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ASSESSING THE ECONOMIC BENEFITS OF FOREST CARBON RESERVOIRS IN VIETNAM: IMPLICATIONS FOR FOREST CARBON TRADING MARKET DEVELOPMENT

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ABSTRACT

The forest carbon sink is a cornerstone in Vietnam's strategy to combat climate change, aiming for carbon neutrality by 2050 as pledged during COP26. Assessing the economic benefits of Vietnam's current forest carbon sinks is crucial for initiating a domestic forest carbon trading market. Following protocols set by the Inter-Ministerial Committee on Climate Change in 2006, market valuation techniques to approximate the economic value of the forest carbon reservoir were employed. Results show Vietnam's forest ecosystems sequester about 1,401.52 million tons of carbon, equivalent to 5,143.60 million tons of CO_2. The estimated economic value is approximately 25,717.95 million USD, with natural forests valued at about 87.44 million USD annually and planted forests at 63 million USD annually. These findings underscore Vietnam's capacity to establish and expand its forest carbon trading market. However, currently the establishment of Vietnam's forest carbon sink market is still in the preparatory phase and has not yet developed into an independent and complete trading system. Therefore, to optimize this potential, Vietnam needs to improve forest quality, promote sustainable forestry economics, and conduct scientific research to provide persuasive and reliable evidence, to support policies for the establishment and development of the forest carbon sink market.

Keywords: Biomass, economic value, forest carbon sink, market value method, stock volume, Viet Nam.

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INTRODUCTION

In recent times, anthropogenic climate change has emerged as a formidable challenge confronting humankind, jeopardizing the sustainable socio-economic progression of nations globally, including Vietnam. The primary contributor to this phenomenon is the anthropogenic emission of carbon dioxide. A contemporary report from the IPCC's AR6 Synthesis Report (Calvin *et al.*, 2023) reveals that emissions of greenhouse gases persist in their ascension across all major sectors internationally, although the rate of increase has decelerated, the Earth's temperature could increase to 1.5°C above pre-industrial levels by the mid-2030s in all scenarios. Scientific communities caution that the probability of exceeding a 2°C increase in global temperatures during the 21st century is high, barring unanimous and immediate global efforts to substantially curtail greenhouse gas emissions. In reaction to these climatic shifts, nations worldwide have pledged political and fiscal commitments directed towards the mitigation of greenhouse gas emissions and the adaptation to the evolving consequences of climate change.

Presently, two primary methodologies exist for the diminution of greenhouse gas emissions. The first entails direct emission abatement, primarily through the restriction of carbon dioxide emissions into the atmosphere. This is achieved by promoting energy efficiency and the deployment of emission reduction technologies to curtail pollution. However, this approach grapples with fiscal impediments, adversely affecting the economic advancement of numerous nations. Conversely, the second methodology centers on indirect emission reduction, emphasizing the augmentation of carbon dioxide absorption and sequestration capacities via forests and other natural ecosystems. This approach is efficacious and has garnered preference in various countries. Scholarly research, both domestic and international, has elucidated that the expenses associated with emission reduction through forestry are markedly inferior to those of industrial emission diminution. For example, it is noted that for each cubic meter of growth, forests can absorb an average of 1.83 tons of carbon dioxide and emitting 1.62 tons of oxygen (Zhang and Yi, 2022). When juxtaposed with direct emission abatement, the establishment of forest-based carbon reservoirs

exhibits a pronounced fiscal advantage. The IPCC's Sixth Assessment Report indicated that forests account for approximately 80% of the carbon stored above-ground and about 40% of the carbon stored below-ground relative to the total organic carbon reserves on the planet (Intergovernmental Panel On Climate Change (IPCC), 2022).

As an emerging economy, Vietnam, similar numerous other developing nations worldwide, faces serious challenges from climate change and the depletion of natural resources, including the imperative of carbon emission reduction. Consequently, enhancing carbon sinks through forest ecosystems has become a significant strategy for Vietnam to address climate change-related issues.

Nevertheless, studies on carbon pricing, the economic valuation of forest carbon, and carbon market mechanisms in Vietnam are still limited. Presently, Vietnam is engaged in an initial trial of carbon credit trading in the North Central region from 2022 to 2026. Existing transactions are predominantly voluntary, with a deficiency in structured trading markets and comprehensive regulatory frameworks. Additionally, public cognizance regarding forest carbon sinks is limited, and there exists a dearth of legal oversight and safeguarding mechanisms. Investment in scientific inquiry in this domain is also constrained. These elements collectively constitute impediments and challenges in the formation and evolution of Vietnam's forest carbon trading market.

Research on estimating forest carbon stocks has employed a variety of methodologies, including satellite products, remote sensing, and carbon flux monitoring. Abbas *et al.* (2020) and Yuan *et al.* (2022) utilized the CASA model to estimate productivity and carbon sequestration. Similarly, Csillik *et al.* (2019) combined airborne LiDAR with Planet Dove satellite imagery to estimate above-ground carbon density (ACD). Other approaches include the use of field data, forest inventories, and model simulations, as demonstrated by Bao Huy and Pham (2008), Baral *et al.* (2009), and Vicharnakorn *et al.* (2014).

The Biomass Expansion Factor (BEF) method has become increasingly popular for assessing forest biomass. Huang *et al.* (2014) refined the biomass conversion factor for more accurate estimates. Significant contributions to the integration of BEF with biomass equations have been made by Lisboa *et al.* (2018), Mateos *et al.* (2016), and Magalhães (2015). The economic value of forest carbon sequestration has been explored by Dieter and Elsasser (2002), Banasiak *et al.* (2015) and Kazak *et al*. (2016). This study follows IPCC guidelines for forest carbon stock estimation using BEF and employs the market method to evaluate the economic value of the forest carbon reservoir (Intergovernmental Panel On Climate Change (IPCC), 2006, 2003).

The primary objective of this study is to select an appropriate calculation method to determine the absorption and storage capacity of forest carbon sinks in Vietnam. Beyond estimating the economic value of these forest carbon sinks, the study aims to analyze and discuss the importance of choosing a precise and efficient calculation method tailored to Vietnamese conditions. Additionally, it evaluates the potential for establishing a market for forest carbon sink transactions, a key factor in promoting investment and attracting diverse funding sources for sustainable forest projects. A deeper understanding of the economic value of forest carbon sinks is essential not only for boosting investment activities but also for the rapid formation and development of the forest carbon market in Vietnam. Furthermore, the results of this study will provide crucial information and reference standards for developing and implementing forest protection and sustainable forest resource management policies. This will contribute to conservation efforts and enhance forest carbon storage under the REDD+ program (Reducing Emissions from Deforestation and Forest Degradation, conservation and enhancement of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon reserves).

MATERIALS AND METHODS

Data sources: The calculations presented in this article are based on data obtained from multiple sources. These sources include the results of the national forest inventory conducted between 2013 and 2016, as well as monitoring data collected during Cycles I, II, III, and IV by the Forest Inventory and Planning Institute (FIPI) in Vietnam. Additionally, official data related to forest resources, sourced from the Ministry of Agriculture and Rural Development, the General Statistics Office, and the Forestry General Department, were incorporated into the analysis.

Furthermore, the article drew upon information from publications related to the Vietnam Forestry Development Strategy for the period 2021-2030 with a vision to 2050, annual statistical yearbooks, and various other relevant documents to support and substantiate the calculations and findings presented in the study.

Methods

Estimation Method for Forest Carbon Stock: The methodology employed to determine forest carbon stock in this study aligns with the guidelines established by the IPCC in 2003 and 2006 (Intergovernmental Panel On Climate Change (IPCC), 2006, 2003). The focus of this methodology is primarily on two key forest carbon reservoirs: above-ground biomass (AGB) and below-ground biomass (BGB). It does not include consideration of four other carbon reservoirs associated with forests,

namely deadwood, litter, soil organic carbon, and harvested wood products. The estimation process encompasses three fundamental steps:

1) Estimating Above-Ground Biomass (AGB): This step involves the estimation of the biomass contained in the above-ground components of trees, including the trunk, branches, leaves, and other woody components. The biomass is then converted into carbon content.
2) Estimating Below-Ground Biomass (BGB): In this phase, the biomass presents in the below-ground parts of trees, such as roots, is estimated. However, studying the below-ground biomass of plants, particularly of trees, is challenging. Excavating tree roots to measure biomass is an expensive and difficult task for large trees with deep and extensive roots. Therefore, estimating below-ground biomass (BGB) primarily relies on conversion factors from the above-ground biomass (AGB).
3) Calculating Carbon Stock and CO_2 Storage in Total Forest Biomass: The final step involves combining the estimates of above-ground and below-ground carbon content to determine the total carbon stock within the forest. This total carbon stock represents the amount of carbon stored in the forest ecosystem, including both living trees and their root systems. Additionally, the calculated carbon stock can be used to infer the amount of carbon dioxide (CO_2) stored within the forest biomass, given that carbon is the primary component of organic matter.

It's important to note that this methodology, while focusing on AGB and BGB, excludes other carbon reservoirs present in forests, which may also play a significant role in the overall carbon balance of forest ecosystems. The choice to concentrate on specific carbon pools aligns with the IPCC guidelines and serves as a standardized approach for assessing and reporting forest carbon stock in the context of climate change mitigation and carbon accounting.

The specific formulas used are as follows:

(1) $AGB = VOB \times WD \times BEF = VOB \times 0.55 \times BEF$

(2) $BGB = AGB \times R = AGB \times 0.275$

(3) $\sum C = \sum(AGB + BGB) \times CF = \sum (AGB + BGB) \times 0.5$

(4) $\sum EF = \sum C \times 44/12$

In the formulas (1), (2), (3), and (4), AGB represents above-ground biomass; BGB represents below-ground biomass; $\sum C$ denotes total carbon in forest biomass; and $\sum EF$ signifies the total CO_2 equivalent absorbed by the biomass. Specific factors are calculated as follows:

+ VOB refers to the volume of debarked wood inventory in m^3, obtained from the national forest inventory conducted between 2013 - 2016 by the FIPI.

+ WD is the ratio of absolute dry weight to fresh sample weight (tons/m^3 or grams/cm^3). The basic wood volume for tropical forests is 0.55 (0.40 - 0.69).

+ Biomass Expansion Factor (BEF) is the biomass expansion factor (tons) that converts stem wood volume to total tree biomass. BEF calculation for tropical forests uses a formula developed by (Brown and Iverson, 1992):

Scenario 1: If SB < 190 tons-dry matter/ha, then BEF = Exp (3.123 – 0.506 x ln(SB))

Scenario 2: If SB > 190 tons/ha, then BEF has a default value of 1.74

Where SB represents branch biomass calculated as follows:

(5) $SB = VOB \times WD$

+ CF: Represents the ratio of carbon in forest biomass, often taken as 0.5 (Intergovernmental Panel On Climate Change (IPCC), 2006).

+ R: The ratio of above and below-ground forest carbon, the default value used to estimate BGB is 0.275.

+ Coefficient: 44/12 = 3.67 is the conversion factor from carbon mass to CO_2.

Estimating the Economic Value of Forest Carbon Storage: In this study, the economic value of forest carbon storage is estimated using a market-based method. The economic value depends on two key factors: the forest carbon stock (C) and the unit price of carbon emission credits in the market (P). The economic value (V) can be calculated using the formula:

(6) $V = C * P$

Where:

V: Represents the economic value of forest carbon storage.

C: Denotes the forest carbon stock, which is the amount of carbon stored in the forest ecosystem.

P: Represents the price of carbon emission credits in the market, which reflects the monetary value of one unit of carbon emissions reduction or sequestration.

RESULTS

Forest Area Dynamics and Coverage in Vietnam: The comprehensive analysis of forest dynamics and coverage in Vietnam from 2010 to 2022, based on the annual forest resource status declaration by the Ministry of Agriculture and Rural Development of Vietnam and data from the General Statistics Office, Statistical Yearbook, is presented in Table 1 and Figure 1.

Table 1. Forest status in Vietnam from 2010 to 2022

Unit: thousand hectares

Year	Area of forest	Of which		Proportion of forest coverage (%)
		Natural forest	Planted forest	
2010	13388.1	10304.8	3083.3	39.5
2011	13515.1	10285.4	3229.7	39.7
2012	13862.0	10423.8	3438.2	40.7
2013	13954.4	10398.1	3556.3	41.0
2014	13796.5	10100.2	3696.3	40.4
2015	14061.9	10175.5	3886.4	40.8
2016	14377.7	10242.1	4135.6	41.2
2017	14415.4	10236.4	4179.0	41.5
2018	14491.3	10255.5	4235.8	41.7
2019	14609.2	10292.4	4316.8	41.9
2020	14677.2	10279.2	4398.0	42.0
2021	14745.2	10171.7	4573.5	42.0
2022	14790.1	10134.1	4656.0	42.0

Source: Ministry of Agriculture and Rural Development of Vietnam General Statistics Office 2020, 2021, 2022 Statistical Yearbook 2020, 2021, 2022

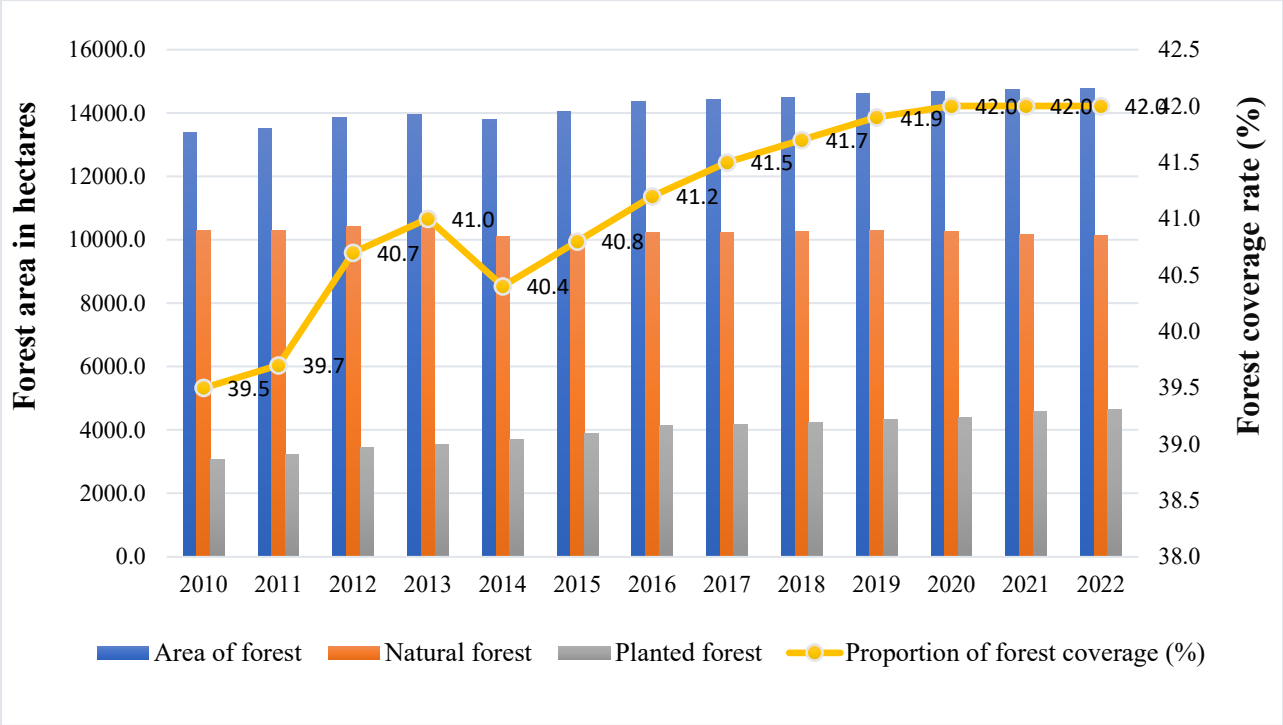

Figure 1. Changes in Vietnam's forest area and coverage in the period 2010-2022

The period from 2010 to 2022 witnessed notable changes in Vietnam's forest area, particularly in the planted forest segment. During this timeframe, Vietnam's forest area expanded, growing from approximately 13,388.1 thousand hectares in 2010 to around 14,790.1 thousand hectares in 2022. This expansion resulted in an increase in the forest cover rate, which rose from 39.5% in 2010 to 42.0% in 2022. Notably, the average annual increase in forest cover rate during this period was 1%.

These statistics indicate that Vietnam stands out as one of the few developing countries within the tropical region that has experienced progressive growth in its forest area. This expansion in forest cover places Vietnam in the fourth stage of the forest transition curve, a concept often used in forest transition theory. This stage signifies a sustained expansion in forested land, marking a positive trend towards increased forested area and associated ecological benefits. This development reflects the efforts and policies aimed at forest conservation,

reforestation, and sustainable forest management in Vietnam.

Both natural and planted forests play crucial roles in carbon sequestration, with natural forests often exhibiting higher carbon absorption capabilities. Despite a slight initial decline in natural forest area from around 10,304.8 thousand hectares in 2010 to approximately 10,100.2 thousand hectares in 2014, it later increased and stabilized around 10,000 thousand hectares, reaching 10,134.1 thousand hectares in 2022. This steady growth demonstrates the positive efforts in managing and conserving Vietnam's natural forests.

The planted forest area continuously increased from 3,083.3 thousand hectares in 2010 to around 4,656.0 thousand hectares in 2022. This growth may reflect Vietnam's efforts in developing planted forests to meet timber demands and ensure the sustainability of forest resources, while enhancing carbon sequestration and retention capabilities.

Calculating the Carbon Storage of Forest Carbon Pools in Vietnam: Data on the area and average wood volume for different forest states were compiled from the nationwide forest inventory project conducted during the 2013-2016 period by the FIPI. Applying formulas (1), (2), and (5) to calculate Aboveground Biomass (ABG) and Belowground Biomass (BGB) for each forest state, the results were consolidated in Table 2.

Table 2. Aboveground Biomass (AGB) and Belowground Biomass (BGB) by Forest State in Vietnam.

No.	Forest State	Standing tree volume (m^3/ha)	AGB (tons/ha)	BGB (tons/ha)
1	Evergreen forest (Rich)	280.6	273.78	75.29
2	Evergreen forest (Medium)	163.9	209.91	57.73
3	Evergreen forest (Poor)	80.2	147.47	40.55
4	Restoring forest	74.9	142.57	39.21
5	Deciduous forest	111.8	173.77	47.79
6	Bamboo forest	21.6	77.14	21.21
7	Mixed bamboo and wood forest	98.7	163.39	44.93
8	Coniferous forest	163.5	209.66	57.66
9	Mixed broadleaf-coniferous forest	137.5	192.47	52.93
10	Mangrove forest	33.4	95.67	26.31
11	Rocky mountain forest	56	123.49	33.96
12	Planted forest	66.5	134.44	36.97
	Average Wood Volume (m^3/ha)	**107.4**		

Source: Compiled from Karsten et al. (2010); Vietnam Administration of Forestry; (Forest Planning and Investigation Institute (FIPI), 2020)

Applying the three steps with the average wood volume, using the compiled data in Table 2 and applying formulas (3) and (4), we calculate the Carbon storage of each forest state and the equivalent CO_2 storage. The results are presented in Table 3. Through the data presented in Table 3, it's evident that the total carbon storage in Vietnam's forests amounts to 1401.52 million tons of Carbon, with an equivalent CO_2 storage of 5143.60 million tons of CO_2. This indicates a significant increase in forest carbon storage during this period compared to the reference period of 1995-2010. The results also reveal considerable differences in carbon storage among various forest states, ranging from 49.17 tons C/ha to 174.53 tons C/ha across different ecological zones. The natural evergreen forest state exhibits the highest carbon storage at 174.53 tons C/ha, while the bamboo forest state shows the lowest at 49.17 tons C/ha. Among the 12 primary forest types, evergreen broadleaf forests, primarily natural forests, account for approximately 55% of the total carbon in forest biomass, while planted forests contribute 20%, mixed forests constitute about 11%, and the rest comprises other forest types. Therefore, conservation efforts should prioritize natural forests, especially implementing advanced techniques in planted forests to enhance wood quality and carbon absorption.

In Vietnam, several scholars have conducted research to determine forest carbon storage across different forest states and regions nationwide. According to the Forest Planning and Investigation Institute (FIPI) (2020) and Vu (2009), the carbon storage in rich forest states nationwide ranges from 123.77 to 206.23 tons C/ha, moderate forests range from 100.10 to 155.49 tons C/ha, poor forests range from 84.61 to 123.88 tons C/ha, and recovering forests range from 66.05 to 106.27 tons C/ha. This shows that the calculations from our study are consistent with these findings above, indicating a certain reliability in the calculations and reflecting the improved potential for carbon absorption and storage in Vietnam's forest carbon pools during this period. This provides a solid scientific foundation for calculating forest carbon

and developing technical forestry interventions in future projects.

Table 3. Total Carbon storage and equivalent CO_2 storage by forest state in Vietnam

No.	Forest State	Carbon Mass (tons C/ha)	Forest reserves (million m^3)	Carbon storage C(AGB) (million tonsC)	Carbon storage C(BGB) (million tonsC)	Total Forest Carbon Storage (million tonsC)	Total Equivalent CO_2 Storage (million tons CO_2e)
1	Evergreen forest (Rich)	174.53	163.08	79.56	21.88	101.44	372.28
2	Evergreen forest (Medium)	133.82	262.78	168.28	46.28	214.55	787.42
3	Evergreen forest (Poor)	94.01	121.68	111.87	30.76	142.63	523.47
4	Restoring forest	90.89	277.21	263.84	72.56	336.39	1,234.56
5	Deciduous forest	110.78	66.22	51.46	14.15	65.61	240.80
6	Bamboo forest	49.17	9.05	16.16	4.45	20.61	75.64
7	Mixed bamboo and wood forest	104.16	64.37	53.28	14.65	67.94	249.32
8	Coniferous forest	133.66	23.35	14.97	4.12	19.09	70.05
9	Mixed broadleaf-coniferous forest	122.70	6.74	4.72	1.30	6.01	22.07
10	Mangrove forest	60.99	8.76	12.55	3.45	16.00	58.71
11	Rocky mountain forest	78.73	40.42	44.56	12.25	56.82	208.52
12	Planted forest	85.70	275.02	277.99	76.45	354.43	1,300.77
	Total		**1,318.68**	**1,099.24**	**302.29**	**1,401.52**	**5,143.60**

As of 2022, Vietnam boasts 14.7 million hectares of forests, covering 42.02% of the land area, with over 10 million hectares of natural forests and more than 4.6 million hectares of planted forests. According to Vu (2022), it's estimated that on average, forests absorb about 69.8 million tons of carbon (CO_2) annually. This underscores the immense potential of Vietnam's forestry sector in participating in the forest carbon market, as it is the only sector with a net negative emission (Government of Vietnam, 2022). Vietnam has the capacity to fulfill its commitment to transfer a reduction of 10.3 million tons of CO_2e in the North Central region from 2018 to 2024 to the Forest Carbon Partnership Facility (FCPF) for a total of $51.5 million USD, as per the program signed on October 22, 2020, between the Ministry of Agriculture and Rural Development (the implementing agency for the North Central region emission reduction program) and the World Bank (as FCPF trustee).

Economic Value of Forest Carbon Reservoirs in Vietnam: The economic value of forest carbon reservoirs is determined by two factors: the carbon storage capacity of the forest and the price of carbon emission credits. Forest carbon reservoirs not only provide ecological benefits but also have economic advantages. Valuing the economic benefits of forest carbon reservoirs allows them to be traded on the market, contributing to the commercialization of forest carbon and the payment for forest carbon services. This study applied the market value method and selected the average trading price of carbon reservoir projects as formed in the international market, adapting them to the conditions in Vietnam.

In the international Carbon market, the price of Carbon consistently fluctuates over time. In 2008, Carbon prices were around 35 USD per tCO_2e but decreased to below 10 USD by the end of 2011 (World Bank, 2012). However, the Forest Carbon Partnership Facility (FCPF) mechanism noted that the willingness to pay (WTP) among its members currently doesn't exceed 5 USD/tCO_2e. Hence, a price of 5 USD/tCO_2e has been proposed for application in Mozambique (World Bank, 2012) and in some UK studies (Lovegrove, 2015). Hamrick and Goldstein (2015) proposed the use of a 3.3 USD/tCO_2e price through the Ecosystem Marketplace project of Forest Trends for environmental finance, market-based mechanisms, and payments for ecosystem services. According to Forest Trends' Ecosystem Marketplace in 2021, the commercial value of carbon in forestry and land use varies significantly annually. For instance, in 2017, it reached 16.9 million tons of CO_2 at an average price of 5.1 USD/ton for a total value of 65.2 million USD. In 2018, it surged to 51.1 million tons of CO_2 with an average price of 3.39 USD/ton for a total value of 173 million USD. By 2019, it decreased to 36.7 million tons of CO_2 at an average price of 4.33 USD/ton for a total value of 159 million USD, as reported by Forest Trends' Ecosystem Marketplace. According to S&P Global, China's carbon credit price in April 2022 stood at 9.29 USD/ton (1 credit).

In Vietnam, the Vietnam Environmental Protection Fund generated carbon emission credits from

five CDM projects at a rate of 3-4 EUR/tCO_2e (Bao Huy and Pham, 2008; Wang and Liu, 2009). As per the commitment to transfer emission reduction quotas in the North Central region from 2018 to 2024, signed on October 22, 2020, between the Ministry of Agriculture and Rural Development of Vietnam (implementing agency for the North Central region emission reduction program) and the World Bank as the FCPF-designated entity, the price was set at 5 USD/tCO_2e.

Considering recent transactions in the Carbon credit market in Vietnam, a price range of around 5 USD/tCO_2e seems suitable. The economic value of Carbon sequestration services is estimated based on the reduction of Carbon emissions (also known as Carbon sequestration). It's crucial to differentiate this Carbon uptake from the Carbon stored in biomass (Zhu, 2010). The ability of forests to absorb CO_2 is determined by the growth rate of forest biomass (m^3/ha/year), converted to biomass (dry ton/ha/year), then to Carbon (ton C/ha/year), and finally to CO_2 (ton/CO_2/ha/year). The CO_2 retention capacity of forests is determined based on the forest's biomass (m^3/ha), converted to biomass (dry ton/ha), then to Carbon (tonC/ha), and eventually to CO_2 (ton CO_2/ha).

According to the calculations in Table 3, Vietnam's equivalent CO_2 storage is 5143.60 million tons CO_2 with a Carbon price of 5 USD/tCO_2e, estimating the economic value of forest CO_2 sequestration services in Vietnam at 25717.95 million USD. According to the Forest Planning and Investigation Institute (FIPI) (2020), the Carbon sequestration activities during the 2010-2020 period were mainly due to natural forest restoration (17.488 million tCO_2e/year) and afforestation, including both new planting and reforestation (12.600 million tCO_2e/year). Therefore, the estimated economic value of Carbon sequestration services in Vietnam's natural forests is around 87.44 million USD/year, and for planted forests, it's approximately 63 million USD/year.

These data adequately demonstrate that the market potential and commercial demand for forest carbon in Vietnam are substantial. If effectively tapped into, this could significantly contribute to the national economy, providing substantial income for forest growers and contributing significantly to the protection and development of forests in Vietnam.

DISCUSSION

Methods for Determining the Stock and Estimating the Economic Value of Forest Carbon Reserves: A crucial factor in effectively managing and commercializing forest carbon reservoirs is the accurate assessment of forests' carbon sequestration and storage capacities, as well as valuing this carbon asset. This presents a significant challenge due to the diversity of calculation methods and the specific application of each, along with differences in measurement standards and accuracy levels.

Methods for estimating forest carbon stocks can include industrial carbon capture and biological carbon sequestration. Biological carbon sequestration, which estimates carbon from timber to reflect the forest's carbon capture capability, mentioned by Wang and Liu (2009), faces limitations in complexity and cost. Additionally, other methods like forest resource inventories, model simulations, remote sensing, and carbon flux monitoring offer their own benefits and limitations. For instance, forest resource inventories and field surveys are straightforward but costly, whereas remote sensing and carbon flux monitoring are suitable for larger areas but require expensive equipment and complex techniques. When it comes to valuing the economic worth of forest carbon, various calculation methods exist, such as cost, market price, and income approaches. Each method has its pros and cons, with the advantages of one possibly being the disadvantages of another.

Therefore, selecting an appropriate method that is not only cost-effective and easy to implement but also ensures accurate measurement results is extremely important. To optimize the management of forest carbon reservoirs, a comprehensive approach that carefully balances cost and accuracy, effectively combining different measurement and evaluation methods, is necessary. This will ensure that the valuation and management of forest carbon are conducted scientifically, with rigorous reasoning and efficiency.

Research on the economic value of forest carbon storage emphasizes the important role of forests in mitigating and adapting to climate change. However, a challenge arises in recognizing and accurately valuing the benefits that forests provide, including functions that cannot be directly commercialized in the market. According to Pearce (2002), some critical functions of forests lack clear economic value due to their absence in the commercial market. Shi *et al.* (2020) argue that the value of forest carbon reserves is properly reflected only when they participate in the commercial market.

The international forest carbon market is in a strong development phase with the participation of many countries and organizations. However, in Vietnam, this market is still in its initial stage, mainly focusing on research and evaluation to establish an independent and complete trading system. The Vietnamese government plans to pilot the carbon market, including the forest carbon market, from 2025, aiming to develop domestic and international carbon exchanges from 2028. This roadmap has been outlined in the Environmental Protection Law 2020 and Decree 06/2022/ND-CP.

Research results show that Vietnam has significant potential in developing the forest carbon market, with an equivalent CO_2 reserve of 5143.60 million tons of CO_2. The economic value of CO_2 storage

services of forests in Vietnam is estimated at 25,717.95 million USD. This opens up significant opportunities to contribute to the national economy and improve income for the people.

However, implementing ecosystem services related to carbon and developing sustainable financial mechanisms such as the Reducing Emissions from Deforestation and Forest Degradation program (2020) requires serious consideration and support from policymakers. Although Vietnam has started participating in some agreements and pilot projects related to emission reduction, many of them are still in the feasibility study stage.

Valuing and determining the economic value of forests is important to ensure the comprehensive and optimal allocation of financial resources for forest protection and development. However, building and developing the forest carbon market in Vietnam faces many challenges and difficulties. It is necessary to conduct pilots, learn from the experiences of countries with developed market models, perfect mechanisms and policies, and prepare all conditions to be ready to participate in the carbon trading market. The government should also develop policies to promote the development of the forest carbon market, aiming to improve efficiency and diversify the functions of the carbon reserve market.

Forest resources or forest ecosystems provide a range of goods and services that offer economic, material, physiological, psychological, emotional, or social benefits directly or indirectly to humans (Sincere Forests, 2021). The ecosystem services provided by forests are diverse, with studies worldwide identifying nearly 100 different services (Aznar-Sánchez *et al*., 2018). Specifically, the CO_2 sequestration service of forests, if converted into monetary value through clean development mechanisms, places the value of forest carbon fixation/storage at between \$14.680 – \$18.350 trillion per year, with the annual value of carbonic gas absorption estimated at around \$1.835 trillion (based on a price of \$5/ton of CO_2). The CO_2 absorption value of natural tropical forests is about \$500 – \$2,000 per hectare, and for temperate forests, this value is estimated to be between \$100 – \$300 (Balasubramanian, 2019; Demir, 2013; Pham, 2021; Rönnbäck, 1999; Shanley *et al*., 2015; Tamayo *et al.*, 1997).

Forest ecosystems play a vital role in providing a wide range of goods and services that benefit humans in multiple dimensions, from economic to material, physiological, psychological, and social, both directly and indirectly. According to Sincere Forests (2021), these services are very diverse, with nearly 100 types of services identified globally according to Aznar-Sánchez *et al*. (2018). Among these, the CO_2 sequestration service of forests, when converted into monetary value through clean development mechanisms, brings an estimated value of \$14.680 to \$18.350 trillion per year for carbon fixation/storage, and about \$1.835 trillion per year for carbonic gas absorption, based on a price of \$5 per ton of CO_2 (Pham, 2021). The CO_2 absorption value of natural tropical forests ranges from \$500 to \$2,000 per hectare, and this value for temperate forests is estimated to be between \$100 to \$300 according to Balasubramanian (2019).

According to Field *et al.* (2014), only through effective carbon storage, sustainable forest management is considered one of the most cost-effective solutions to climate change mitigation in forestry. Recognizing the importance of sustainable forest management as a cost-effective climate change mitigation measure, the Vietnamese government has identified forests as an indispensable element in socio-economic development and climate change response strategy, aiming for carbon neutrality by 2050 as committed at COP26. This is also reflected in the land use, land-use change, and forestry (LULUCF) sector being identified as having a significant role in climate change mitigation, with the forestry sector alone achieving net negative emissions during the 2010-2020 period at -39.3Mt CO_2e (Government of Vietnam, 2022; Vu, 2022).

Research analysis shows that forest carbon reserves vary between forest states, with natural forest carbon reserves higher than those of plantation forests. Across different ecological regions, forest carbon reserves also vary significantly, with Vietnam's forest carbon reserves ranging from about 1 – 19 million tons of carbon per hectare to >150 million tons of carbon per hectare across ecological zones, where old-growth evergreen broadleaf forests in the Central Highlands and South Central Coast have the highest carbon reserves (>150 tons). This discrepancy highlights the importance of selecting appropriate tree species and management methods to optimize carbon sequestration efficiency. Studies have shown that planting broadleaf and young trees, enhancing vertical distribution in forests, and converting trees into long-lasting wood products can increase the total forest value and optimize carbon efficiency (Pache *et al*., 2020; Zhao *et al*., 2022).

Therefore, to leverage the potential carbon reserves from forests and expand the forest carbon credit market in Vietnam, supportive policies aimed at improving forest quality, enhancing management, protection, and forest development are needed. This includes identifying priority forest areas for protection and development, especially old-growth forests, to optimize carbon efficiency and biodiversity. Simultaneously, investment in forest carbon research and the development of a legal framework for the forest carbon market, including detailed technical guidelines and the selection of carbon standards suitable for Vietnamese conditions, are necessary to seize opportunities and achieve emission reduction goals.

Conclusion: Over the past decades, Vietnam is among the few developing countries in the tropical region that has experienced a positive trend in forest area. From 2010 to 2022, the forest area increased from 13,388.1 thousand hectares to 14,790.1 thousand hectares, and the forest coverage rate rose from 39.5% to 42.0%. The average annual increase in forest coverage during this period was 1%. The total forest carbon stock in Vietnam reached 1,401.52 million tons, with a tCO_2e stock of 5,143.60 million tons, showing a significant increase compared to the reference period of 1995-2010. Among the 12 main forest types, natural forests account for approximately 55% of the carbon stock. The estimated suitable price for Carbon is around 5 USD/tCO_2e considering Vietnam's conditions. With this Carbon price, the economic value of Vietnam's forest carbon sink is estimated at 25,717.95 million USD. The economic value of carbon sequestration services in Vietnam's natural forests is estimated at 87.44 million USD annually, while planted forests account for 63 million USD annually. These figures reflect Vietnam's substantial potential in developing forest carbon sinks. However, to optimize this potential and advance policies and forest carbon projects, Vietnam needs to intensify forest management and protection efforts, enhance forest quality, promote sustainable forestry economics, and prioritize scientific research to provide credible evidence for upcoming policies, considering appropriate pathways and directions for Vietnam's future development.

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