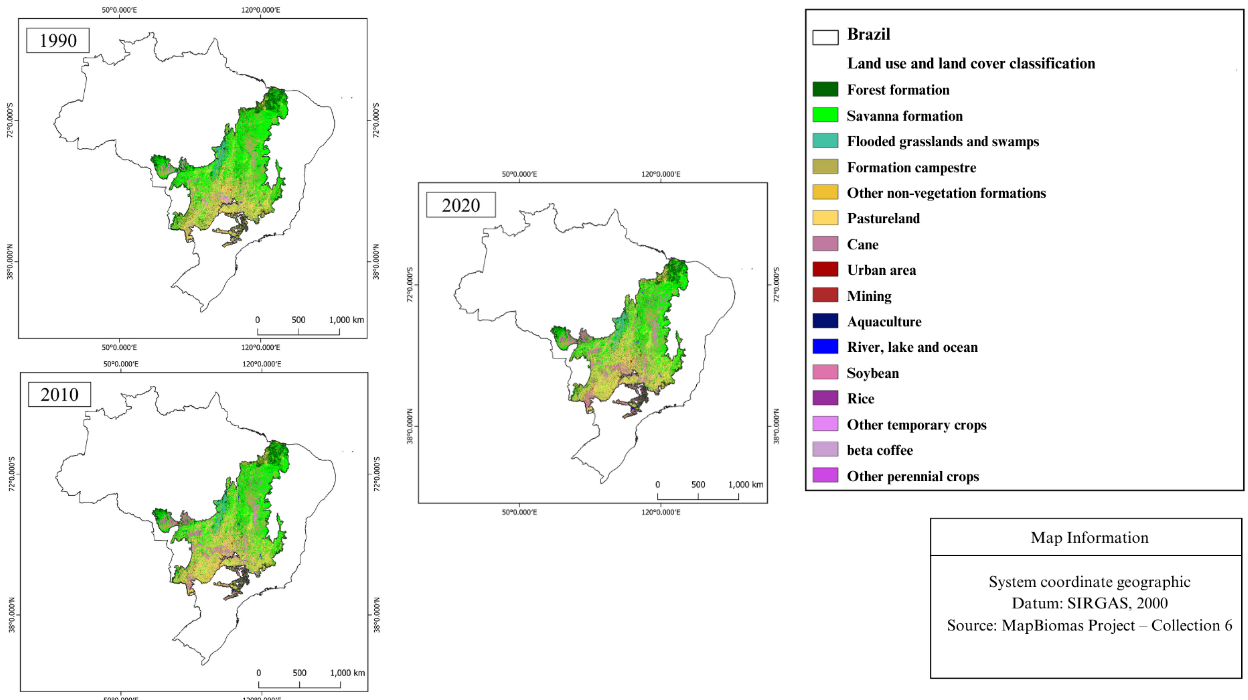

Figure 3. Changes in Land Use and Land Cover over the last decades in the Cerrado biome, where it is possible to observe the loss of approximately 50% of the vegetation. Data source: MapBiomas Project – Collection 6.0 of Brazil's Annual Series of Land Use and Land Cover Maps. Accessed on 13 April 2023 through the link: https://mapbiomas.org/".

The Cerrado is Brazil's second largest biome (MMA, 2004), characterised by highly diverse vegetation (Marimon *et al*., 2014), potentially contributing to carbon sequestration and storage. In addition, it is characterized by being a source of food, shelter, and water supply for various species of trees, birds, amphibians, insects, and mammals (Klink & Machado, 2005), as well as for us humans. It is also a source of income for indigenous communities, quilombolas, women and mothers who make a living from collecting native seeds, such as the collectors of the Xingu Seed Network (RSX) (Marimon & Lima, 2019). Therefore, ecosystem services in the Cerrado function as a web that connects ecological and social relationships.

We know that the amount of carbon stored in the aerial part of Cerrado trees is much less than that of trees in the Amazon. The amount of biomass stored in the vegetation (50 per cent of which is carbon stock) in the Cerrado varies greatly in each vegetation type, as shown in the tables below, forest ecosystems (Tab. 1), savannah ecosystems (Tab. 2) and grassland ecosystems (Tab. 3).

Cerrado vegetation accumulates a large amount of underground biomass, around 18.3 per cent of the total biomass in forest ecosystems, 58 per cent of the total biomass in the case of savannah plants and 70 per cent in grassland ecosystems (Miranda *et al*., 2014), and this more than doubles the CO_2 stock in each tree when we consider the root compartment. For example, we have 32.4 Mg ha^{-1} x 0.58%= 18.79 extrapolating and adding the root compartment. It is worth emphasizing that successional vegetation and climax vegetation have different carbon storage characteristics. While successional vegetation grows constantly, capturing larger quantities of CO_2 from the atmosphere for its continued development, climax vegetation acts predominantly as large carbon reservoirs (Lopes & Miola, 2010).

Calculation of estimated percentage below-ground biomass from Miranda *et al*. (2014):

32.4 + 18.79= 51.19 (total biomass)

51.19/2= 25.59 (carbon stock)

In this equation, we still need to add the avoided carbon, (i.e. the carbon removed from the atmosphere). Each tonne of carbon stored in plants equals 3,67 tonnes of CO_2 (Fernandes *et al.*, 2008; Ronquim *et al.*, 2008) product is traded in carbon banks.

In this case, we have

25.59 × 3.67= 93.91 Mg ha^{-1} of CO_2 removed from the atmosphere.

According to the most currently used pricing of the Dashboard of the Observatory of Knowledge and Innovation in Bioeconomy (2023), the tonne of carbon for Forests and Land Use is worth R$27.98 (US$5.4).

Regarding carbon credit pricing: 93.91 x R$27.98 = R$2,627.60 or US$507.11 per hectare.

Table 1. Amount of biomass stored in the vegetation of the Cerrado in savannah ecosystems.

Savannah ecosystems	Biomass aboveground (*Mg ha*$^{-1}$)	Carbon aboveground (*Mg ha*$^{-1}$)	Biomass belowground (*Mg ha*$^{-1}$)	Carbon belowground (*Mg ha*$^{-1}$)	Carbon total (*Mg ha*$^{-1}$)	Reference
Cerrado Typical	32.40	16.20	18.79*	9.40	25.60	Miranda *et al*. (2014) Morandi *et al*. (2020);
Cerrado Dense	29.40	14.70	17.05*	8.53	23.23	Castro e Kauffman (1998); Miranda *et al*. (2014)
Cerrado Dense	58.69	29.35	34.04*	17.02	46.37	Fernandes *et al*. (2008); Miranda *et al*. (2014)
Cerrado Typical	25.10	12.55	46.63	23.32	35.87	Rezende *et al*. (2006) Paiva *et al*. (2011)
Cerrado Dense	58.10	29.05	33.69*	16.85	45.90	Miranda *et al*. (2014)
Cerrado Typical	62.96	31.48	37.50	18.75	50.23	Ribeiro *et al*. 2011
Cerrado Typical	31.60	15.80	41.10	20.55	36.35	Abdala *et al*. (1998)
Median Value	44.32	22.16	32.68	16.34	38.50	

* Below-ground data obtained according to the percentage estimates of Miranda *et al*., (2014).

Table 2. Amount of biomass stored in the vegetation of the Cerrado in ecosystems forest.

Ecosystems forest	Biomass aboveground (*Mg ha*$^{-1}$)	Carbon aboveground (*Mg ha*$^{-1}$)	Biomass belowground (*Mg ha*$^{-1}$)	Carbon belowground (*Mg ha*$^{-1}$)	Carbon total (*Mg ha*$^{-1}$)	Reference
Cerradão	97.5	48.75	17.84	8.92	57.67	Miranda *et al*. (2014)
Cerradão	36.63	18.32	7.22	3.61	21.93	Morais *et al*. (2013)
Gallery Forest	30.20	15.10	5.53*	2.77	17.87	Miranda *et al*., (2014); Scolforo *et al*., (2015);
Cerradão	61.21	30.61	11.20*	5.60	36.21	Miguel *et al*. (2015); Miranda *et al*. (2014)
Cerradão	56.30	28.15	32.65*	16.33	44.48	Scolforo *et al*. (2015); Miranda *et al*. (2014)
Cerradão	97.88	48.94	17.91*	8.96	57.90	Fernandes *et al*. (2008) Miranda *et al*. (2014)
Median Value	56.44	31.65	12.53	7.70	39.34	

* Below-ground data obtained according to the percentage estimates of Miranda *et al*., (2014).

Table 3. Amount of biomass stored in the vegetation of the Cerrado in grassland formations.

Ecosystems grassland	Biomass aboveground (*$Mg\ ha^{-1}$*)	Carbon aboveground (*$Mg\ ha^{-1}$*)	Biomass belowground (*$Mg\ ha^{-1}$*)	Carbon belowground (*$Mg\ ha^{-1}$*)	Carbon total (*$Mg\ ha^{-1}$*)	Reference
Clean Camp	5.50	2.75	16.30	8.15	10.90	Castro e Kauffman (1998)
Clean Camp	7.97	3.99	5.13	2.57	6.55	Fearnside *et al.* (2009)
Clean Camp	24.00	12.00	16.8*	8.40	20.40	Miranda *et al.* (2014)
Clean Camp	11.40	5.70	7.98*	3.99	9.69	Scolforo *et al.*, (2015); Miranda *et al.* (2014)
Dirty Camp	5.90	2.95	4.13*	2.07	5.02	Goodland (1971); Miranda *et al.* (2014)
Camp Cerrrado	14.80	7.40	10.36*	5.18	12.58	Coutinho (1990); Miranda *et al.* (2014)
Camp Cerrrado	22.40	11.20	15.68*	7.84	19.04	Delitti *et al.*, (2006); Miranda *et al.* (2014)
Median Value	13.14	6.57	10.72	5.46	12.03	

* Below-ground data obtained according to the percentage estimates of Miranda *et al.*, (2014).

Discussion

Over the past decades, the voluntary carbon market has taken on grand proportions, surpassing the milestone of 1 billion dollars traded (Ecosystem Marketplace, 2022). Soon after the Kyoto Protocol (1997), trade adhered to the carbon certificate (Godoy, 2009), and other treaties such as the Paris Agreement improved trade with incentive mechanisms for Reducing Emissions from Deforestation and Degradation (REDD+), (Börner *et al*., 2010).

In addition, with the reinforcement granted by the climate agreements, the two carbon markets (e.g. regulated market and voluntary market) have been boosted in recent years (Ecosystem Marketplace, 2023), reaching an exponential growth of 478 million carbon credits issued in 2021 (World Bank, 2022).

In Brazil, the voluntary carbon market (VCM) has shown promise (Ecosystem Marketplace, 2023), especially after the implementation of Law 14.119/21 by the Federal Government, which regulates the Payment for Environmental Services Policy. In addition, the Federal Government has been working on the National Policy for Payment for Environmental Services (PNPSA) and the National REDD+ System (dealt with by PLs 195/2011 in the Federal Chamber and 212/2011 in the Senate) (Santos *et al*., 2012), including the National Registry for Payment for Environmental Services (CNPSA) and Federal Payment programs for Environmental Services (PFPSA) through Law 14. 119/21, with the implementation of carbon credit payment projects on private properties, with Environmental Reserve Quotas (CRAs), Private Natural Heritage Reserves (RPPNs) and Conservation Units (CUs) (Agência Senado, 2021).

The implementation of the Floresta+ Carbon Programme, through Ordinance Nº. 518 (MMA, 2020), also signalled Brazil's positive involvement, stimulating the voluntary carbon market through autonomy and more significant investment by the private sector in its negotiations, bringing the MVC in Brazil up to par with other countries (Biofílica, 2022). Another measure that should boost the carbon market in Brazil is the drafting of the new decree (11.075) of 21 March 2022 by the Federal Government, which establishes rules and plans for climate change mitigation and government involvement in public policies to encourage CCM, as well as active private companies and institutions, with strong growth in trading on the Carbon Efficient Index (ICO_2-B3) of B3, the official Brazilian stock exchange, between 2011 and 2025 (Bolsa de Valores – B3, 2010, Fig. 4)

The high cost and bureaucracy of carbon credit verification and certification procedures (Vargas *et al.*, 2022), as well as the lack of public policies committed to reducing implementation costs (Santos *et al*., 2012), is the main challenge facing the carbon market in Brazil (Silveira & Oliveira, 2021), especially for small companies or rural properties.

Figure 4. Chart of trading metrics for the efficient carbon index (ICO_2), Stock Exchange – B3 with future projections in the range from 2011 to 2025. https://www.b3.com.br. Accessed on 23 jul. 2024 (Bolsa de Valores – B3, 2010).

Therefore, for vegetation to be certified for the sale of carbon credits on the global market, interested parties must hire companies that specialise in floristic surveys (Silveira *et al*., 2008), quantifying carbon stocks and managing carbon credits on the global market (Ecosystem Marketplace, 2022).

According to this reference, because it is time-consuming and complex work, the cost of providing these services is significant (Vargas *et al*., 2022), which hinders the growth of the carbon market in Brazil, especially in the Cerrado, where its potential for carbon storage is often neglected (Sawyer *et al*., 2017). In addition, the prohibition of public funds in the payment for environmental services described in Article 10 of Law 14.119 of January 2021 also shows a retreat by the government, which should be the main party involved in this issue (Santos *et al*., 2012).

The Cerrado biome is considered an "inverted forest" because it has deep roots, a characteristic that allows plants to resist and be resilient to lack of water and disturbances caused by fire (Miranda, 2010; Reis *et al*., 2015; Terra *et al*., 2023). These functional characteristics make plants in the Cerrado more adapted to tolerate climate change (Sano, 1998; Araújo *et al*., 2021), contributing to growth and carbon accumulation, a fundamental characteristic of carbon credit projects. The findings of Terra *et al.* (2023) reinforce the significant potential for carbon storage in the Cerrado biome, revealing an average of 20.4 $Mg.ha^{-1}$ of carbon in the surface, 14.24 $Mg.ha^{-1}$ of carbon in the roots and 123.13 $Mg.ha^{-1}$ of carbon in the soil, totaling an average of 145.62 $Mg.ha^{-1}$ of the three compartments (tree+root+soil), these figures emphasize the importance of conserving the Cerrado. We therefore strongly recommend that payment for ecosystem services programs be targeted at the Cerrado as a strategy for conserving its essential ecosystems. PES programmes should also be targeted primarily at traditional communities and smallholdings where family farming takes place. Carbon credit payment projects should become increasingly common in the Cerrado biome, such as the recent project published by Votorantim and the Votorantim Reset newspaper, with more than 300,000 carbon credits generated in native Cerrado vegetation between 2017 and 2021 (Reset, 2023; Votorantim, 2022). This reinforces the high potential for implementing carbon credit payment projects in the Cerrado Biome.

Since the formation of the first civilizations, it has been known how critical natural resources were. However, there was no concern about conserving nature. The market for payment for ecosystem services arises as an incentive to maintain biodiversity through the generation of alternative income, with the precept that it is possible to conserve biodiversity and have income from conservation, building a relationship of co-benefits, which makes the market for payment for ecosystem services, a market with high growth potential in the world's financial investment exchanges. Like any financial market, the payment for ecosystem services market also presents challenges to be overcome, such as reducing the bureaucracy of verification and certification of carbon credits for commercialization in the global market and reducing the cost of implementation. However, according to platforms specialized in environmental finance analysis (Ecosystem Marketplace, 2022), all indications are that these challenges will soon be overcome. Therefore, we expect the market for payment for ecosystem services to be even more promising in the future, both for climate change mitigation and for supplementing the income of traditional communities, small landowners, and small businesses.

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Authors' Contribution

Following the taxonomic structure of the CRediT (Contributor Roles Taxonomy), the authors of this work performed the following functions: **conceptualisation**: ideas; formulation or evolution of overarching research goals and objectives, and **supervision**: supervisory and leadership responsibility for the planning and execution of the research activity, including external guidance to the core team, authors Ludimila Rodrigues de Almeida and Paulo Sérgio Morandi. As for **methodology**: development or design of methodology; creation of models, and **review and editing**: preparation, creation and/or presentation of published work by members of the original research group, specifically critical review, commentary or revision – including pre- or post-publication stages, author Nayane C. C. Prestes. All the contributions made by the authors were fundamental to the development and conclusion of this research.

Conflicts of interest

The authors declare that there are no personal, scientific, commercial, political or financial conflicts of interest in the submitted manuscript that might appear to influence this work.

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