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Economic Profitability of Carbon Sequestration of Fine-Aroma Cacao Agroforestry Systems in Amazonas, Peru

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Abstract: Currently, the economic profitability of cocoa is being affected by the increasing incidence of pests, low selling prices, high production costs, and the presence of cadmium in cocoa farms, posing a potential risk of crop abandonment. Therefore, the objective of the present research was to evaluate the economic profitability of carbon sequestration of fine-aroma cacao agroforestry systems in Amazonas, Peru, using the economic indicators of NPV, EIRR, and the benefit–cost ratio. For this purpose, 53 small cocoa producers of the APROCAM cooperative were involved, from which data were obtained on the general characteristics of the production system, production and maintenance costs, indirect costs, and administrative costs; in addition, the costs of implementation and maintenance of an environmental services project were calculated to finally make a cash flow projected over 5 years. As part of the results, the economic analysis was carried out on 104.25 hectares of cocoa belonging to the total number of farmers evaluated, who reported an average yield of 957.32 kg of dry cocoa per he. In addition, it was found that the production cost is PEN 3.91/kg of dry cocoa, and the average selling price is PEN 7.38/kg of dry cocoa. After the economic analysis, it was found that the implementation of an environmental services project is profitable (NPV = PEN 1,454,547.8; EIRR = 44% and B/C = 1.86). These results open up an opportunity for cocoa farmers to diversify and increase their income by contributing to climate change mitigation.

Keywords: environmental services; production costs; cocoa; NPV; EIRR; B/C; sensitivity analysis

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1. Introduction

In Peru, 89,749 producers depend directly on cocoa cultivation, with 11,666 producers located in Amazonas. Cocoa represents 3.4% of the total national agricultural production of Peru and ranks eighth among the main export products (Free on Board (FOB) USD 154,094.92) [1]. In Amazonas, at the end of 2023, cocoa became the third highest-exported product (FOB USD 420,682) after coffee and tara, reporting a negative variation (−21.4%) compared to exports in 2022 [2]. On the other hand, cocoa production in the Amazon region has experienced variations in the last three years. From 2021 to 2022, there was an increase of 26%, from 3085.50 tons to 5887.60 tons. However, in 2023, production fell by 14.18% compared to the previous year, to 3085.50 tons [1].

The decline in production and yields may be attributed to farms being affected by the increasing incidence of pests, which results in crop migration. Additionally, other factors impacting yield and therefore profitability include the high cost of inputs required for production, limited access to credit, and low selling prices of fine-aroma cocoa [3]. In addition to the above, there are current limitations in the market due to the presence of cadmium in cocoa beans [4], which hinders the entry of cocoa to all markets, making economic profitability one of the most important weaknesses of cocoa production [5].

If we analyze the profitability of cocoa according to the benefit–cost ratio and yield, it is said that cocoa cultivation becomes profitable if it reaches a minimum production of 770 kg of dry cocoa per hectare [6]. However, cocoa farms that are associated under an agroforestry system can be more beneficial as they can contribute up to 12% of gross income [7] and can diversify economic income; this diversification of income also serves as an alternative to mitigate the impacts of climate change [8], thereby seeking to minimize the negative effect of market price and production fluctuation on household income [9].

On the other hand, reducing tax obligations for producers, companies, and/or organizations by employing more efficient energy in their activities is a mitigation alternative that has gained more prominence in recent years, known as the carbon tax [10]. These actions are necessary, as unsustainable energy use and land use change are the main drivers for the ongoing increase in greenhouse gas emissions, collectively representing 47% of total greenhouse gas (GHG) emissions in Latin America and the Caribbean [11,12]. Despite the persistent issue, a few countries such as Colombia, Costa Rica, Chile, and Uruguay have presented and/or are implementing strategies to address this problem. Therefore, the IPCC, in its sixth assessment report, mentions that there are options in all areas to reduce emissions by at least half by 2030 [11].

Furthermore, the Kyoto Protocol details regulations for the operation of the international carbon emissions market, where developed countries have a commitment to reducing the level of GHG emissions and not exceeding the permissible level. To achieve this, through the Clean Development Mechanism, the World Bank finances carbon sequestration [13]. The adoption of this mechanism involves transactions between developed and developing countries through projects aimed at mitigating and/or capturing GHGs [14]. Therefore, Peru, a developing country, currently has potential for implementing these types of projects, which facilitate the sale or issuance of certificates for reduced GHG emissions.

Under this context, recent trends show that carbon market opportunities continue to expand. For example, the total value of global markets grew by 11%, from USD 159,210 million in 2010 to USD 176,027 million in 2011. The volume has also increased from 88,835 to 101,189 tons of CO_2 equivalent per year [15]. By 2021, the increase in global emissions of more than 2 billion tons was the largest in absolute terms ever, as energy demand in this year recovered compared to the previous year [16]. Additionally, global revenues from carbon pricing increased by almost 60% in 2021 compared to 2020 levels, reaching approximately USD 84 billion [17]. Therefore, more than two-thirds of countries now plan to use carbon markets to meet their nationally determined contributions stipulated in the Paris Agreement [18], a document in which all developing countries commit to reducing their GHG emissions to limit warming to below 1.5 °C by 2030.

In this context, cocoa production faces significant challenges to improve its profitability. Efforts should focus on increasing production, combating phytosanitary problems, and addressing the effects of climate change. The implementation of agroforestry systems in cocoa cultivation emerges as a strategy to diversify income, conserve biodiversity, and provide ecosystem services, among others. Therefore, the implementation of research and programs that quantify the amount of CO_2 sequestered by cocoa agroforestry systems and their economic evaluation in the region are vital to improve profitability and develop climate change mitigation strategies.

Therefore, the objective of this study was to evaluate the economic profitability of carbon sequestration of native fine-aroma cacao agroforestry systems in Amazonas, Peru. The specific objectives of this study were (i) to calculate the dry cocoa yield per hectare and CO_2 sequestration of agroforestry systems (tons of CO_2 per hectare per year), (ii) to calculate the income and expenditures of cocoa production, and (iii) to calculate the economic evaluation (Economic Net Present Value (NPV), Economic Internal Rate of Return (EIRR), and benefit–cost ratio (B/C)) of carbon sequestration in the agroforestry systems through the implementation of an environmental services project.

2. Materials and Methods

2.1. Study Area

The study was conducted in the cocoa agroforestry systems of the Multiple Service Cooperative APROCAM. The cooperative is composed of 235 small cocoa producers distributed across 4 districts of the province of Bagua (Aramango, Copallín, La Peca, and Imaza), 2 districts of the province of Utcubamba (Cajaruro and El Parco), and 1 district of the province of Santa María de Nieva (Nieva) in the Amazonas region [19]. APROCAM leads cocoa exports in whole or broken beans, raw except for sowing (Tariff item: 1801001900), with an FOB of USD 428,962 for 2022 and USD 366,020 for November 2023, with Spain and Italy as its main markets [2].

2.2. Sample Selection and Sampling Criteria

The sample was calculated from a population of 235 cocoa producers from the APROCAM cooperative. It consisted of 53 cocoa producers (at 90% reliability), which was calculated by the finite population random sampling technique (Equation (1)) [20,21], with an average of 2.97 hectares each, totaling 104 hectares involved in the study. This sample was obtained using simple random sampling technique for finite populations [21]. Utilizing stratified sampling by proportional allocation, the sample was divided into the 4 intervention districts, obtaining separate sub-samples for each district (Equation (2) and Table 1). This approach allowed for increased accuracy of the survey results [22].

$$\begin{gathered} \mathrm{n} = \frac{Z^2PQN}{E^2(N-1)+Z^2PQ} \\ \mathrm{Np} = \frac{n}{N}n1 \end{gathered} \tag{1}$$

where the following are defined:

n: Sample size;
N: target population: 235 cocoa producers from APROCAM;
P: Proportion of units having the characteristics: 50% or 0.5;
Q: Proportion of units that do not have the characteristics: 50% or 0.5;
E = Error = 10% or 0.1.

$$\mathrm{p} = \frac{n}{N}n1 \tag{2}$$

where the following are defined:

Np = Sample size per district;
N = Sample size (53);
n1 = Population size per district;
N = Target population (235).

Table 1. Distribution of cocoa producers by district for information collection.

District	n1	n/N	Np	Np *
Aramango	4	0.23	0.90	1
Cajaruro	26	0.23	5.88	6
Copallin	55	0.23	12.44	12
El Parco	5	0.23	1.13	1
Imaza	83	0.23	18.77	19
La Peca	57	0.23	12.89	13
Nieva	5	0.23	1.13	1
Total	**235**		**53.14**	**53**

* Real number of producers considered.

2.3. Assessing the Economic Importance of Carbon Sequestration in Cocoa Agroforestry Systems

To evaluate the importance of carbon sequestration in agroforestry systems of fine-aroma cocoa, a 5-year cash flow projection was made, which considered the implementation of a project for the sale of environmental services through the sale of carbon credits at the cooperative level financed with non-refundable resources. To determine the feasibility of implementing the project, three economic profitability indicators were considered: the Net Present Economic Value (NPV), the Economic Internal Rate of Return (EIRR), and the benefit–cost ratio (B/C).

The economic profitability analysis was divided into two phases: (i) the field phase, in which the producers were responsible for providing information through the administration of surveys, which comprised qualitative or quantitative questions (Table 2), (ii) and the office phase, during which tabulations were utilized to calculate the total production of dry cocoa in kg/year, investment costs for cocoa installation, direct management and maintenance costs for cocoa, indirect costs such as tools and machinery, and administrative expenses for cocoa production.

Table 2. Components of the survey for field data collection.

Component	Quantitative Variables	Qualitative Variables
General characteristics	Hectares of cocoa in production, dry cocoa yield in kg/ha, cocoa planting density, cocoa selling price (PEN/kg), daily wage price (PEN).	General data of the producer, Main activity
Variables for determining maintenance and production costs	Number of labor days for pruning, harvesting, weeding, fertilizer application, pest and disease control, and transportation cost (PEN/bag of 50 kg).	

2.3.1. Application of Surveys

For the collection of field information, surveys were applied to 53 producers; the surveys consisted of 11 questions of qualitative and quantitative variables directly related to the information useful for the economic analysis (Table 2).

2.3.2. General Characteristics of Evaluated Agroforestry Systems (AFS)

To describe the general characteristics of cocoa farms under AFS, the following variables were considered: planting density (plants/ha), cocoa AFS in production (ha), cocoa AFS evaluated (ha), dry cocoa yield (kg/ha), and selling price (PEN per kg/dry cocoa). These values were calculated based on the results obtained from the surveys. Each surveyed producer was responsible for providing this data during the survey administration. Planting density was determined by the spacing of cocoa plants (plant and row), from which the number of cocoa plants per hectare per producer was calculated. For economic analysis purposes, the average number of plants per hectare from all evaluated farms was calculated. The same criterion was used to calculate the yield of dry cocoa, selling price of dry cocoa, and total area of cocoa under AFS in production. The only difference is that for the total area of cocoa under AFS in production used for economic analysis, it was the sum of all areas reported by the producers.

2.3.3. Total Cocoa Production in kg per Year

Annual cocoa production was calculated by multiplying the average yield per hectare by the total number of hectares of cocoa production in AFS evaluated, which was determined by summing the total AFS cocoa production per producer. Additionally, a 5% allowance for self-consumption and waste was accounted for.

The total production in kg/ha per year was projected for 5 years, without considering an increase, as the implementation of the project (environmental services for carbon sales) does not directly impact cocoa production. For economic analysis, it was decided to exclude this percentage of production, as there are inherent losses in cocoa cultivation due to various post-harvest management factors, environmental conditions, or other external factors directly affecting yield. Additionally, within this percentage, there is cocoa that may be allocated for the producer's self-consumption during their daily activities.

2.3.4. CO_2 Sequestration of Cocoa Agroforestry Systems

To calculate the CO_2 sequestration of the agroforestry systems in tons per hectare per year, the CO_2 values reported by Goñas et al. 2022 [19] were utilized. These values were obtained from 15 cocoa agroforestry systems divided into three age strata ranging from 8 to 40 years. A scatter plot was generated to illustrate the amount of CO_2 retained by each farm of different ages. The age range of farms where CO_2 shows an increase (12 to 20 years of age) was identified, and a linear projection was conducted to determine the trend of CO_2 sequestration increase per year, supported by the application of the r^2 formula. This procedure allowed us to find the value of CO_2 sequestered per hectare per year, which was used consistently for the 5 years of economic evaluation.

2.3.5. Investment Costs for Cocoa Production

Within the investment costs of cocoa production, we considered the value of the land for cocoa planting, the price of the seedlings needed to install one hectare of cocoa, the cost of transporting the seedlings from the nursery to the final field, and the cost of installation (planting) of one hectare of cocoa. These data were projected based on the total number of hectares in the study area.

2.3.6. Direct, Indirect, and Administrative Costs Evaluated

The direct costs for cocoa management and maintenance were calculated considering the general characteristics of the evaluated agroforestry systems and the total cocoa production in the study area. To calculate the total direct costs per year, we aggregated the labor costs for farm management (pruning, weed control, shade management, fertilizer application, pest and disease control) and harvesting, along with the costs of inputs. Subsequently, these data facilitated the calculation of the unit cost per kg of cocoa produced by dividing the total direct costs by the total productivity in kg of dry cocoa per year.

Indirect costs encompassed the acquisition of tools and machinery necessary for crop management, such as machetes, picks, shovels, motorized harvesters, etc.

Administrative costs included the minimum expenses required by the APROCAM cooperative to carry out its activities, as well as payments for basic services such as water, electricity, internet, and telephone.

2.3.7. Costs for Implementation of the Environmental Service Project—Sale of Carbon Credits

To calculate the cost of implementing environmental services—sale of carbon credits in the cooperative—we considered the fees of the internationally recognized certifier VERRA (https://verra.org/about-verra/who-we-are/, accessed on 3 November 2022). Additionally, costs were accounted for the implementation of consultancy services for project implementation, along with an allocation for maintenance and monitoring expenses to oversee the project once it has been implemented.

2.3.8. Cash Flow with 5-Year Projection and Economic Evaluation

Based on all the previously calculated data, a 5-year cash flow projection was conducted. Among the assumptions, income and expenses were considered both with and without the implementation of the environmental service project—sale of carbon credits. It was assumed that there would be no intervention of a financing source directly impacting crop yields in the next 5 years. Therefore, it was considered that cocoa yields in kg/ha, farm management and maintenance costs, and the selling price of cocoa would remain constant for all years evaluated. The assumptions with and without the sale of carbon credits were distinguished by including the sale of carbon credits as part of the economic income for the producer.

These assumptions allowed for the calculation of the net present economic value (NPEV), economic internal rate of return (EIRR), and the benefit–cost (B/C) ratio, as shown in Equations (3)–(5), respectively.

The NPEV represents the present value of the net cash flows of a proposal, where net cash flows are defined as the difference between periodic income and periodic expenses [23].

$$\mathrm{NPEV} = \sum \frac{\mathrm{B_t} - \mathrm{C_t}}{(1+\mathrm{r})^2} \tag{3}$$

where the following are defined:

B = Profit in year t; C = Costs in year t; r = discount rate applied.

In an economic analysis, if the NPV value is positive, it indicates that the project will achieve a positive return on the initial investment of the project. If the opposite happens and this value is negative, it indicates losses on the initial investment of the project. Therefore, if the NPV is greater than or equal to 0, the project is accepted; if it is not, the project is rejected [23].

On the other hand, the EIRR is that relative value that equates the present value of the income stream with the present value of the estimated expenditure stream. In other words, it involves updating an income stream (expected net flows) at the zero or initial moment of the investment, and comparing it with the present value of a stream of expenditures (volume of investment at that time) at a rate K or i, referred to as the cost of capital or opportunity cost of a project, within a suitable framework, which is determined beforehand [24] (Equation (3)).

$$0 = -A + \sum_{i=1}^{n} \frac{Qi}{(1+EIRR)^i} \tag{4}$$

where the following are defined:

A = initial investment;

Qi = net cash flow for period i (from time one to time n);

EIRR = Economic Internal Rate of Return;

N = time in years.

The following criteria will be used to make the decision: If EIRR < 1 (the proposal is profitable); EIRR = 1 (the proposal is not profitable) and if EIRR > 1 (the proposal is not profitable) [25].

Additionally, the benefit–cost ratio was calculated according to Equation (4). This analysis consists of comparing the benefits and costs of a project; if the benefits exceed the costs, it provides data for decision making and tends to the acceptance of a project [26]. A B/C relationship greater than 1 indicates that the benefits outweigh the costs; if the opposite occurs, it is suggested that the project lacks economic profitability.

$$\mathrm{B/C} = \frac{\mathrm{Tbe}}{\mathrm{Tcd}} \tag{5}$$

where the following are defined:

B/C = Benefit–cost ratio.

Tbe = Total benefits found.

Tcd = Total costs encountered.

Finally, the sensitivity analysis was conducted by affecting the key variables that could impact the profitability of the project with their possible variations. Different scenarios of negative variation were considered in cocoa production (−10% to −47.49%), carbon sequestration (−30% to −80%), sales cost per kg of dry cocoa (−15% to 47.79%), and selling cost per ton of carbon (−20% to −80%). Additionally, scenarios of increased costs for the implementation of environmental services were considered (20% to 100%).

3. Results

3.1. General Characteristics of Evaluated Agroforestry Systems

The 53 farmers evaluated had cocoa farms under agroforestry systems, with the level of cocoa in production under these systems ranging from 0.25 ha to 5 ha, totaling 104.25 ha of cocoa in production, this amount being part of the economic evaluation; in addition, the average yield of these systems is 957 kg of dry cocoa per hectare, which is sold at an average price of 7.30 PEN per kg (Table 3).

Table 3. General characteristics of cocoa agroforestry systems evaluated.

Concept	Unit of Measure	Value
Number of agroforestry systems	AFS	53
Planting density	Plants/ha	897
AFS cocoa in production	ha	104.25
AFS cocoa in evaluated	ha	104.25
Dry cocoa yield	kg/ha	957.32
Selling price	PEN/kg	7.38

3.2. Total Cocoa Production in the Study Area

According to the average yield of dry cocoa in kg/ha, it was found that cocoa production for the 104.25 hectares evaluated is 99,800.95 kg; considering 5% of losses and self-consumption, the total production would be 94,810.90 kg. The values projected for the next 5 years are equal to the base year, since the economic analysis of the sale of carbon credits was carried out without considering the intervention in cocoa production (Table 4).

Table 4. Total cocoa production in the study area.

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Hectares	104.25	104.25	104.25	104.25	104.25	104.25
Productivity (kg/ha)	957.32	957.32	957.32	957.32	957.32	957.32
Total production (kg)	99,800.95	99,800.95	99,800.95	99,800.95	99,800.95	99,800.95
Losses and self-consumption %	5%	5%	5%	5%	5%	5%
Total kg	**94,810.90**	**94,810.90**	**94,810.90**	**94,810.90**	**94,810.90**	**94,810.90**

3.3. Investment, Management and Maintenance Costs for Cocoa Production in the Study Area

The investment cost for the installation of the cocoa crop amounts to PEN. 2,298,048.50, including the cost of the land, the number of plants per hectare, transportation of the seedlings and the total cost to install one hectare of cocoa (Table 5).

Table 5. Investment costs for cocoa production in the study area.

Description	Unit	Quantity	Unit Cost	Total Cost
Total land area (Ha)	Hectare	104.25	20,000.00	2,085,000.00
Planting density (Seedling/ha)	Seedling	827	5.00	4135.00
Seedling transportation cost (PEN)	Seedling	827	0.50	413.50
Planting installation cost—sowing (PEN)	Hectare	104.25	2000.00	208,500.00
Total			**PEN**	**2,298,048.50**

Within the costs of management and maintenance for cocoa production considered as direct costs, labor costs for weed control, shade management, fertilizer application, pest and disease control, and cocoa harvesting amounted to PEN 258,520.33. Additionally, the costs for the purchase of inputs amounted to PEN 112,590.00. Therefore, adding the two items together, the total production cost amounts to PEN 371,110.33. Finally, the cost per unit of kg of dry cocoa is PEN 3.91 (Supplementary Table S1)

Indirect costs for cocoa production can vary between the base year and the 5 years projected for the economic evaluation. The highest indirect cost is reported in year 2 of project implementation, amounting to PEN 102,290.00. This increase is due to the purchase of a motorized scythe for each of the producers. Additionally, it was projected that field tools should be purchased in the base year and 3 years after project implementation, and personal protection equipment should be purchased once a year because they are accessories with a short useful life (Supplementary Table S2).

Finally, the basic administrative costs for cocoa production are PEN 92,560.00 per year, starting in year 1 and for the next 4 years of project evaluation. The items considered are the basics that the cooperative needs to be able to develop its activities (Supplementary Table S3).

3.4. CO_2 Sequestration in Cocoa Agroforestry Systems

The carbon sequestration of cocoa AFS is variable, the younger systems, ranging from 8 to 9 years, sequester less carbon (465 and 441 Tn/ha, respectively) compared to the systems aged 10 to 20 years. However, there is a decline in carbon sequestration at 30 years, with older systems (40 years) capable of retaining only 332 t of CO_2/ha (Figure 1). This decline in carbon sequestration for systems with cocoa trees older than 30 years may be due to the harvesting of the associated timber shade trees in the system and the cocoa trees reaching the end of their life cycle, resulting in plant death. Consequently, as the age of the systems advances, there is a likelihood of a lower plant density within the systems, reflected in the reduction in carbon sequestration. Therefore, this behavior serves as an indicator to consider the renovation of a cocoa farm.

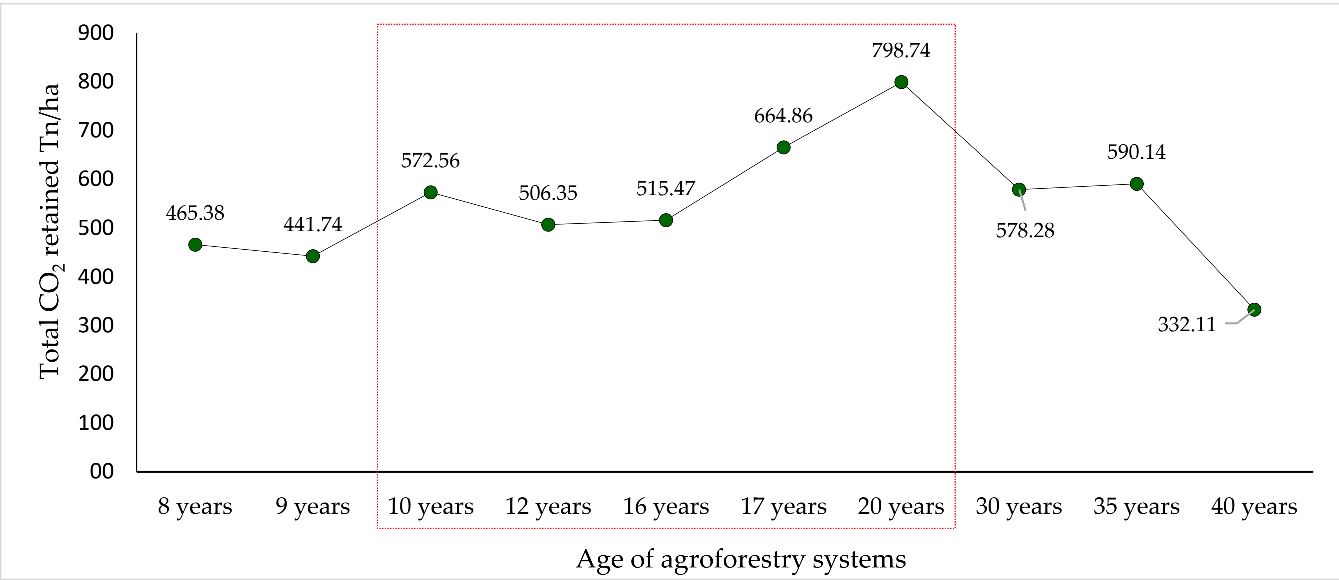

Figure 1. CO_2 sequestration according to the age of cocoa.

Figure 1 also demonstrates that the CO_2 sequestration increases in the 12- to 20-year-old systems (506 and 798 Tn/ha, respectively) remain constant (highlighted in the red rectangle). Consequently, these data were utilized to create a linear trend projection of the increase in CO_2 sequestration (Figure 2). As the system ages over the years, the linear equation applied to the projection exhibited an R^2 = 0.9117 (Figure 2). The values of carbon sequestered from systems older than 30 years were not used for this projection because at that age, cocoa production begins to decline.

After the application of the linear equation for the projection of the carbon sequestration of the systems, the calculation of the CO_2 retained in Tn/ha year was made. Taking the 12-year systems as a base year, it was found that the CO_2 retained was 103 Tn/ha year, these data were used to perform the economic analysis of the sale of carbon credits of the evaluated systems (Table 6).

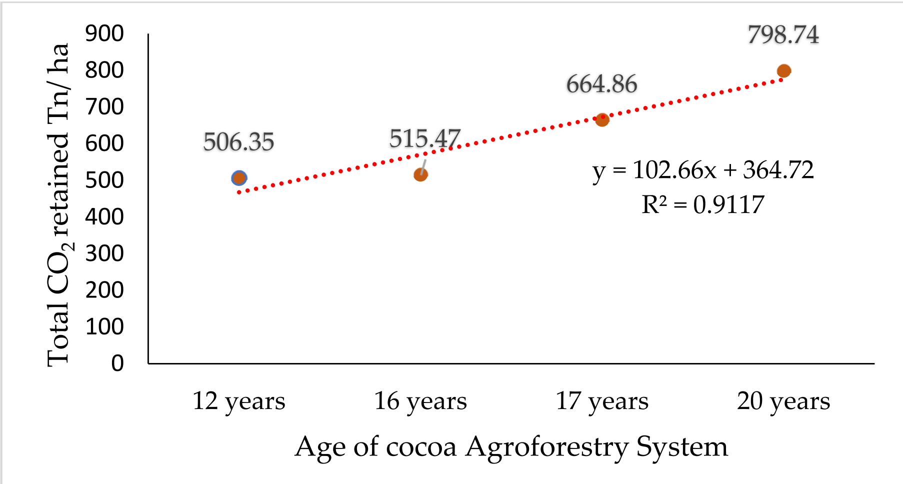

Figure 2. Linear trend of carbon sequestration increases per year.

Table 6. Projected CO_2 sequestration per year of agroforestry systems.

Period	System Age in Years	Total, of CO_2 Retained Tn/ha	CO_2 Sequestered Tn/ha Year
Year 0	12	506.35	
Year 1	13	1597	1090
Year 2	14	1699	103
Year 3	15	1802	103
Year 4	16	1905	103
Year 5	17	2007	103
Year 6	18	2110	103

3.5. Costs for Implementation of the Environmental Service Project—Sale of Carbon Credits

According to the calculation of the costs for the implementation of the environmental service project—sale of carbon credits—in the base year, it amounts to PEN 152,608.45. If the maintenance and monitoring expenses of the project are added, the total cost of implementation amounts to PEN 212,608.45. Additionally, from year 1 to year 5, the costs decrease to PEN 69,645.00 per year (Table 7). On the other hand, the maintenance and monitoring costs amount to the sum of PEN 60,000.00 annually, starting from year 0 and remaining constant until year 5.

Table 7. Costs for the implementation of the environmental service—sale of carbon credits in PEN *.

Concept	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
A. IMPLEMENTATION COSTS (A1 + A2) (PEN)	**152,608.45**	**9645.00**	**9645.00**	**9645.00**	**9645.00**	**9645.00**
A1 consulting services for the implementation of the sale of carbon credits (PEN)	**80,000.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Consulting services for the implementation of the sale of carbon credits (PEN)	80,000.00					
A2 Project certification (PEN)	**72,608.45**	**9645.00**	**9645.00**	**9645.00**	**9645.00**	**9645.00**
Account opening and registration (PEN)	**6057.95**	**-**	**-**	**-**	**-**	**-**
Account opening fee (PEN)	1929.00					
Enrollment fee (PEN)	4128.95					
Methodology approval process	**66,550.50**	**9645.00**	**9645.00**	**9645.00**	**9645.00**	**9645.00**
Methodology concept note application fee (PEN)	7716.00					
Processing fee when methodology element is accepted (PEN)	50,154.00					
Methodology concept note application fee (PEN)	5787.00					

Table 7. *Cont.*

Concept	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Expert application fee—AFOLU Experts—Agriculture Forestry and Land Use (PEN)	1446.75					
Expert application fee—Methodology Experts (PEN)	1446.75					
Validation/Verification Bodies Annual Fee (PEN)		9645.00	9645.00	9645.00	9645.00	9645.00
	-	-	-	-	-	-
B. MAINTENANCE COST (PEN)	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**
B1 Project maintenance and monitoring costs						
Field Specialist (PEN)	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00
Field Technician (PEN)	24,000.00	24,000.00	24,000.00	24,000.00	24,000.00	24,000.00
TOTAL (A + B) (PEN)	**212,608.45**	**69,645.00**	**69,645.00**	**69,645.00**	**69,645.00**	**69,645.00**

* Reference costs extracted from VERRA, 2013 [27].

3.6. Cash Flow to Calculate the Economic Profitability of the Implementation of an Environmental Services Project

To perform the cash flow and calculate the economic profitability of implementing an environmental services project, assumptions were considered, as they are the basic and necessary criteria for performing the 5-year projected cash flow (Table 8). The matrix was created with all the values of direct costs, indirect costs, administrative costs of cocoa production, total production of dry cocoa (kg), unit cost of dry cocoa production (PEN/kg), selling price of cocoa (PEN/kg), and loss due to self-consumption (5%). These costs were grouped into the following criteria: income and expenses without the sale of carbon credits, and income and expenses with the sale of carbon credits. To the latter, the production of carbon dioxide per hectare (Tn/ha) per year, the implementation cost of the project, and the selling price in PEN/Ton of CO_2 were added within the assumptions.

Table 8. Assumption for project implementation.

Supposes		**Cocoa Production Projection**				
Without the Sale of Carbon Credits	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Dry cocoa production in kg	99,801.00	99,801.00	99,801.00	99,801.00	99,801.00	99,801.00
Production cost per kg dry cocoa	3.91					
Sales cost per kg dry cocoa (PEN/kg)	7.38					
Loss due to self-consumption 5%.	5%					
With the sale of carbon credits		**Cocoa production projection**				
Dry cocoa production in kg	99,801.00	99,801.00	99,801.00	99,801.00	99,801.00	99,801.00
Production cost per kg dry cocoa	3.91					
Sales cost per kg dry cocoa (PEN/kg)	7.38					
Loss due to self-consumption	5%					
		Projected CO_2 sequestration Tn/ha per year				
Production (sequestration) of carbon dioxide (Tn/ha)	103	10,738.00	10,738.00	10,738.00	10,738.00	10,738.00
Cost for implementation of environmental service (PEN)		212,608.45	69,645.00	69,645.00	69,645.00	69,645.00
Selling cost per ton of carbon in USD	7.17					
Exchange rate *	3.859					

* https://www.sbs.gob.pe/app/pp/sistip_portal/paginas/publicacion/tipocambiopromedio.aspx, accessed on 2 March 2024.

The projected CO_2 sequestration was 10,738.00 Tn/ha per year in the 104.25 hectares of cocoa AFS evaluated. The selling price per ton of CO_2 was USD 7.17, a social price established by the Ministry of Economy and Finance for its application in projects [28] (Table 8).

The cash flow for the economic profitability analysis is presented in Table 9, and the economic analysis metrics are displayed in Table 10. The implementation of an environmental service project for the sale of carbon credits records an NPV of PEN 1,365,432.31. This means that, after discounting the investment and production costs over a period of 5 years, the cooperative will have a profit or gain of PEN 1,365,432.31. Based on this indicator, it can be suggested to invest in the implementation of the project.

Table 9. Cash flow of the implementation of the carbon credits sales project.

Items	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
I. Investment module (Expressed in "negative") (PEN)	**−2,297,548.5**	**0**	**0**	**0**	**0**	**0**
Plot installation	−2,297,548.5					
II. Operating module (A - B) (PEN)	**486,667.00**	**926,733.00**	**963,537.00**	**963,537.00**	**963,537.00**	**963,537.00**
A. Incremental revenues (a - b) (PEN)	0	297,103.13	297,103.13	297,103.13	297,103.13	297,103.13
(a) Revenues from sale of carbon credits	699,275.13	996,378.26	996,378.26	996,378.26	996,378.26	996,378.26
Sale of dry cocoa in PEN	699,275.13	699,275.13	736,079.09	736,079.09	736,079.09	736,079.09
Sale of retained $C0_2$ in PEN	0	297,103.13	297,103.13	297,103.13	297,103.13	297,103.13
(b) Revenues without sale of carbon credits (PEN)	699,275.13	699,275.13	699,275.13	699,275.13	699,275.13	699,275.13
Sale of dry cocoa in PEN	699,275.13	699,275.13	699,275.13	699,275.13	699,275.13	699,275.13
B. Incremental operating expenses (c - d) (PEN)	**212,608.45**	**69,645.00**	**69,645.00**	**69,645.00**	**69,645.00**	**69,645.00**
(c) Operating costs and expenses with carbon credits (PEN)	663,080.60	556,007.15	651,407.15	564.222,15	556,007.15	556,007.15
The cost of production involves all costs generated by production and sale (PEN)	663,080.60	556,007.15	651,407.15	564,222.15	556,007.15	556,007.15
(d) Operational costs and expenses without carbon credits (PEN)	450,472.15	486,362.15	581,762.15	494,577.15	486,362.15	486,362.15
Cost of production includes all costs generated by production and sale (PEN)	450,472.15	486,362.15	581,762.15	494,577.15	486,362.15	486,362.15
Nominal cash flow (I + II) (PEN)	**−1,811,381.81**	**926,733.26**	**926,733.26**	**926,733.26**	**926,733.26**	**926,733.26**
Cumulative cash flow (PEN)	**−1,811,381.81**	**−884,648.55**	**1,853,466.52**	**1,853,466.52**	**1,853,466.52**	**1,853,466.52**

Table 10. Metrics of the economic analysis.

Metric	Valor
Economic net present value in PEN	1,365,432.3
Economic internal rate of return	42.43%
Minimum interest rate	12%
Benefit–cost ratio (B/C)	1.79

Similarly, the project records an EIRR of 42.43%, indicating the profitability that the organization will achieve with the project's implementation. Regarding the benefit–cost ratio (B/C) indicator, the cash flow reports a value of 1.79 (Table 10). The economic indicators used in this research are the same as those used to determine the economic viability of public investment projects, research projects, business plans, and/or ventures. Under this scenario, considering the assumptions and scenarios presented in this research, the economic indicators suggest that implementing an Environmental Services Project through the sale of carbon credits is profitable and therefore viable for the APROCAM cooperative.

The sensitivity analysis scenarios revealed that as cocoa production decreases, the project's profitability also decreases. Based on the scenarios of a decrease in cocoa production (kg/year), it is observed that if production falls by 20%, the project would still be profitable, as the ENPV would reach a value of PEN 790,431.33, with an EIRR of 29.07% and a benefit–cost ratio of 1.54; this suggests that for every sol invested, you would still earn PEN 0.54. However, if production decreased by 47.49%, the project would be at the limit of its profitability. Although the ENPV still remains above zero with a value of PEN 92.48

and the benefit–cost ratio is 1.19, the EIRR would reach 12%, indicating that the project has reached its minimum expected profitability limit. Furthermore, when analyzing scenarios of carbon sequestration decrease (Tn/ha), it is deduced that if carbon sequestration decreases by up to 80% (20.60/ha), the project would still be profitable. In this case, the ENPV would be PEN 64,441.53, with an EIRR of 28.36% and a benefit–cost ratio of 1.36. This implies that for every sol invested, you would still earn PEN 0.36 (Table 11).

Table 11. Sensitivity analysis of the determining variables of economic analysis.

Affected Variable	Variation	Value	Results		
			ENPV	EIRR	B/C
Cocoa production (kg/year)	0.00%	94,810.90	1,365,432.31	42.43%	1.79
	−10.00%	85,329.81	1,077,931.82	35.61%	1.67
	−20.00%	75,848.72	790,431.33	29.07%	1.54
	−47.490%	49,785.21	92.48	12.00%	1.19
Carbon sequestration Tn/ha	0.00%	103.00	64.441.53	28.36%	1.79
	−30.00%	72.10	64.441.53	28.36%	1.63
	−50.00%	51.50	64.441.53	28.36%	1.52
	−80.00%	20.60	64.441.53	28.36%	1.36
Sales cost per kg dry cocoa (PEN/kg)	0.00%	7.38	1,365,432.31	42.43%	1.79
	−15.00%	6.27	934,181.58	32.31%	1.60
	−30.00%	5.16	502,930.84	22.74%	1.41
	−47.49%	3.87	92.48	12.00%	1.19
Selling cost of carbon (PEN/Tn)	0.00%	27.67	1,365,432.31	42.43%	1.79
	−20.00%	22.14	1,174,184.05	38.48%	1.69
	−40.00%	16.60	982,935.79	34.45%	1.58
	−80.00%	5.53	600,439.26	26.12%	1.36
Cost for implementation of environmental service (PEN)	0.00%	212,608.45	1,365,432.31	42.43%	1.79
	20.00%	255,130.14	1,282,635.33	40.12%	1.75
	50.00%	318,912.67	1,158,439.86	36.80%	1.69
	100.00%	425,216.90	951,447.41	31.63%	1.59

On the other hand, concerning a scenario of cocoa selling price decrease (PEN/kg), the project's profitability behaves similarly to the cocoa production decrease (kg/year). This suggests a positive relationship between both variables. For instance, if the selling price drops by 47.49% (3.87 PEN/kg), the project would reach profitability limits, with an EIRR of 12%. This indicates that the project has reached its lowest expected profitability point. Regarding the decrease in carbon selling price (PEN/Tn), the analysis shows that even with an 80% drop (5.53 PEN/Th), the project remains profitable. In this scenario, the NPV would be PEN 600,439.26, the EIRR would be 26.12%, and the benefit–cost ratio would be 1.36, suggesting that for every sol invested, you would still earn PEN 0.36. However, the risk would increase if the selling price decrease continues to decline (Table 11).

Regarding the increase in implementation costs of the environmental services project, it is deduced that even if implementation costs increase by up to 100% (PEN 425,216.90), the project would still be profitable. The NPV would have a value of PEN 951,447.41, the EIRR would be 31.63%, and the benefit–cost ratio would be 1.59, implying that for every sol invested, you would still earn PEN 0.59 (Table 11).

According to the sensitivity analysis, the critical points the project must handle are the decrease in cocoa production and the decrease in selling price. When either of these variables decreases, the project risks losing profitability, as the EIRR reaches its lowest point at 12% to the profitability limits.

4. Discussion

The study reported that the producers involved own farms ranging from 0.25 ha to 5 ha, which may explain why 95% of Peru's annual cocoa production comes from small producers with a planted area of between one and five hectares [29].

The average yield of the APROCAM cooperative's AFS is 957 kg of dry cocoa per hectare, which is above the national average (850 kg/ha) [30]. This could support the consistent projection of production over the 5-year evaluation period of the study. The possibility that cocoa yields will increase and be higher is as the producer's experience and access to credit is greater [31]. In addition, the producer's membership in an association increases the probability of improving crop yields [31]. This positive relationship is due to the fact that farmers with greater experience in cultivation can more confidently understand appropriate agronomic practices, soil management, pest and disease control, as well as the selection of suitable varieties, as these are the factors directly impacting cocoa profitability. Additionally, access to credit allows the producer to invest in agricultural inputs and the adoption of improved practices in cocoa agroforestry systems. Finally, producer association will be reflected in the improvement of opportunities for access to competitive and broader markets. Associated producers can offer volume and product quality, which leads to improved selling prices.

In 2022, the national farm-gate selling price was reported to be PEN 7.17/kg dry cocoa, and in 2023, the farm-gate selling price was reported to be PEN 8.08/kg dry cocoa, evidencing an increase in PEN 0.91 in one year [1]. These prices are within the sales range of APROCAM cooperative producers, who in 2022 sold their dry cocoa at an average price of 7.30 soles per kg at the farm gate, exceeding the national price that year. The higher selling price compared to the national average price may be due to cooperative members growing fine-flavor cocoas, which command a premium price in specialty markets. However, these data may be affected by external factors such as possible extreme weather events affecting production, market fluctuations, regulations, policies, and fluctuations in the dollar exchange rates, among others. However, in the economic analysis, a selling price of PEN 7.30/kg of dry cocoa was used because it was assumed that these external factors could be compensated for by the advancement of technological innovations, sales to differentiated markets, and the application of sustainable farm management.

The criterion to keep the yield and selling price of cocoa constant over the 5 years of evaluation is conservative, as the analysis of implementing environmental services does not directly intervene in cocoa production. Although the statistics show that from 2019 to 2022, cocoa yield has experienced a slight increase, from 5107.58 tons in 2019 to 5887.60 tons of dry cocoa harvested at the regional level, it does not guarantee that in 2023 the yield will decrease by 14% [1].

Therefore, the instability of production in each year can affect its profitability. This is compounded by the high production costs, which, by being elevated, decrease the return on investment, making it difficult to cover and finance the future growth of the production unit [32]. To address this issue, stakeholders in the chain are seeking alternatives to improve cocoa profitability. Recent international climate documents highlight the significant importance of afforestation of agricultural lands, which has a positive impact on CO_2 levels, not only through carbon absorption by trees that can be economically valued but also through the substitution of fossil fuels with biomass [33]. Therefore, valuing the ecosystem systems of multifunctional agroforestry would result in a change in land use [34], which directly favors producers. Exploiting these opportunities is made effective through the implementation of environmental service projects that sell carbon credits, allowing cocoa producers to diversify their income and obtain a carbon-neutral certification in the future.

In Latin America, to evaluate the profitability of the implementation of a project, the NPV and EIRR values are evaluated [35]. These indicators are essential tools for assessing the feasibility and profitability of various ventures, aiding in decision making related to resource allocation [36]. Their use is based on the close relationship between both indicators;

NPV is a popular metric used to assess the economic performance of a project and is also used to calculate the value of EIRR [37].

Therefore, NPV, EIRR, and the benefit–cost ratio are the most common and reliable indicators for investment decision making. According to these economic profitability indicators, the implementation of an environmental services project selling carbon credits in the study area would be profitable, yielding a profit of PEN 1,454,994.2 after 5 years of investment, with an EIRR of 44%, affirming the project's viability.

In Colombia, a study determined that payments for ecosystem services exceeding 453.6 USD/ha/year are considered highly profitable in terms of NPV. Additionally, agroforestry systems with cocoa can receive payments of up to 36 USD/Tn CO_2 [38], in this context, the cocoa agroforestry systems in this study can generate an NPV of PEN 13,956.78/ha/year, a value similar to that reported in previous research. Analyzing these payments for environmental services is important as they have become a means to promote biodiversity conservation and rural development, particularly in tropical and subtropical regions [39,40].

The results do not include a financial profitability analysis, because the analysis did not consider access to a loan for the project implementation, and thus, the financial profitability is the same as the economic one. APROCAM did not consider acquiring a loan, as a cooperative has the opportunity to acquire non-repayable funds from local, regional governments, NGOs, and other national and international funding sources. Access to credit for project implementation could raise production costs, and the return on investment might be slower. Regarding the benefit–cost ratio, the results indicate a positive ratio greater than 1. This value suggests that the project is economically viable, as the expected benefits of the project are 1.86 times greater than the implementation costs. In a different scenario, if the costs were to exceed the benefits, the project would not be economically viable and therefore would not be accepted for financing [26].

When exploring the impact of carbon income on the profitability of agroforestry systems compared to monoculture, it was found that there is a possibility to increase profitability minimally by 0.5% when the carbon price ranges between 8 USD/Tn CO_2e and a maximum of 70% when considering the highest carbon price (40 USD/Tn CO_2e) and the highest carbon discount rate (17.2 Tn C/ha for year) [41]. The present study conducted in the APROCAM cooperative demonstrates that, when considering a selling price of 7 USD/Tn CO_2e, cocoa agroforestry systems that include the carbon price are economically profitable, thus reinforcing the theory that the economic values of associated ecosystem services always have to increase the profitability of the system [34]. Additionally, the sensitivity analysis of project implementation suggests that the decline in cocoa production (kg/ha) and the selling price of dry cocoa (PEN/ha) may jeopardize the project's profitability, as a decrease of 47.49% in both leads to the EIRR value reaching the minimum profitability threshold (12%). Conversely, in a scenario where carbon selling prices and sequestration decrease by 80%, the project remains profitable. Therefore, the implementation of an environmental services project can significantly support the profitability of cocoa production under agroforestry systems. This is because the proper integration of trees into cultivated lands can provide greater welfare benefits for society as a whole, a case that does not occur with treeless agriculture or forest systems alone [42].

Therefore, the implementation of agroforestry systems must be accompanied by principles related to land use planning and biodiversity, which will allow for a greater positive social and environmental impact [43]. The social impacts will be reflected in the improvement of the quality of life of producers, as there will be greater opportunities to access basic services, especially education and health, job creation, community support through associativity, among others.

Therefore, the efficient use of agricultural lands is an alternative to contribute to the fulfillment of the Kyoto Protocol and the Paris Agreement objectives, which were created to reduce global greenhouse gas emissions. Agricultural lands are an important potential sink and could absorb large amounts of carbon. It is important to reintroduce trees into systems and manage them wisely along with the main crops and/or animals [44]. These carbon-sequestering agricultural production systems have the potential to generate income for producing families [45]. Peru, being a developing country, also has the commitment to adopt technologies, processes, and programs to limit global warming to below 1.5 °C by 2030; implementing a carbon tax and carbon bond sales can be carried out to counteract emissions from developed countries. To implement these strategies, cocoa agroforestry systems play a very important role, as it has been explained that their benefits are wide-ranging, involving economic, environmental, and social factors. The success of the implementation of these strategies will depend on the support of local and regional governments involved in the sector through the implementation and execution of political and environmental regulations.

Therefore, the economic analysis of this study serves as a precedent for local, regional, and national governments to implement environmental payment programs, either through fiscal incentives and/or subsidies. The coordination that governments can establish between environmental certifiers and cocoa producer organizations is the basis for developing environmental certification and labeling standards. These actions should be accompanied by continuous education and training for cocoa producers on the proper management of agroforestry systems and the benefits that carbon capture within these systems provides.

5. Conclusions

The results of the economic evaluation suggest that the implementation of a project focused on selling carbon credits could be economically viable. With an NPV of PEN 1,454,547.8, an EIRR of 44%, and a benefit–cost ratio of 1.86, the economic viability of the proposed project is evident.

These findings highlight the potential of carbon sequestration and emissions trading as innovative approaches for rural economic development and environmental conservation. According to the economic indicators evaluated, a promising alternative exists for national, regional, local governments, and/or peasant organizations to implement and promote ecosystem service programs. These programs can not only contribute to cocoa production income but also have the potential to mitigate climate change by promoting sustainable agricultural practices.

For future research, in addition to studying the socioeconomic characteristics of cocoa producers, should focus on validating the methodology for quantifying carbon sequestration in agroforestry systems. It is essential to subject this methodology to rigorous evaluation by an environmental services certifier, especially regarding the accurate quantification of carbon sequestration per hectare per year.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f15030500/s1, Table S1: Direct costs for cocoa management and maintenance in the area of research intervention. Table S2: Indirect costs for cocoa production. Table S3: Administrative costs for cocoa production.

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References

1. MIDAGRI (Ministerio de Desarrollo Agrario y Riego). Perfil Productivo y Competitivo de Los Principales Cultivos Del Sector Agrario. Available online: https://app.powerbi.com/view?r=eyJrIjoiMWZmNDY2NTEtODg4NC00ZmQxLTk1NjItNWRiYmE4OGY2MDA4IiwidCI6IjdmMDg0NjI3LTdmNDAtNDg3OS04OTE3LTk0Yjg2ZmQzNWYzZiJ9 (accessed on 2 March 2024).
2. PROMPERU. Exportaciones Regionales Por Partidas: Amazonas. Available online: https://app.powerbi.com/view?r=eyJrIjoiYzU3MjViOGMtMDk0MC00OGZmLWI5NTItMGQ1Y2JjMzE3NmNiIiwidCI6Ijk2YTM3OTA5LTljOTktNDAyNS05NWE1LTlmMDgwNWY1M2QyOCIsImMiOjR9 (accessed on 2 March 2024).
3. Antolinez-Sandoval, E.Y.; Almanza-Merchán, P.J.; Barona-Rodriguez, A.F.; Polanco-Díaz, E.; Serrano-Cely, P.A. Estado Actual de La Cacaocultura: Una Revisión de Sus Principales Limitantes. *Cienc. Y Agric.* **2020**, *17*, 1–11. [CrossRef]
4. Gramlich, A.; Tandy, S.; Gauggel, C.; López, M.; Perla, D.; Gonzalez, V.; Schulin, R. Soil Cadmium Uptake by Cocoa in Honduras. *Sci. Total Environ.* **2018**, *612*, 370–378. [CrossRef] [PubMed]
5. Caicedo-Vargas, C.; Pérez-Neira, D.; Abad-González, J.; Gallar, D. Assessment of the Environmental Impact and Economic Performance of Cacao Agroforestry Systems in the Ecuadorian Amazon Region: An LCA Approach. *Sci. Total Environ.* **2022**, *849*, 157795. [CrossRef]
6. Espinosa-García, J.A.; Uresti-Gil, J.; Vélez, I.A.; Moctezuma, L.G.; Inurreta, A.H.D.; Gongora, G.S.F. Productividad y Rentabilidad Potencial Del Cacao (*Theobroma cacao* L.) En El Trópico Mexicano. *Rev. Mex. Ciencias Agrícolas* **2015**, *6*, 1051–1063. [CrossRef]
7. Magne, A.N.; Nonga, N.E.; Yemefack, M.; Robiglio, V. Profitability and Implications of Cocoa Intensification on Carbon Emissions in Southern Cameroun. *Agrofor. Syst.* **2014**, *88*, 1133–1142. [CrossRef]
8. Amfo, B.; Ali, E.B. Climate Change Coping and Adaptation Strategies: How Do Cocoa Farmers in Ghana Diversify Farm Income? *For. Policy Econ.* **2020**, *119*, 102265. [CrossRef]
9. Viteri-Salazar, O.; Ramos-Martín, J.; Lomas, P.L. Livelihood Sustainability Assessment of Coffee and Cocoa Producers in the Amazon Region of Ecuador Using Household Types. *J. Rural Stud.* **2018**, *62*, 1–9. [CrossRef]
10. García-Rebollo, I.J. *El Impuesto Al Carbono Como Medida de Mitigación Del Cambio Climático*; Universidad de País Vasco: Bilbao, Spain, 2023.
11. IPCC (Intergobernmental Panel on Climate Change). Summary for Policymakers. In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; The Core Writing Team, Lee, H., Romero, J., Eds.; IPCC: Geneva, Switzerland, 2023. [CrossRef]
12. Banco Mundial. *Hoja de Ruta Para La Acción Climática En América Latina y El Caribe (2021–2025)*; Oficina Regional de América Latina y el Caribe del Banco Mundial: Washington, DC, USA, 2021.
13. Fernández Simón, L. *El Banco Mundial y La Financiación Del Carbono*; Universidad de León: Léon, Spain, 2018.
14. Torres, N. Mercados de Carbono: Alcances y Desafíos Para Afrontar El Cambio Climático. *Derecho Público Económico* **2023**, *3*, 89–102. [CrossRef]
15. Seeberg-Elverfeldt, C.; Gordes, A. *Agriculture, Forestry and Other Land Use Mitigation Project Database: Second Assessment of the Current Status of Land-Based Sectors in the Carbon Markets*; FAO: Rome, Italy, 2013; ISBN 9789251074640.
16. ONU. Las Emisiones Mundiales de CO2 Repuntaron En 2021 Hasta Su Nivel Más Alto de La Historia. Available online: https://unfccc.int/es/news/las-emisiones-mundiales-de-co2-repuntaron-en-2021-hasta-su-nivel-mas-alto-de-la-historia#:~:text=Las%20emisiones%20mundiales%20de%20di%C3%B3xido,del%20carb%C3%B3n%20para%20impulsar%20ese (accessed on 2 March 2024).
17. World Bank. *State and Trends of Carbon Pricing 2021*; Bank World, Ed.; The World Bank: Washington, DC, USA, 2021; ISBN 978-1-4648-1728-1.
18. World Bank. Países En La Cima de Los Mercados de Carbono. Available online: https://www.bancomundial.org/es/news/feature/2022/05/24/countries-on-the-cusp-of-carbon-markets#:~:text=Pa%C3%ADses%20como%20Chile,%20Ghana,%20Jordania,los%20mercados%20internacionales%20de%20carbono (accessed on 2 March 2024).
19. Goñas, M.; Rojas-Briceño, N.B.; Culqui-Gaslac, C.; Arce-Inga, M.; Marlo, G.; Pariente-Mondragón, E.; Oliva-Cruz, M. Carbon Sequestration in Fine Aroma Cocoa Agroforestry Systems in Amazonas, Peru. *Sustainability* **2022**, *14*, 9739. [CrossRef]
20. Di Rienzo, J.; Balzarini, M.; Robledo, C.; Casanoves, F.; Gonzales, L.; Tablada, E. *InfoStat, Versión 2008. Manual Del Usuario*; FCA Universidad Nacional de Córdoba: Córdoba, Argentina, 2008.
21. Balzarini, M.G.; Gonzalez, L.A.; Tablada, E.M.; Casanoves, F.; Di Rienzo, J.A.; Robledo, C.W. *InfoStat Manual Del Usuario*; Brujas Editorial: Cordoba, Argentina, 2008.
22. Lavrakas, P. Proportional Allocation to Strata. In *Encyclopedia of Survey Research Methods*; 2455 Teller Road, Thousand Oaks California 91320 United States of America; Sage Publications, Inc.: Newbury Park, CA, USA, 2013; ISBN 9781412963947.

23. Mete, M.R. Valor Actual Neto Y Tasa De Retorno: Su Utilidad Como Herramientas Para El Análisis Y Evaluación De Proyectos De Inversión. *Fides Ratio Rev. Difusión Cult. Científica Univ. La Salle Boliv.* **2014**, *7*, 67–85.
24. Altuve, J.G. El Uso Del Valor Actual Neto y La Tasa Interna de Retorno Para La Valoración de Las Decisiones de Inversión. *Actual. Contab. Faces* **2004**, *7*, 7–17.
25. Vásquez, A.; Matus, J.A.; Cetina, V.M.; Sangerman, J.; Rendón, G.; Caamal, I. Análisis de Rentabilidad de Una Empresa Integradora de Aprovechamiento de Madera de Pino * Profitability Analysis of an Integrating Company of Pine Wood Utilization Resumen Introducción. *Rev. Mex. Cienc. Agrícolas* **2017**, *8*, 649–659.
26. Arévalo Briones, K.; Pastrano Quintana, E.; Armijos Jumbo, V. Relación Beneficio—Costo Por Tratamiento En La Producción Orgánica de Las Hortalizas (Cilantro, Lechuga, Cebolla Roja, Cebolla de Rama) En El Cantón Santo Domingo de Los Colorados. *Rev. Publicando* **2016**, *3*, 503–528.
27. VERRA. VCS AFOLU Requirements: Crediting GHG Emission Reductions for Agriculture, Forestry, and Other Land Use. Available online: https://verra.org/wp-content/uploads/2016/05/FactSheet-AFOLU-2013-UPDATED.pdf (accessed on 2 March 2024).
28. MEF (Ministerio de Economía y Finanzas). *Nota Técnica Para El Uso Del Precio Social Del Carbomo En La Evaluación Social de Proyectos de Inversión*; MEF: Lima, Peru, 2021.
29. MINAGRI (Ministerio de Agricultura y Riego). *Estudio Del Cacao En El Perú y El Mundo: Un Análisis de La Producción y El Comercio*; Dirección de Estudios Económicos e Información Agraria, Ed.; Primera: Madrid, Spain, 2016.
30. Portilla, A. *Análisis Causa-Raíz de Los Problemas Que Afectan a La Cadena Productiva de Cacao-Chocolate*; MIDAGRI: Lima, Peru, 2020.
31. Monealegre-Bustos, F.; Rojas-Molina, J.; Jaimes-Suárez, Y. Factores Agronómicos y Socioeconómicos Que Inciden En El Rendimiento Productivo Del Cultivo de Cacao. Un Estudio de Cacao En Colombia. *Rev. FAVE Ciencias Agrar.* **2021**, *20*, 59–73.
32. Saldarriaga-Ramirez, B.J. *Precio En Chacra, Rendimineto y Costo Deproducción Como Factores de Rentabilidad En La Producción de Cacao En La Provincia de Leoncio Prado Campaña 2012–2013*; Universidad Nacional Hermilio Valdizán: Huánuco, Peru, 2016.
33. Korneeva, E.A. Economic Assessment and Management of Agroforestry Productivity from the Perspective of Sustainable Land Use in the South of the Russian Plain. *Forests* **2022**, *13*, 172. [CrossRef]
34. Kay, S.; Graves, A.; Palma, J.H.N.; Moreno, G.; Roces-Díaz, J.V.; Aviron, S.; Chouvardas, D.; Crous-Duran, J.; Ferreiro-Domínguez, N.; García de Jalón, S.; et al. Agroforestry Is Paying off—Economic Evaluation of Ecosystem Services in European Landscapes with and without Agroforestry Systems. *Ecosyst. Serv.* **2019**, *36*, 100896. [CrossRef]
35. Valencia, W. Indicador de Rentabilidad de Proyectos: El Valor Actual Neto (VAN) o El Valor Económico Agregado (EVA). *Ind. Data* **2011**, *14*, 15–18. [CrossRef]
36. Rodrigues, B.F.F.; Amaral, A.R.; Assunção, F.P.C.; Bernar, L.P.; Santos, M.C.; Mendonça, N.M.; Pereira, J.A.R.; de Castro, D.A.R.; Duvoisin, S.; Oliveira, P.H.A.; et al. Economic Feasibility Study of the Production of Biogas, Coke and Biofuels from the Organic Fraction of Municipal Waste Using Pyrolysis. *Energies* **2024**, *17*, 269. [CrossRef]
37. Jarunglumlert, T.; Chantanuson, R.; Hayashi, R.; Katano, Y.; Kusakari, T.; Nagamine, S.; Matsumiya, K.; Kobayashi, T.; Nakagawa, K. Techno-Economic Assessment of Plant-Based Meat Analogue Produced by the Freeze Alignment Technique. *Futur. Foods* **2023**, *8*, 100269. [CrossRef]
38. Mena-Mosquera, V.E.; Andrade, H.J. Valuation of Carbon Sequestration and Storage Ecosystem Services in a Tropical Moist Forest of Chocó, Colombia. *Floresta Ambient.* **2021**, *28*, 1–11. [CrossRef]
39. Gutman, P. Ecosystem Services: Foundations for a New Rural–Urban Compact. *Ecol. Econ.* **2007**, *62*, 383–387. [CrossRef]
40. Calvet-Mir, L.; Corbera, E.; Martin, A.; Fisher, J.; Gross-Camp, N. Payments for Ecosystem Services in the Tropics: A Closer Look at Effectiveness and Equity. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 150–162. [CrossRef]
41. Waldén, P.; Ollikainen, M.; Kahiluoto, H. Carbon Revenue in the Profitability of Agroforestry Relative to Monocultures. *Agrofor. Syst.* **2020**, *94*, 15–28. [CrossRef]
42. García de Jalón, S.; Graves, A.; Palma, J.H.N.; Williams, A.; Upson, M.; Burgess, P.J. Modelling and Valuing the Environmental Impacts of Arable, Forestry and Agroforestry Systems: A Case Study. *Agrofor. Syst.* **2018**, *92*, 1059–1073. [CrossRef]
43. Murguerito, R.E. Sistemas Agroforestales Para La Producción Ganadera En Colombia. *Pastos Forrajes* **2000**, *3*, 1–11.
44. Albrecht, A.; Kandji, S.T. Carbon Sequestration in Tropical Agroforestry Systems. *Agric. Ecosyst. Environ.* **2003**, *99*, 15–27. [CrossRef]
45. Rügnitz, M.; Chacón, M.; Porro, R. *Guía Para La Determinación de Carbono En Pequeñas Propiedades Rurales*, 1st ed.; Centro Mundial Agroflorestal (ICRAF)/Consórcio Iniciativa Amazônica (IA): Lima, Peru, 2009; ISBN 9789290592549.