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Analysis of the Prices and Opportunity Costs of Carbon Capture Projects in Mangroves Compared to Those in Other Productive Systems

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Abstract

Mangroves are highly productive ecosystems due to their great capacity to store carbon, but they are also vulnerable to human activities and adverse environmental conditions. Their conservation is often constrained by the opportunity costs of shifting from traditional economic activities to blue carbon projects. This work analyzes the prices of the different carbon markets in ecosystems, compares them with the benefits obtained from other productive activities, and evaluates the viability of implementing carbon projects in mangroves. An exhaustive literature search is conducted to assess the carbon prices of ecosystems worldwide. The opportunity costs of mangrove carbon capture projects in Mexico are estimated from site-specific and regionally relevant economic data; additionally, broader national benchmarks are presented for contextual comparison but are not interpreted as direct opportunity costs where they do not represent realistic land-use alternatives for the mangrove sites analyzed. The price of carbon ranges from 4 to 86 USD per Mg CO_2e. The most studied natural ecosystems are forests. The highest gross annual profit (*GAP*) from carbon sales is observed in Tabasco and Campeche. *GAP* with mangrove wood harvesting ranges from 628.0 USD ha^{-1} year^{-1} to 3917.7 USD ha^{-1} year^{-1}. The highest *GAP* for crops is obtained for white corn in the state of Hidalgo. *GAP* of the economic activity of livestock ranges from 3167.59 USD ha^{-1} year^{-1} to 3365.71 USD ha^{-1} year^{-1}. The blue carbon projects are competitive with other productive activities at relatively high prices (86 USD per Mg CO_2e). In Tabasco, under certain high-price and high-sequestration scenarios, blue carbon projects can be competitive with local agricultural activities; however, this competitiveness is highly conditional on carbon price, sequestration rates, and local opportunity costs, and therefore cannot be generalized to all mangrove owners without site-specific appraisal. Fair carbon prices are required to make mangrove conservation projects attractive to producers.

Keywords: crops; livestock; carbon markets; annual gross profit

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1. Introduction

Mangroves are considered highly productive ecosystems because of their great capacity to store carbon [1]. However, mangroves are vulnerable to human action and adverse environmental conditions, such as changes in the mean sea level and prolonged droughts [2]. In recent decades, mangroves have experienced loss and degradation due to activities such as agriculture and aquaculture. In Southeast Asia, for example, between 2000 and 2012, 38% of the mangrove area was used for rice and oil palm agriculture, whereas 30% was used for aquaculture [3]. The conversion of mangroves to land with other uses, such as pastures for livestock, has high costs in terms of greenhouse gas (GHG) emissions, as well as losses of other important ecosystem services. The large carbon stocks, high rates of deforestation of mangroves, and consequently high GHG emissions indicate the importance of including mangroves in appropriate national strategies for climate change mitigation and adaptation [4]. This global relevance has led to the recognition of mangroves as critical "blue carbon" ecosystems, essential for both biodiversity and climate regulation [5].

Carbon pricing has become a central mechanism for reducing emissions and guiding countries toward sustainable growth trajectories [6,7]. Carbon markets, both mandatory and voluntary, enable flexible transactions through the purchase and sale of CO_2 emission permits [8]. The voluntary carbon market, in particular, arises from the demand of companies and individuals seeking to offset their emissions, often motivated by corporate social responsibility and reputational benefits [9,10].

Carbon credits are tradable titles accredited by carbon project certification agencies and are put up for sale to companies that wish to compensate for their emissions on a voluntary basis [9], with certification processes that provide environmental and social co-benefits, enhance reputation, and contribute to sustainability goals [9,11]. The value of carbon credits varies according to project scale, type, and location, with larger projects generally offering lower prices and smaller projects achieving higher values [10].

The valuation of ecosystem services, including carbon sequestration, directly influences community decisions regarding conservation and land use [12,13]. Blue carbon projects, when certified and sustainably managed, can generate income for local populations, improving livelihoods and reducing poverty rates [14,15].

Projects for the restoration and protection of blue carbon ecosystems (mangroves, seagrasses, and marshes) have the potential to offset GHG emissions; however, this potential depends on the level of global investment in restoration and protection [16]. The creation of a powerful financial incentive for forest restoration, by converting the value of forest carbon into cash income, depends on several socioeconomic and political factors, highlighting the need for transparent carbon markets accessible to farmers. Such conditions are consistent with the challenges identified in REDD+ programs, where opportunity costs of alternative land use often determine feasibility [3,17].

Estimating opportunity costs allows us to know the causes and factors that motivate deforestation [18]. In some areas, conservation is not possible, owing to the opportunity costs of shifting from an economic activity (for example, livestock or sugarcane) to carbon offsets to protect wetlands [19]. Furthermore, great variability in opportunity costs exists within and between countries, and thus, carbon prices are generally estimated for specific regions; it is not clear how applicable these estimated values are to other regions. For example, previous studies have focused solely on carbon payments for the conservation of mangrove forests on the basis of national averages of mangrove extent and carbon stocks [3]. Therefore, site-specific analyses are essential to capture local economic realities and improve the design of conservation incentives [20]. This study evaluates the opportunity costs of the change from carbon offsets to wood production, which is an alternative activity to carbon storage in mangroves. In addition, the income generated by carbon offsets at specific sites is compared with the profits obtained from other productive agricultural activities in Mexico (corn and cattle).

Slowly growing demand for offsets in the carbon market could be met by the blue carbon pool [21]. In this way, accounting for carbon emissions from mangrove soils should greatly increase the priority of mangrove forests in terms of their ability to receive funds for protection under carbon trading programs [22]. However, blue carbon programs are rarely implemented, and mangroves are rapidly being converted to alternative uses [3]. In this sense, according to Ranero et al. [10], in Mexico, there are no existing projects in the voluntary market for the sale of mangrove carbon credits. Therefore, generating reliable information on the carbon price in Mexico is essential to support mangrove conservation and discourage changes in land use for other economic activities.

The objective of this study is to conduct a cost–benefit analysis of three productive activities (wood harvesting, corn cultivation, and livestock) and a conservation project (carbon capture) to compare each project and calculate optimal margins for those conservation projects associated with carbon sequestration. To achieve this goal, an exhaustive literature search of carbon equivalent prices is carried out, as is a literature review of the selected production systems and the cost structure according to the type of technology selected. With these results, the owners of the mangroves of environmental management units (EMUs) in Mexico can have practical tools based on evidence, not only for better decision-making in the sustainable management of their resources but also for the successful management of greater economic benefits in payment programs for ecosystem services.

2. Materials and Methods

The methodology of this work was divided into two stages. The first stage focused on a systematic search for carbon equivalent prices in carbon sequestration projects in different ecosystems. The second stage consisted of the estimation of the opportunity costs of a conservation activity (carbon capture) and the cost–benefit analysis of three productive activities—wood harvesting, corn cultivation, and extensive livestock (fattening, dual purpose, and the sale of milk)—through a literature review of their economic values to later compare the results and estimate the optimal margins of conservation projects on the basis of minimum carbon storage.

2.1. Systematic Search for Carbon Prices in Ecosystems

An exhaustive literature search was conducted to assess the carbon prices of ecosystems worldwide. The methodological framework applied is outlined in Figure 1 [23].

2.2. Information Sources and Search Strategy

An electronic literature search was carried out on carbon prices in the different ecosystems of the world. Web of Science was the main database used, and the search was conducted with English and Spanish keywords. In the initial phase, the titles and abstracts of the network were screened to identify eligible studies. In the second phase, the full texts of the selected articles were read to determine if they met the inclusion and exclusion criteria.

The search for carbon prices ran from 1992 to 2024 in order to assess the historical evolution of carbon prices. Two series of searches were conducted. The first search for information (Table 1) was carried out by applying the following keywords: (“carbon sequestration” OR “carbon capture” OR “carbon sink” OR “carbon stock”) AND (forest OR biomass OR mangrove) AND (payment OR standard OR broker OR “economic analysis” OR “economic valuation” OR “economic assessment” OR “carbon assessment” OR “carbon valuation” OR “carbon tax” OR “cost and benefit” OR “carbon pricing”) AND (Mg ha^{-1} OR Mg C ha^{-1} OR Mg CO_2e ha^{-1}) in the title and abstract.

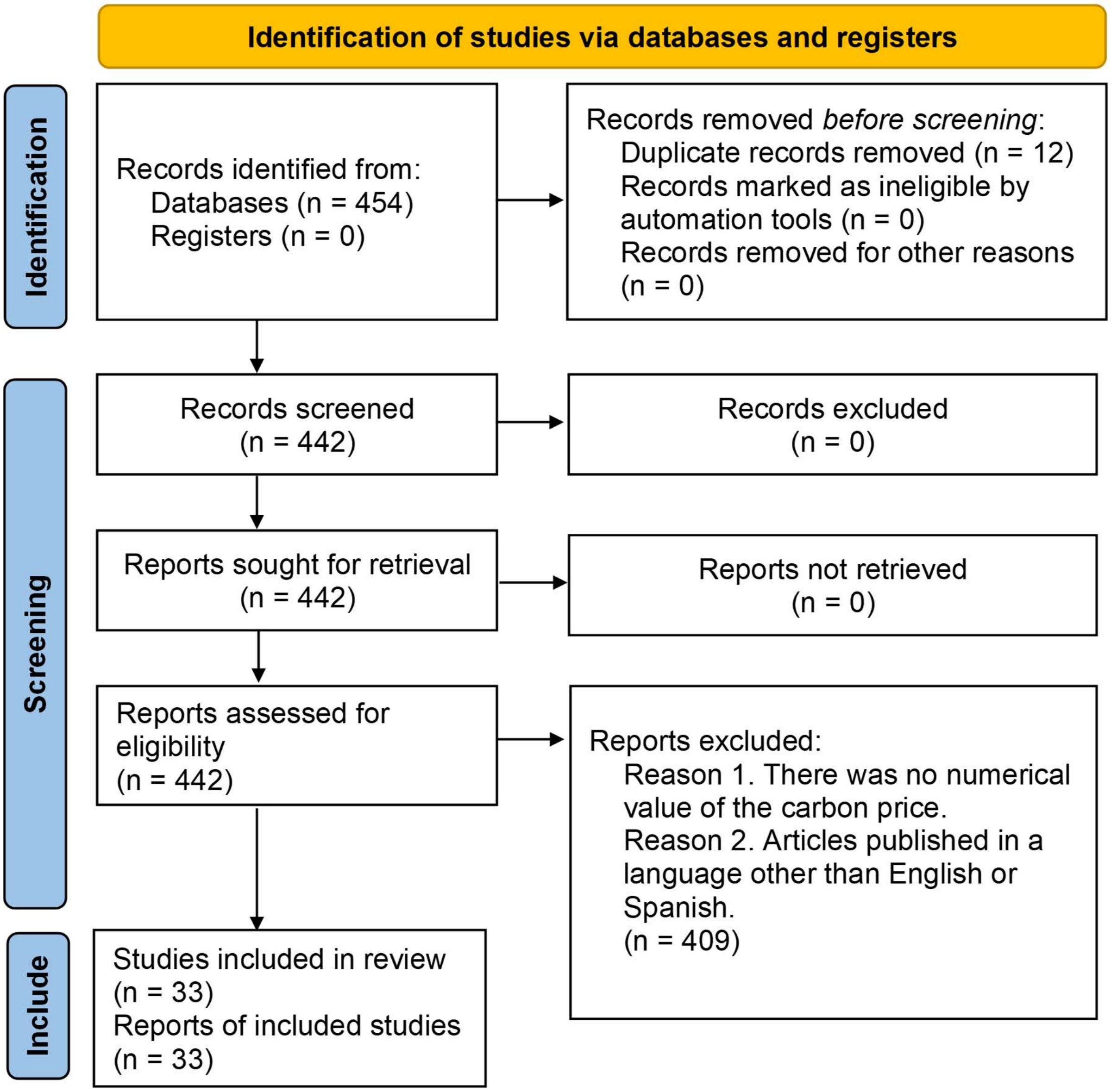

Figure 1. Flow diagram process for exhaustive literature search of carbon prices [23,24].

Table 1. Query codes used in the first search for information.

ID	Consultation Code	Result
01	All databases; all years; mangrove OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic); Refining results: Date: newest first (Sort by)	31,377
02	All databases; all years; mangrove OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic) AND carbon (Topic); Refining results: Date: newest first (Sort by)	5563
03	All databases; all years; mangrove OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic) AND carbon (Topic) AND Mg ha OR ton ha (Topic); Refining results: Date: newest first (Sort by)	381
04	All databases; all years; mangrove OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic) AND carbon (Topic) AND Mg ha OR ton ha (Topic); Refining results: USD (Search within topic) Date: newest first (Sort by)	2

Because the first search did not yield satisfactory results, we conducted a second search by refining the search terms, focusing specifically on carbon price, and expanding the scope to include documents published in both English and Spanish. The second search

(Table 2) was carried out with the keywords USD CO_2 ton OR USD CO_2 Mg in the title and abstract, as well as a refinement of the search with the following words: forest OR bosque (Topic) and carbon OR carbono (Topic) and Mg ha OR ton ha (Topic) and price OR precio OR USD/ha OR USD.

Table 2. Query codes used in the second search for information.

ID	Consultation Code	Result
01	All databases; all years; usd CO_2 ton OR usd CO_2 Mg (Topic); Refining results: Date: newest first (Sort by)	454
02	All databases; all years; forest OR bosque (Topic) and carbon OR carbono (Topic) and Mg ha OR ton ha (Topic) and price OR precio OR USD/ha OR USD (Topic); Refining results: Date: newest first (Sort by)	86
03	All databases; all years; mangrove OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic) AND carbon (Topic) AND Mg ha OR ton ha (Topic); Refining results: Date: newest first (Sort by)	7
04	All databases; all years; manglares OR *Laguncularia* OR *Avicennia* OR *Rhizophora* (Topic) AND carbono (Topic) AND Mg ha OR ton ha (Topic); Refining results: Date: newest first (Sort by)	1

2.3. Eligibility Criteria

The inclusion criteria for the study were as follows: (1) a numerical value of the carbon price; (2) articles published in English or Spanish; and (3) articles published at any time, that is, without an established deadline. Ecosystems were classified according to the classification proposed by Ning et al. [25]:

Forest: includes the different types of forests.

Wetland: formed by swamps, mangroves, and saturated lands.

Water: includes seas, streams, rivers, lakes, and other bodies of water (natural or artificial).

2.4. Data Extraction and Analysis

The abstracts of the articles were screened, and full texts that reported quantitative carbon estimates and associated prices were retained for data extraction. Data extraction was performed independently by the first author (C.R. Ávila-Acosta) and the third author (C.J. Vázquez-Navarrete). Extracted items included reported carbon price, units, ecosystem type, carbon compartments considered, and methodological details. All extracted values were cross-checked between the two reviewers; disagreements or ambiguous entries were discussed and, if consensus was not reached, the first author (C.R. Ávila-Acosta) made the final decision. To enable comparison, all price data were homogenized to USD per Mg CO_2e using standard conversion factors under a fixed nominal exchange rate assumption; when studies reported prices in different units or for different carbon pools, we converted units where possible and recorded the original reporting units and assumptions. Not all of these studies took into account all the compartments in the tree to determine carbon (such as aboveground carbon (AGC), underground carbon (BGC), and soil carbon) and thus estimate the carbon price. To derive a rough estimate of the carbon price, it was assumed that the carbon price applies to the carbon stock of the entire ecosystem.

2.5. Ecosystem Service/Conservation Opportunity Cost (Mangrove Carbon Sequestration)

A literature review of different projects in Mexico related to the determination of aboveground biomass was carried out (Figure 2). The sources from which the analyzed information was obtained are described below:

- The public lands Úrsulo Galván, La Solución Somos Todos, Francisco Trujillo Gurría, Puerto Ceiba, and El Golpe are all located in the state of Tabasco. The mangrove ecosystem at these sites is composed of three main mangrove species: *R. mangle*, *L. racemosa*, and *A. germinans* [26–28].
- The Úrsulo Galván public land encompasses a forest area of approximately 930 ha, situated at a minimum distance of 2750 m from the sea. It is crossed by the Los Caballos River, influenced by the El Eslabón—La Tinaja–Sí Señora lake system, and contains both riverine and basin-type mangroves [27]. The site has a management plan approved by Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), which includes practices such as manual clearing for the control of weeds and parasitic species. No timber harvesting is carried out, and the mangroves in the area are managed by the local community.
- La Solución Somos Todos public land is located south of Laguna Mecoacán and has a forest area of 1936 ha. The site has a history of timber harvesting; in 2005, an annual volume of 5855 m^3 was authorized. The mangroves at this site have been managed under a management plan establishing an annual extraction volume of 4 m^3 ha^{-1} $year^{-1}$ [29].
- The Francisco Trujillo Gurría public land is located southwest of Laguna Mecoacán. Its mangrove reserve area covers 1278 ha [30], of which SEMARNAT authorized an annual harvesting volume of 4158 m^3 in 2005. The harvested mangroves are managed under a plan establishing an annual extraction volume of 2.72 m^3 ha^{-1} $year^{-1}$ [29].
- The Puerto Ceiba public land is located west of Laguna Mecoacán and comprises 568 ha. The ejido operates under a forest management program. The harvested mangroves are regulated by a management plan establishing an annual extraction volume of 13.63 m^3 ha^{-1} $year^{-1}$ [29].
- The El Golpe public land is located southwest of Laguna de la Machona and has a forest area of 1500 ha. The hydrography is defined by the Río Santa Ana. In 2002, it received authorization to harvest a total volume of 30,000 m^3 of timber over a ten-year period. The mangroves are managed under a plan establishing an annual extraction volume of 1.70 m^3 ha^{-1} $year^{-1}$ [29].
- La Encrucijada Reserve is located in southern Chiapas, within the physiographic region known as the Pacific Coastal Plain. It covers an area of 144,868 ha, of which 36,216 ha correspond to two core zones (La Encrucijada and Palmarcito) and 108,651 ha comprise the buffer zone. The site contains a fluvial system of short-course rivers averaging approximately 45 km in length and strongly influenced by the rainy season. The hydrography consists of 17 main watercourses: Huixtla, Cintalapa, Vado Ancho, Comaltitlán, Coapa, Urbina, Pijijiapan, Margaritas, Novillero, San Nicolás, Cacaluta, and Sesecapa, among others [31]. The dominant mangrove forests are riverine, although fringe and basin mangroves are also present [32]. There are five mangrove species: *R. mangle*, *Rhizophora harrisonnii*, *A. germinans*, *L. racemosa*, and *Conocarpus erectus*. Swamp forests dominated by *Pachira aquatica* and *Zygia conzattii* occur on gently sloping lands and riverbanks, while freshwater marsh communities dominated by *Typha domingensis* cover extensive areas at river mouths. Flooded pastures are dominated by *Paspalum conjugatum* [33]. In the Mangrove, Zapotonal, Medium-stature Tropical Forest, Palm Grove, Tular, and Popal zones, only preservation activities such as scientific research, monitoring, education, and training are permitted. Activities that alter ecological balance—such as habitat modification, introduction of exotic species, and tourism, among others—are prohibited [31].
- The Marismas Nacionales Wetland System is located within the Reserva de la Biosfera Marismas Nacionales, along the northern Pacific coast of Mexico. It is a protected natural area (ANP) covering 133,000 hectares and includes a network of brackish coastal

lagoons, floodplains, tidal creeks, estuaries, ancient sandy barriers, semi-parallel lagoons, deltas, swamps, marshes, and mangroves. Mangroves are the dominant vegetation, extending over 67,096 ha, primarily as fringe and riverine types. The mangrove species present are *R. mangle*, *L. racemosa*, *A. germinans*, and *Conocarpus erectus* [34].

- Pantanos de Centla and Laguna de Términos are formed on an extensive coastal plain with several large coastal lagoons associated with the Río Usumacinta and Río Grijalva rivers. River inputs help maintain flooded conditions year-round. Marshes dominate the landscape, while forested areas are mainly distributed around the lagoons. Mangrove surface is estimated at 5214 ha [35]. Species composition is comparable to that described for La Encrucijada Reserve; however, in Centla–Términos, mangroves are dominated by *R. mangle*, and swamp forests by *Bucida buceras*. In addition to river discharge, the wetland area receives substantial inputs of upwelling groundwater [33].
- The Boquilla-Mancha Wetlands are located along a narrow coastal plain with small rivers. Groundwater feeds the system, and wetlands occur in geomorphological settings that allow water accumulation. These wetlands include mangroves, freshwater swamps, and freshwater marshes. Common species include *R. mangle*, *A. germinans*, and *L. racemosa* in mangroves, and *P. aquatica* and *Annona glabra* in freshwater swamps [33].

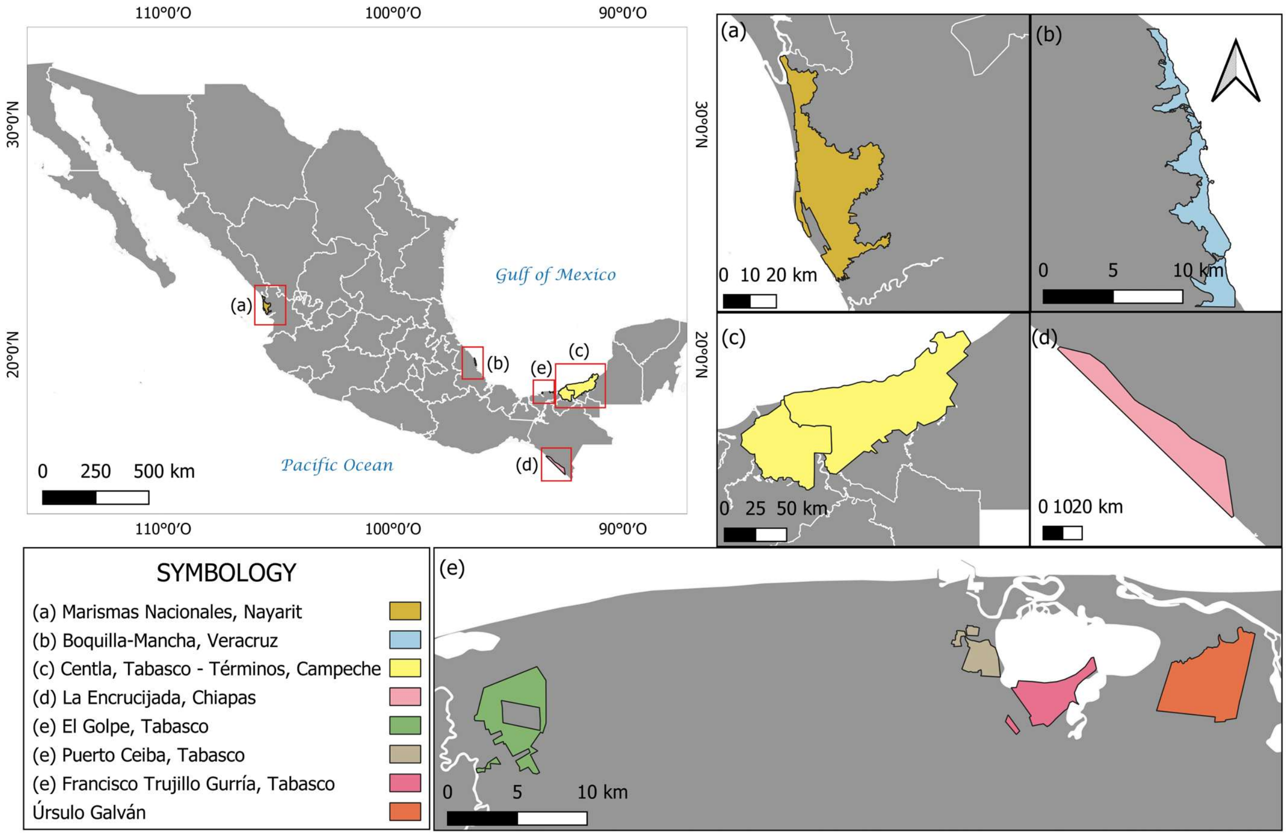

Figure 2. Study area of the different projects in Mexico related to aboveground biomass capture (Shapefiles source: [33,36–38]).

The annual CO_2e sequestration was estimated using a regionally relevant diameter growth rate reported for mangrove species in La Encrucijada Reserve, Chiapas, Mexico [39]. In La Encrucijada Reserve, the initial diameter at breast height (DAP) ranged from 5.5 ± 4.5 cm to 8.6 ± 6.8 cm, and tree heights ranged from 7.6 ± 4.5 m to 11.5 ± 6.8 m; these stand structure values were compared with mangroves in Úrsulo Galván, Tabasco, where DAP values range from 9.2 ± 0.7 cm to 11.6 ± 1.3 cm [27], and with Centla, Tabasco-Términos, Campeche (trees with DAP > 10 cm), and Boquilla-Mancha, Veracruz (trees with DAP < 10 cm) [33]. We emphasize that we used external, site-referenced estimates rather than growth rates measured directly at the study sites; therefore, these values define plausible scenarios for carbon accumulation. To address uncertainty in this key biological input, we performed a sensitivity analysis with three growth-rate scenarios tied to observed species-level variation: Low = 0.20 cm year^{-1} (*A. germinans*), Medium = 0.4 cm year^{-1} (*L. racemosa*), and High = 0.55 cm year^{-1} (*R. mangle*). This range reflects documented interspecific differences and provides a transparent envelope of plausible sequestration outcomes; results are reported for each scenario so readers can assess how economic conclusions depend on the growth-rate assumption. We also note that local factors (species composition, stand density, salinity, hydroperiod, sediment and nutrient conditions, freshwater inputs, and disturbance or management history) can substantially alter growth and sequestration rates, and therefore our analysis is presented as a conditional scenario exercise rather than a definitive site-specific appraisal.

Average annual income was calculated considering the minimum and maximum prices observed in the systematic literature review of carbon prices in the world's ecosystems.

Project costs were estimated using the Climate Action Reserve (CAR) scenario: we modeled a single-site (communal property) project registered under the Climate Action Reserve. For this scenario, we used the CAR cost–benefit tool and assumed a 30-year project lifetime with a five-year verification interval (i.e., periodic verification events every five years). The CAR scenario assumes a single area of activity with no logging (0% harvest) and excludes belowground/soil carbon in line with the CAR protocol. Cost components included in the CAR calculation were: baseline and project development (inventory and baseline studies), project implementation, monitoring and MRV (field measurements and data management), third-party validation/verification fees, registry and issuance fees, project administration, and routine operational costs. Annual project cost was obtained by annualizing the total 30-year cost; cost per unit area was calculated by dividing the annual cost by the project area. Gross annual profit (*GAP*) was calculated by subtracting the cost per unit area from the average annual income.

The present analysis adopts a simplified scenario for carbon-credit income: we treat the estimated annual CO_2e capture at each site as the flow that could be valued at the selected carbon price. This approach does not account for the full set of rules and adjustments that determine the number of accreditable carbon credits and the net revenues of a certified project. In practice, credit issuance and payments depend on additionality and baseline setting, leakage assessments, permanence risks (and associated buffer deductions), uncertainty discounts, and the costs and requirements of monitoring, verification, registration, and transactions. Consequently, the income values reported here should be interpreted as a simplified scenario and not as guaranteed payments that producers would receive under a complete certification process.

For consistency with the cost calculations and the CAR protocol used in this study, our carbon estimates are limited to aboveground biomass. The CAR standard applied in our scenarios does not account for soil or belowground carbon; therefore, payments under the CAR-based scenario would not include compensation for carbon stored in soils or other belowground pools. As a result, the figures presented do not represent the total climate value of blue carbon ecosystems if soil and sediment carbon were to be credited under alternative protocols that explicitly include those compartments.

For clarity and spatial–economic coherence, we distinguish three types of comparisons used in this study: (1) Direct opportunity costs—income streams that represent realistic alternative uses of the same mangrove land or immediate decision context (e.g., authorized timber extraction or local extensive livestock practiced within the same EMU); (2) regional livelihood comparisons—productive activities occurring within the same coastal region or state that may represent plausible livelihood alternatives for some mangrove owners (e.g., crop or livestock systems documented in the same state or neighboring coastal states); and (3) national benchmarks (reference scenarios)—productivity and profitability values from other states or contexts presented for broader comparison but not treated as direct opportunity costs for the mangrove sites. Only values classified as (1) are used to compute site-level opportunity costs and to draw conclusions about the economic incentives facing owners of the studied mangrove areas; values in categories (2) and (3) are presented as contextual information and are explicitly labeled as such in tables and text.

We use gross annual profit (*GAP*) as a primary comparative metric for simplicity and transparency. However, carbon projects are long-term investments with uneven costs and revenues over time (upfront investments, periodic monitoring and verification, buffer set-asides, and deferred credit issuance). Annualizing total project costs by simple division over the project lifetime may not capture true cash-flow dynamics, the timing of upfront expenditures, or the periodic nature of verification and transaction costs [40]. Therefore, *GAP* should be interpreted as a simplified comparative indicator rather than a full investment appraisal. We explicitly acknowledge that *GAP* alone does not reflect the time value of money, investment risk, or the timing of returns; supplementary discounted cash-flow analyses and sensitivity tests are required for project-level investment decisions.

2.6. Cost–Benefit Analysis of Productive Activities

For the timber harvest, the estimation of *GAP* was carried out via Equation (1) [41]:

$$GAP = \left(\rho_{extraction} \times P_{average}\right) - \left(C_{production} + C_{borrowing}\right) \quad (1)$$

where

GAP = Gross annual profit in USD ha^{-1} year^{-1}.

$\rho_{extraction}$ = Volume of wood extraction in m^3 ha^{-1} year^{-1}.

$P_{average}$ = Average price of wood in USD m^{-3}.

$C_{production}$ = Production cost in USD ha^{-1} year^{-1}.

$C_{borrowing}$ = Cost of borrowing in USD ha^{-1} year^{-1}.

GAP from timber harvesting was calculated from the extraction densities reported by Domínguez-Domínguez et al. [29] in various places in the state of Tabasco. These data were complemented by information obtained from the systematic literature review, where the aboveground biomass from different sites in Mexico was collected. The extraction volume at these sites was calculated using a diameter growth rate of 0.4 cm year^{-1} (medium-growth scenario), as reported by Velázquez-Pérez et al. [39] for La Encrucijada Reserve, Chiapas, Mexico. It was assumed that 50% of tree growth was used, in line with what was proposed by Domínguez-Domínguez et al. [29], to ensure the conservation of the site and guarantee sustainability.

A literature review was conducted to obtain data on labor costs, motorboats, and chainsaws within the defined study area. Based on this information, the wood production cost was estimated through a cost analysis that considered only the essential inputs for the operation. It was assumed that these resources were sufficient to cover the entire study area. Finally, financial costs associated with the financing of the main inputs were included, applying a defined interest rate for the calculation of the required loans.

Comparison with crops was carried out following the methodology of [42] to estimate gross earnings from corn cultivation. *GAP* was obtained with Equation (2):

$$GAP = \left(R_{average} \times P_{average}\right) - \left(C_{production} + C_{borrowing}\right) \quad (2)$$

where

GAP = Gross annual profit in USD ha^{-1} year^{-1}.

$R_{average}$ = Average yield in kg ha^{-1} year^{-1}.

$P_{average}$ = Average price of corn in USD kg^{-1}.

$C_{production}$ = Production cost in USD ha^{-1} year^{-1}.

$C_{borrowing}$ = Cost of borrowing in USD ha^{-1} year^{-1}.

A literature review was carried out to obtain the yield of the corn crop for Mexico in Mg ha^{-1}, as well as the average prices of the crops in USD Mg^{-1} and the production costs in USD ha^{-1}. The cost of borrowing to finance the inputs was obtained using the 4.875% interest rate for production costs proposed by Jantawong et al. [42].

The calculation of *GAP* for livestock was carried out using the following Equation (3) proposed by Román et al. [43]:

$$GAP = I_{total} - C_{milk\ and\ meat} \quad (3)$$

where

I_{total} = Total income in USD ha^{-1} year^{-1}.

$C_{milk\ and\ meat}$ = Total cost of milk and meat in USD ha^{-1} year^{-1}.

Total income = Sales of milk + Sales of animals.

Sales of milk = Milk production (L ha^{-1} year^{-1}) × Unit sale price (USD L^{-1}).

Milk production = Production (L AU^{-1}) × Yield (AU ha^{-1} year^{-1}).

Sale of animals = Production of meat (kg ha^{-1} year^{-1}) × Unit sale price (USD kg^{-1}).

Production of meat = Heifer weight (kg AU^{-1}) × Yield (AU ha^{-1} year^{-1}).

Total cost of milk and meat = Variable costs (USD ha^{-1} year^{-1}) + Fixed costs (USD ha^{-1} year^{-1}).

The estimation of the total cost of milk and meat was based on a literature review, from which information on variable and fixed costs was derived. The data were reported in USD per kilogram. The variable cost in USD ha^{-1} year^{-1} was derived by multiplying the variable cost value by the livestock yield in Tabasco (AU ha^{-1}) and the corresponding live weight per animal unit (kg AU^{-1}).

A price homogenization was conducted due to differences in the dates on which the information was obtained from the various sources consulted. To ensure comparability, the values were adjusted based on the cumulative inflation from the publication date of each source up to January 2024. The tool used to calculate inflation according to the year of data collection was as follows: https://www.inegi.org.mx/app/indicesdeprecios/CalculadoraInflacion.aspx (accessed on 30 January 2024).

After homogenizing values in MXN, all amounts were converted to USD using a single market exchange rate of 1 USD = 16.88 MXN, corresponding to the consultation date 12 January 2024. Inflation adjustments were applied dynamically according to the year of each source prior to currency conversion to ensure temporal comparability. We did not apply purchasing-power-parity (PPP) adjustments; all conversions use the nominal market exchange rate stated above. This choice was made to preserve comparability with the international carbon-price literature that typically reports nominal USD values, but we acknowledge that it does not account for differences in local purchasing power.

2.7. Comparison of Carbon Prices for the Use of Wood, Crops, and Livestock

The comparison of carbon prices with production systems was structured according to the three comparison types defined above. For direct opportunity cost calculations, we selected only those production scenarios that are documented as occurring in the same EMU or in immediately comparable mangrove-adjacent land (e.g., timber extraction volumes authorized for the same public lands). For regional comparisons, we report *GAP* values from productive systems documented within the same coastal state or neighboring coastal states and discuss their plausibility as alternatives. For national benchmarks (e.g., high-yield maize systems in inland states), values are reported solely as reference points and are not used to compute site-level opportunity costs. The AMC calculation (Equation (4)) is applied to scenarios classified as direct alternatives, regional and benchmark scenarios.

The comparison between carbon prices and production systems was carried out by calculating the minimum annual carbon store (AMC) required for a carbon-capture project to match the net return of an alternative activity. To obtain AMC, we equated the project's net annual income to the Gross Annual Profit (*GAP*) of the alternative and solved for the annual carbon capture required. The break-even expression used was:

$$AMC = \frac{GAP_{alt} + C_{proj}}{P} \tag{4}$$

where

AMC = minimum annual carbon capture required in Mg CO_2e ha^{-1} year^{-1}.

GAP_{alt}: gross annual profit of the alternative activity USD ha^{-1} year^{-1}.

C_{proj}: annualized project cost per hectare (USD ha^{-1} year^{-1}).

P = Price of CO_2e in USD per Mg CO_2e.

A sensitivity analysis was performed by combining three cost scenarios and two price scenarios: cost scenarios C_{proj} (Low, Medium, and High) derived from the *GAP* analysis of blue carbon projects in Mexican mangroves, and price scenarios P (Low, High) obtained from the literature review. For each cost–price combination, we computed AMC using Equation (4) and reported results for the minimum and maximum *GAP* values of each alternative activity.

3. Results

3.1. Systematic Literature Review

A total of 454 articles were identified according to the search criteria; however, 412 articles were considered inappropriate as a result of the review of the abstracts of the articles and were not used in the final analysis. In total, 33 articles meet the quality requirements for this study (Figure 1). Among the 33 publications, 32 are scientific articles and one is a book chapter.

The number of investigations related to the carbon price has changed over time, with a positive trend with respect to the evaluation period. Figure 3 shows the temporal distribution of publications. Although the overall trend is positive, the Figure highlights fluctuations between 2016 and 2020, reflecting periods of increased and decreased research activity. The absence of publications in 1993–2004, 2006–2011, and 2013–2014 is also evident, underscoring gaps in the literature. The highest number of publications was observed in 2022.

The average price of carbon was 26.8 USD per Mg CO_2e. Figure 4 shows the temporal evolution of carbon prices differentiated by type: VC (Voluntary Credits), ETS (Emission Trading Scheme), SP (Shadow Price), and SCC (Social Cost of Carbon). Carbon prices vary across categories and over time. For VC, initial values were 5 USD per Mg CO_2e in 1992, with subsequent fluctuations that reached 45.5 USD per Mg CO_2e in 2024. ETS display a more pronounced upward trend, with a minimum of 0.4 USD per Mg CO_2e in 2005 and peaks of 53.5 USD per Mg CO_2e in 2016 and 66.1 USD per Mg CO_2e in 2022. SP shows intermediate values, with a peak of 51.3 USD per Mg CO_2e in 2023 followed by a decline to 16.1 USD per Mg CO_2e in 2024. SCC is reported at 28 USD per Mg CO_2e in 2016 as a normative reference. Overall, there was an upward trend in carbon prices, with notable fluctuations between 2016 and 2020, and a marked peak in 2022. In this

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analysis, VC (Voluntary Credits) values range from 4 USD per Mg CO_2e [44] to 86 USD per Mg CO_2e [45]. The detailed price calculations are shown in the Supplementary Material (Supplementary dataset [3,12,19,25,42,44–71]).

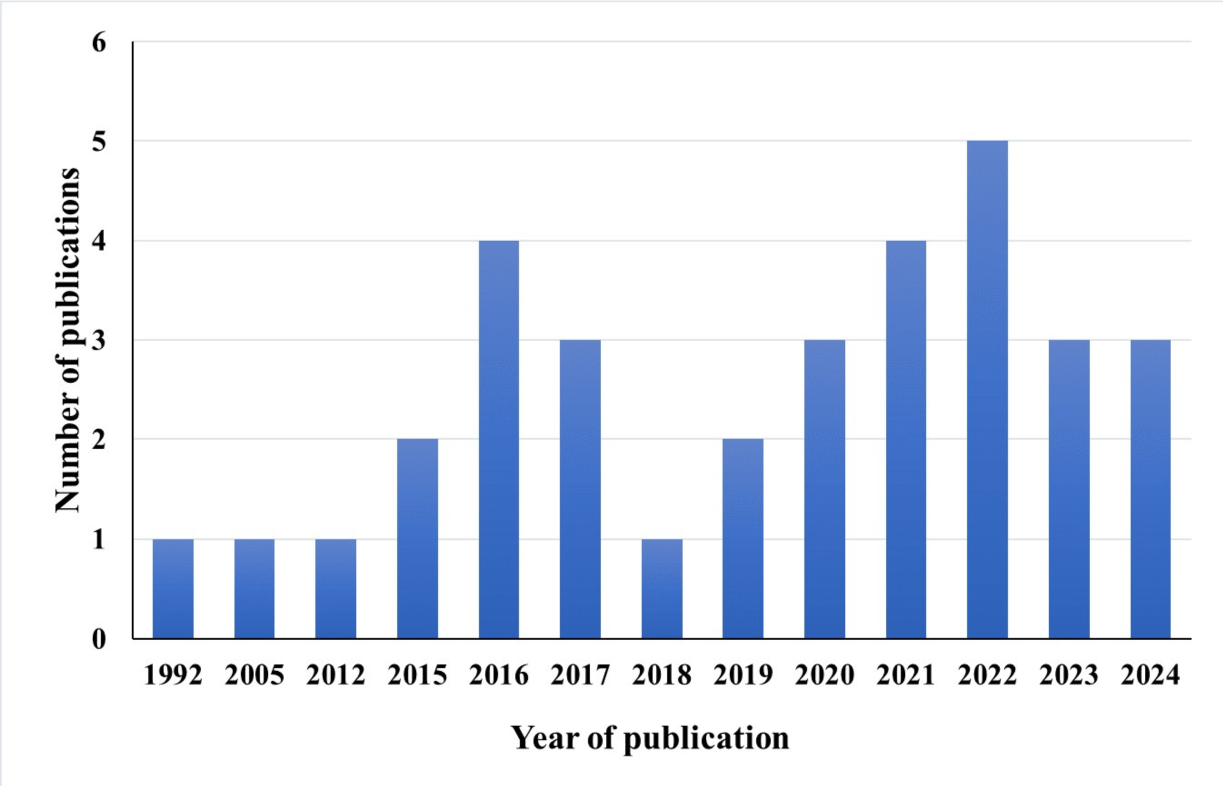

Figure 3. Number of publications according to year of publication.

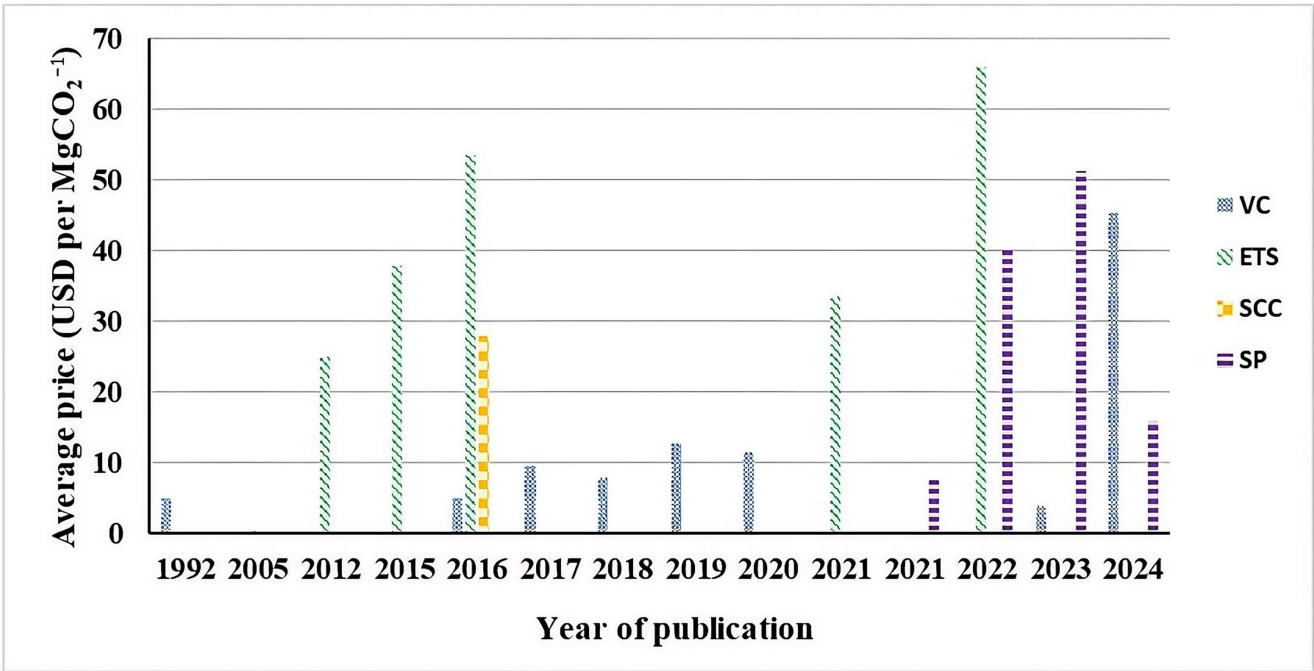

Figure 4. Number of publications according to year of publication and price type. VC = Voluntary credits, ETS = Emission Trading Scheme, SP = Shadow Price, and SCC = Social Cost of Carbon.

The average carbon price is very similar in natural ecosystems (forests, wetlands, and marine environments), averaging 20 USD per Mg CO_2e (Figure 5). Figure 5 compares the average carbon prices across ecosystem types, differentiated by price category: VC (Voluntary Credits), ETS (Emission Trading Scheme), SP (Shadow Price), and SCC (Social Cost of Carbon). In forests, values show a wide range: 14.4 USD per Mg CO_2e for VC, 33.2 USD per Mg CO_2e for ETS, 46.5 USD per Mg CO_2e for SCC, and 18.4 USD per Mg CO_2e for SP. In wetlands, prices are more extreme, with a very low value of 1.9 USD per Mg CO_2e for SCC and a maximum of 100 USD per Mg CO_2e for SP. In marine environments, 25 USD per Mg CO_2e is reported for ETS and 10 USD per Mg CO_2e for SP, while no values are recorded for VC or SCC. Carbon prices differ across ecosystems and price types, with forests showing more consistent values and a higher number of observations.

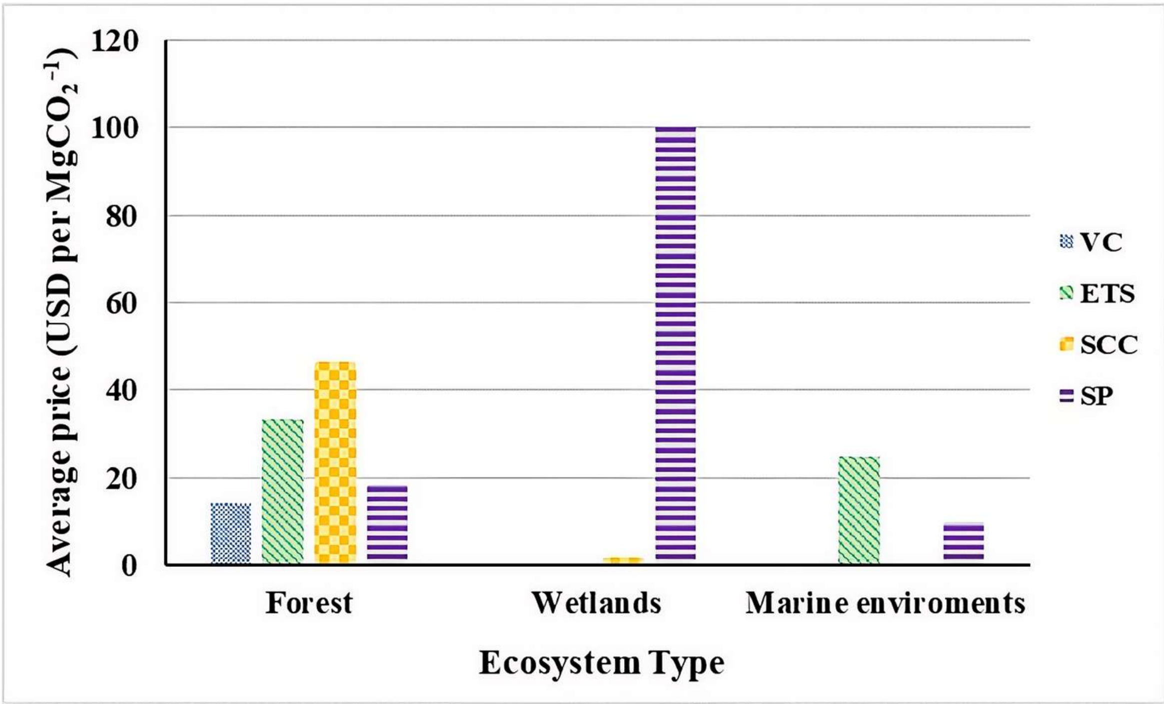

Figure 5. Average price of carbon according to ecosystem type and price type. VC = Voluntary credits, ETS = Emission Trading Scheme, SP = Shadow Price, and SCC = Social Cost of Carbon.

3.2. Opportunity Costs of Carbon Sequestration in Mangroves

Profits were calculated in blue carbon projects in different mangroves in Mexico (Table 3). The annual increase in aboveground biomass was estimated at 4.07% under the low-growth scenario (0.2 cm year^{-1}), 9.3% under the medium-growth scenario (0.4 cm year^{-1}), and 13.6% under the high-growth scenario (0.55 cm year^{-1}), as reported by Velázquez-Pérez et al. [39] in La Encrucijada Reserve, Chiapas, Mexico. The total cost of a 30-year CAR blue carbon project was 217,452.7 USD [72], and thus, the annual cost was 7248.4 USD year^{-1}.

Table 3. Revenues, costs, and profits of blue carbon projects in mangroves in Mexico.

Place	Project Area (ha)	Aboveground Biomass (Mg ha^{-1})	Growth Rate Scenario	Annual CO_2 Capture (Mg CO_2e ha^{-1} Year^{-1})	Average Annual Income (USD ha^{-1} Year^{-1})		Cost (USD ha^{-1} Year^{-1})	Profit (USD ha^{-1} Year^{-1})	
					Minimum Income	Maximum Income		Minimum Profit	Maximum Profit
[a] Úrsulo Galván, Tabasco	930	124.8 ± 13.9	Low	9.0 ± 1.0	36.0 ± 4.1	773.9 ± 67.2	7.8 ± 0.0	28.2 ± 4.1	766.1 ± 67.2
			Medium	20.6 ± 2.3	82.2 ± 9.3	1768.4 ± 153.5	7.8 ± 0.0	74.5 ± 9.3	1760.6 ± 153.5
			High	30.1 ± 3.4	120.3 ± 13.6	2586.0 ± 224.4	7.8 ± 0.0	112.5 ± 13.6	2578.2 ± 224.4
[b] La Encrucijada, Chiapas	16,000	181.3 ± 25.6	Low	13.0 ± 1.8	52.0 ± 7.3	1117.6 ± 121.3	0.5 ± 0.0	51.5 ± 7.3	1117.1 ± 121.3
			Medium	29.7 ± 4.2	118.8 ± 16.8	2553.7 ± 277.1	0.5 ± 0.0	118.3 ± 16.8	2553.2 ± 277.1
			High	43.4 ± 6.1	173.7 ± 24.6	3734.4 ± 405.2	0.5 ± 0.0	173.2 ± 24.6	3734.0 ± 405.2
[c] Marismas Nacionales, Nayarit	67,096	72.4 ± 20.4	Low	5.4 ± 1.5	21.6 ± 6.1	465.3 ± 100.4	0.1 ± 0.0	21.5 ± 6.1	465.2 ± 100.4
			Medium	12.4 ± 3.5	49.4 ± 13.9	1063.2 ± 229.3	0.1 ± 0.0	49.3 ± 13.9	1063.0 ± 229.3
			High	18.1 ± 5.1	72.3 ± 20.3	1554.7 ± 335.3	0.1 ± 0.0	72.2 ± 20.3	1554.6 ± 335.3
[d] Pantanos de Centla, Tabasco-Laguna de Términos, Campeche	131,603	247.6 ± 36.4	Low	18.5 ± 2.7	74.0 ± 10.9	1590.3 ± 179.4	0.1 ± 0.0	73.9 ± 10.9	1590.2 ± 179.4
			Medium	42.3 ± 6.2	169.0 ± 24.8	3633.9 ± 410.0	0.1 ± 0.0	169.0 ± 24.8	3633.8 ± 410.0
			High	61.8 ± 9.1	247.2 ± 36.3	5314.0 ± 599.5	0.1 ± 0.0	247.1 ± 36.3	5314.0 ± 599.5
[d] Boquilla—La Mancha, Veracruz	897	247.6 ± 36.4	Low	11.3 ± 3.0	45.0 ± 11.9	968.6 ± 197.2	8.1 ± 0.0	37.0 ± 11.9	960.5 ± 197.2
			Medium	25.7 ± 6.8	102.9 ± 27.3	2213.2 ± 450.5	8.1 ± 0.0	94.9 ± 27.3	2205.1 ± 450.5
			High	37.6 ± 10.0	150.5 ± 39.9	3236.5 ± 658.8	8.1 ± 0.0	142.5 ± 39.9	3228.4 ± 658.8

SOURCE: [a] [27], [b] [32], [c] [34], and [d] [33]. Notes: The growth rate scenario was defined at three levels: Low, corresponding to a growth of 0.2 cm year^{-1}; Medium, at 0.4 cm year^{-1}; and High, at 0.55 cm year^{-1}. Estimates correspond to a simplified scenario valuing annual aboveground CO_2e sequestration at the selected carbon price. Values do not include adjustments for additionality, leakage, permanence buffers, uncertainty discounts, monitoring/verification, registration, transaction costs, or soil/belowground carbon.

3.3. Cost Analysis of Production Systems

3.3.1. Productive Activity: Mangrove Wood (Direct Alternatives)

In the use of mangrove wood, yield, production cost, borrowing cost, and annual gross profit are estimated (Table 4). The price of mangrove wood for the final consumer is 257.4 USD Mg^{-1} [41]. The values are adjusted to USD m^3 using the density of specific types of wood, including *L. racemosa* (0.61 Mg m^{-3}), *A. germinans* (0.8116 Mg m^{-3}), and *R. mangle* (0.9064 Mg m^{-3}) [73]. Better prices are obtained with *L. racemosa* (233.3 USD m^{-3}), whereas the lowest prices are obtained with *R. mangle* (157.0 USD m^{-3}). Therefore, the average income for this activity is in the range of 628.0 USD ha^{-1} to 4048.3 USD ha^{-1}.

Table 4. Yield, production costs, borrowing costs, and *GAP* from mangrove wood harvesting.

Performance			
Site	**Extraction volume (m^3 ha^{-1} $year^{-1}$)**	**Minimum average income (USD ha^{-1} $year^{-1}$)**	**Average Maximum Income (USD ha^{-1} $year^{-1}$)**
[a] La Solución Somos Todos, Tabasco	4.0	628.0	933.2
[a] Ejido Francisco Trujillo Gurría, Tabasco	4.0	628.0	933.2
[a] Ejido el Golpe, Tabasco	10.0	1570.1	2333.0
[a] Puerto Ceiba, Tabasco	13.6	2140.1	3179.9
[b] Úrsulo Galván, Tabasco	8.7	1373.2	2040.4
[c] La Encrucijada Reserve, Chiapas	12.7	1994.4	2963.5
[d] Marismas Nacionales, Nayarit	5.1	797.1	1184.4
[e] Centla, Tabasco, and Laguna de Términos, Campeche	17.4	2724.5	4048.3
[e] Boquilla—La Mancha, Veracruz	10.6	1659.3	2465.6
Cost of production and debt			
Concept	**Adjusted costs (USD ha^{-1} $year^{-1}$)**	**Borrowing costs (USD ha^{-1} $year^{-1}$)**	**Total costs (USD ha^{-1} $year^{-1}$)**
Gang labor	20.7	0.0	20.7
Boats	20.6	1.0	21.6
Chainsaw	2.6	0.1	2.8
GAP			
Site	**Extraction volume (m^3 ha^{-1} $year^{-1}$)**	**Minimum profit (USD ha^{-1} $year^{-1}$)**	**Maximum Profit (USD ha^{-1} $year^{-1}$)**
[a] La Solución Somos Todos, Tabasco	4.0	583.0	888.2
[a] Ejido Francisco Trujillo Gurría, Tabasco	4.0	583.0	888.2
[a] Ejido el Golpe, Tabasco	10.0	1525.1	2288.0
[a] Puerto Ceiba, Tabasco	13.6	2095.0	3134.9
[b] Úrsulo Galván, Tabasco	8.7	1328.1	1995.3
[c] La Encrucijada Reserve, Chiapas	12.7	1949.4	2918.5
[d] Marismas Nacionales, Nayarit	5.1	752.1	1139.4
[e] Centla, Tabasco and Laguna de Términos,, Campeche	17.4	2579.5	4003.3
[e] Boquilla—La Mancha, Veracruz	10.6	1614.3	2420.6

SOURCE: [a] [29], [b] [27], [c] [32], [d] [34] and [e] [33,41].

The cost of wood production is determined from the cost analysis carried out by Villalobos-Zapata et al. [41] in the Laguna de Términos, Campeche, covering an area of 2500 ha. For the purposes of this study, only labor costs (five people per crew), motor boats, and chainsaws are considered. It is assumed that these inputs are sufficient to take advantage of the 2500 ha of land [41], as well as borrowing costs at an interest rate of 4.875% to finance the inputs (motorboat and chainsaw). The total cost of wood production is 45.0 USD ha^{-1}. The profits are between 583.0 USD ha^{-1} year^{-1} and 4003.3 USD ha^{-1} year^{-1}, which is the best scenario for Pantanos de Centla, Tabasco, and Laguna de Términos, Campeche, in which an extraction volume of 16.8 can be achieved in m^{3} ha^{-1} year^{-1}.

3.3.2. Productive Activity: Corn (National Benchmark)

In Mexico, the average yield of white corn is greater than that of yellow corn [74]. In contrast, the price of the yellow variety is higher than that of the white variety [75]. Considering the above situation, the average income from white corn (4003 USD Mg^{-1} year^{-1}) is higher than that from yellow corn (3484 USD ha^{-1} year^{-1}). Table 5 shows the average yield of the two varieties of corn, the costs of production and indebtedness, and the calculation of the annual gross profit.

Table 5. Yield, costs of production, costs of indebtedness, and *GAP* in the cultivation of corn.

Performance				
Cultivation	**[a] Adjusted price (USD Mg^{-1})**	**[b] Performance (Mg ha^{-1} year^{-1})**	**Average income (USD ha^{-1} year^{-1})**	
Yellow corn	366.8	9.5	3484.4	
White corn	364.0	11.0	4003.9	
Cost of production and debt				
Place	**Technology**	**Adjusted production costs (USD Mg^{-1} year^{-1})**	**Borrowing costs (USD Mg^{-1} year^{-1})**	**Total costs (USD Mg^{-1} year^{-1})**
[c] Hidalgo	Rainfed	645.3	31.5	676.7
[d] Guanajuato	Rainfed	1806.2	88.1	1894.3
GAP				
Place	**Technology**	**Cultivation**	**Annual profit (USD ha^{-1} year^{-1})**	
[c] Hidalgo	Rainfed	Yellow corn	2807.7	
[c] Hidalgo	Rainfed	White corn	3327.2	
[d] Guanajuato	Rainfed	Yellow corn	1590.1	
[d] Guanajuato	Rainfed	White corn	2109.6	

SOURCE: [a] [75], [b] [74], [c] [76], and [d] [77].

The production costs of corn in the states of Hidalgo and Guanajuato, which use rainfed cultivation, are analyzed. The cost of production is greater in the state of Guanajuato (1806 USD ha^{-1} year^{-1}). Adding the costs of borrowing to finance the inputs (interest rate of 4.875%), the total costs of the cultivation of corn are determined to be between 676 USD ha^{-1} year^{-1} and 1894 USD ha^{-1} year^{-1}.

The lowest *GAP* is obtained with yellow corn in the state of Guanajuato (1590 USD ha^{-1} year^{-1}), whereas the highest *GAP* is obtained with white corn in the state of Hidalgo (3327 USD ha^{-1} year^{-1}).

In Tabasco, Mexico, by 2010, a maize area of 59,293 ha was planted, with a production of 83,520 Mg [78], which resulted in yields of 1.4 Mg ha^{-1} year^{-1}. The average earnings were only USD 513 ha^{-1} year^{-1} with yellow corn.

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In the case of Úrsulo Galván, Tabasco, it has been reported that the salinity of mangrove soil varies between 2.6 dS cm^{-1} and 6.2 dS cm^{-1} [79]. Conversely, the tolerance of corn to salinity is 1.7 dS cm^{-1}, with a loss of 50% of production at 5.8 dS cm^{-1} [80]. Therefore, the yield at this site is estimated to be 0.64 Mg ha^{-1} $year^{-1}$ to 1.25 Mg ha^{-1} $year^{-1}$, with an average income of 234.7 USD ha^{-1} $year^{-1}$ to 458.5 USD ha^{-1} $year^{-1}$, respectively.

3.3.3. Productive Activity: Cattle (Regional Comparison/National Benchmark)

In Tabasco, the livestock population for 2022 is 1,711,069 animal units (AUs) [81], and the livestock area is 1,617,000 ha [82], which brings in a return for the state of 1.05 AU ha^{-1}. In this scenario, considering the average price of carcass meat in Mexico and assuming the sale of 350 kg of heifers, the income from the sale of animals is 2064 USD ha^{-1} $year^{-1}$ (Table 6).

Table 6. Yield of meat and milk, costs of meat production, and *GAP* in livestock. An animal unit (AU) is defined as an adult cow weighing 450 kg, with or without a suckling calf, that consumes approximately 12 kg of dry matter from forage per day.

Meat performance				
Breed	**Heifer weight (kg)**	**[a] Price (USD kg^{-1})**	**Yield (AU ha^{-1})**	**Average income (USD ha^{-1} $year^{-1}$)**
Swiss American	350.00	5.62	1.05	2064.14
Holstein	350.00	5.62	1.05	2064.14
Milk yield				
Breed	**[b] Milk production (L UA^{-1} $year^{-1}$)**	**[c] Price (USD L^{-1})**	**Yield (AU ha^{-1})**	**Average income (USD ha^{-1} $year^{-1}$)**
Swiss American	3595.00	0.54	1.05	2034.97
Holstein	3945.00	0.54	1.05	2233.09
Costs				
Breed	**[d] Variable costs (USD kg)**	**[d] Fixed costs (USD kg)**	**Variable costs (USD ha^{-1} $year^{-1}$)**	**Fixed costs (USD ha^{-1} $year^{-1}$)**
Swiss American	2.32	0.21	854.12	77.40
Holstein	2.32	0.21	854.12	77.40
GAP				
Breed	**Profit (USD ha^{-1} $year^{-1}$)**			
Swiss American	3167.59			
Holstein	3365.71			

SOURCE: [a] [83], [b] [84], [c] [85], and [d] [86].

The milk production of Swiss American cows is 3696 kg $year^{-1}$, and that of Holstein cows is 4056 kg $year^{-1}$ [84]. Considering that the density of cow milk is 1028 kg/L, the yield is 3595 L $year^{-1}$ for the American Swiss breed and 3945 L $year^{-1}$ for the Holstein breed. The highest income is obtained with Holstein specimens (2233.09 USD ha^{-1} $year^{-1}$).

Variable cost in the state of Mexico for the production of calves is 2.32 USD kg^{-1} of meat, and the fixed cost is 0.21 USD kg^{-1} of meat [86]. Considering the production of 1.05 heifers ha^{-1} with weights of 350 kg, variable costs are 854.1 USD ha^{-1} and 77.4 USD ha^{-1} in fixed costs for both breeds of cows. *GAP* is 3167.59 USD ha^{-1} with Swiss American specimens and 3365.71 USD ha^{-1} with Holstein specimens.

Table 7 compares two scenarios of livestock production systems, obtained via a literature review. The first scenario is a regional comparison, obtained from the cost analysis carried out by Granados-Rivera et al. [87], which evaluated a dual-purpose production system in Rural Development District 151 in Tabasco (Cárdenas, Comalcalco, Cunduacán, Jalpa de Méndez, Nacajuca, Huimanguillo and Paraíso), with production units (PUs) with average surfaces of 19 ha, 20 cows, a stallion, and four heifers, with an average yield of 1.1 AU ha^{-1}.

Table 7. Meat and milk yield, meat production costs, and *GAP* of livestock in two livestock production systems.

Income				
Stage	**Income from sales of milk (USD year^{-1})**	**Income from sales of calves (USD year^{-1})**	**Total income (USD year^{-1})**	
[a] Dual purpose	3005.63	4196.56	9735.92	
[b] Sale of milk	15,594.65	2125.82	23,954.52	
Costs				
Stage	**[a] Variable costs (USD kg)**	**[a] Fixed costs (USD kg)**	**Variable costs (USD year^{-1})**	**Fixed costs (USD year^{-1})**
Dual purpose	2.32	0.21	4229.93	383.30
Sale milk			17,320.94	1648.40
Annual gross profit				
Stage	**Place**	**PU size (AU)**	**PU profit (USD year^{-1})**	**Profit (USD ha^{-1} year^{-1})**
Dual purpose	Tabasco	21	5122.70	269.62
Sale milk	State of Mexico	21	4985.19	262.38

SOURCE: [a] [87] and [b] [88].

The second scenario is a national benchmark, based on an assessment by Sánchez-Medina et al. [88] of a milk production system in the municipalities of Texcoco and San Andrés Chiautla in the state of Mexico. This system is made up of PUs with an average area of approximately 0.1 ha, which house a total of 21 Holstein breed animals, with an average of nine cows in production. For this scenario to be comparable to the first scenario, the total area per PU is considered 19 ha.

Total income is higher for the milk sale scenario (23,954 USD year^{-1}); however, the variable costs represent 72% of total income, whereas fixed costs represent 7%. The above results indicate that the *GAP* is similar in both scenarios due to the low-level production costs of extensive livestock compared with the high costs of intensive livestock.

3.4. Comparison of Carbon Prices with Production Systems

Table 8 shows the profits of the worst and best scenarios of the productive activities analyzed, as well as the minimum carbon store (Mg CO_2e ha^{-1}) of a blue carbon project, making it comparable to the productive activity of the locality near the mangrove.

The *GAP* of the blue carbon projects is in the range of 21.5–72.2 USD ha^{-1} year^{-1} in Marismas Nacionales, Nayarit, which consists of short and unproductive mangroves, and 1590.2–5314.0 USD ha^{-1} year^{-1} in Centla, Tabasco, and Laguna de Términos, Campeche. Conversely, the *GAP* of the productive activity of wood harvesting ranges from 628.0 to 3917.7 USD ha^{-1} year^{-1}, while the *GAP* of the corn crop ranges from 1590.1 to 3327.21 USD ha^{-1} year^{-1}, and that of the livestock ranges from 262.38 to 3365.71 USD ha^{-1} year^{-1}.

Table 8. Minimum carbon storage level in blue carbon projects in corn cultivation, wood harvesting, and livestock, considering a minimum price of 4 USD per Mg CO_2e and a maximum price of 86 USD per Mg CO_2e.

Economic Activity	Stage		Profit (USD ha^{-1} $year^{-1}$)		Project Cost Scenario	Minimum Carbon Store with Prices of 4 USD per Mg CO_2e ($MgCO_2$e ha^{-1} $year^{-1}$)		Minimum Carbon Store with Prices of 86 USD per Mg CO_2e ($MgCO_2$e ha^{-1} $year^{-1}$)	
	Worse	**Better**	**Worse**	**Better**		**Worse**	**Better**	**Worse**	**Better**
Wood harvesting	Extraction volume of 4 m^3 ha^{-1}	Extraction volume of 16.8 m^3 ha^{-1}	628.00	3917.70	Low	157.03	979.45	7.30	45.56
					Medium	158.00	980.43	7.35	45.60
					High	159.03	981.45	7.40	45.65
Cultivation	Yellow corn	White corn	1590.10	3327.21	Low	397.55	831.83	18.49	38.69
					Medium	398.52	832.80	18.54	38.73
					High	399.55	833.83	18.58	38.78
Livestock	Sale of Swiss American breed meat	Sale of Holstein breed meat	3167.59	3365.71	Low	791.92	841.45	36.83	39.14
					Medium	792.90	842.43	36.88	39.18
					High	793.92	843.45	36.93	39.23
Livestock	Sales of milk 21 AU	Dual purpose 21 AU	262.38	269.62	Low	65.62	67.43	3.05	3.14
					Medium	66.59	68.40	3.10	3.18
					High	67.62	69.43	3.15	3.23

Note: The economic activity wood harvesting is classified as a direct alternative (realistic land-use alternative for the same mangrove site), livestock as regional comparison (plausible alternative within the same coastal region), or national benchmark (reference value from other contexts, and cultivation as national benchmark (reference value from other contexts). Project costs were defined using three scenarios derived from the *GAP* analysis of blue carbon projects in Mexican mangroves: Low = 0.1 USD ha^{-1} $year^{-1}$, observed in Marismas Nacionales (Nayarit) and Pantanos de Centla–Laguna de Términos (Tabasco–Campeche); Medium = 4.0 USD ha^{-1} $year^{-1}$, an intermediate value of project costs; and High = 8.1 USD ha^{-1} $year^{-1}$, observed in Boquilla–La Mancha (Veracruz). An animal unit (AU) is defined as an adult cow weighing 450 kg, with or without a suckling calf, that consumes approximately 12 kg of dry matter from forage per day.

4. Discussion

4.1. Systematic Literature Review

The results demonstrate a progressive expansion of scientific interest in carbon pricing, particularly since 2016, coinciding with the strengthening of carbon markets and the implementation of international policies such as the Paris Agreement [7]. The increase in publications in recent years aligns with the World Bank's State and Trends of Carbon Pricing report, which documents the proliferation of pricing instruments and the expansion of emission coverage under market schemes [7].

Carbon prices show an upward trajectory, with clear differences across price types. Voluntary Credits (VC) exhibit a gradual increase over time, while Emission Trading Schemes (ETS) display a steeper rise, reflecting the consolidation of regulated markets. Shadow Prices (SP) present intermediate values with fluctuations, and the Social Cost of Carbon (SCC) is reported as a normative benchmark. These distinctions highlight the coexistence of regulated and voluntary mechanisms, as well as the methodological diversity in estimating carbon values [89].

Regarding ecosystems, the differentiation by price type underscores notable contrasts. Forests show relatively consistent values across categories, wetlands present extreme variations depending on the methodology applied, and marine environments remain underrepresented in the literature. These differences suggest that forests dominate the research due to their central role in mitigation policies and greater data availability, consistent with Griscom et al. [90], while wetlands and marine systems highlight the need for further investigation.

Taken together, the data show that carbon prices tend to increase over time and diversify according to ecosystem type, supporting the need to expand research in less-studied environments.

4.2. Opportunity Costs of Carbon Sequestration in Mangroves

Readers should interpret the economic comparisons with caution because the analysis is based on a simplified income scenario and on aboveground carbon only. In real-world certification processes, the number of credits that can be issued—and therefore the revenues available to producers—may be substantially lower than the simplified estimates presented here due to: (1) additionality and baseline-setting requirements; (2) leakage effects that reduce net mitigation; (3) permanence risks that require buffer set-asides or discounts; (4) uncertainty adjustments in carbon accounting; and (5) monitoring, verification, registration, and transaction costs. Without adjusting for these factors, the economic comparison is likely to overestimate the net income producers could obtain from carbon credits.

Moreover, because the CAR protocol used in our cost calculations does not credit soil or belowground carbon, the monetary values reported here exclude any payments that might arise from those compartments. If future protocols or markets explicitly credit soil and sediment carbon, the economic viability of blue carbon projects could improve, but such outcomes would require different accounting rules and market recognition.

Average annual income depends on the aboveground biomass of the study area and the growth rate of trees. The greater the aboveground biomass is, the higher the average income, with Pantanos de Centla, Tabasco, and Laguna de Términos, Campeche, being the places where the highest income was obtained, whereas the lowest income corresponded to the Marismas Nacionales in Nayarit. When the price of carbon is low (4 USD per Mg CO_2e), although the cost of the project is also low, the profits are small, in this case generating profits of 21.5–72.2 USD ha^{-1} $year^{-1}$ in Marismas Nacionales in Nayarit and up to 73.9–247.1 USD ha^{-1} $year^{-1}$ in Pantanos de Centla and Laguna de Términos. High carbon prices (86 USD per Mg CO_2e) result in profits even with high costs, obtaining profits of at least 465.2–1554.6 USD ha^{-1} year^{-1} in Marismas Nacionales in Nayarit and of up to 1590.2–5314.0 USD ha^{-1} year^{-1} in Pantanos de Centla, Tabasco, and Laguna de Términos.

As a direct outcome of the site-specific analysis, blue-carbon projects are compared with local alternatives documented for the same mangrove areas (e.g., authorized timber extraction in Tabasco and Campeche). These direct comparisons provide the most relevant estimate of opportunity cost for landowners in the studied EMUs.

4.3. Comparison of Carbon Prices with Production Systems

Blue carbon projects are an alternative for communities to generate economic income through the management of their forests [14]; however, it is necessary for the blue-carbon project to be equal to or more economically attractive than the productive activities of the mangrove localities [12]. Our results show that this competitiveness is not universal: many sites require relatively high carbon prices and/or above-average sequestration rates to be financially viable. Consequently, any claim that blue carbon projects are viable alternatives for mangrove producers must be explicitly linked to (i) local opportunity costs, (ii) realistic implementation scenarios that include upfront investments and recurring verification costs, and (iii) the carbon-price and sequestration thresholds identified in our sensitivity analysis. Policy and project decisions should therefore be based on site-level appraisals rather than generalized statements of viability.

Wood harvesting is the most profitable activity in terms of *GAP*, whereas the least profitable activities were dual-purpose livestock and milk sales. Compared with that of carbon projects, continuing local wood harvesting activities continues to be more profitable for producers. The same situation occurs with the cultivation of corn, which generates income higher than that obtained in carbon projects in productive soils; however, in the saline soils of the state of Tabasco, corn production is at a low level. The foregoing agrees with previous authors, who have found that agricultural producers renounce profits by not converting forests to rainfed agriculture [18]. For example, Vázquez-González et al. [19] reported that growing sugarcane is more profitable than conserving wetlands. However, this situation is highly dependent on crop performance. For example, in Tabasco, where the yield of the corn crop is low, the salinity of the mangrove soil has negative effects [54]. As a result, blue carbon projects are more profitable than corn production in such areas.

4.3.1. Wood Harvesting vs. Blue Carbon Projects (Direct Alternatives)

The *GAP* from the economic activity of wood harvesting ranges from 583.0 USD ha^{-1} year^{-1} to 4003.3 USD ha^{-1} year^{-1}. Wood harvesting is more profitable than carbon sequestration; however, these profits depend largely on the density of wood extraction. In this sense, for example, the mangroves of Úrsulo Galván in Tabasco generate 124.8 Mg ha^{-1} of biomass, equivalent to 188.07 m^3 ha^{-1} of wood, with an annual growth of 17.5 m^3 ha^{-1}, where, to ensure the conservation of the site and guarantee its sustainability, no wood extractions should be carried out, through wildlife conservation management units (WCMUs), in excess of this amount. Thus, considering an extraction rate of 50% of the growth of trees, gross profits are estimated to be between 1328.1 USD ha^{-1} year^{-1} and 1995.3 USD ha^{-1} year^{-1}. In contrast, the gross profit from blue carbon projects in Úrsulo Galván reaches a maximum of 2578.2 USD ha^{-1} year^{-1} under the high-growth-rate scenario; however, under the worst-case scenario, profits remain modest, with a maximum of 112.5 USD ha^{-1} year^{-1} observed under the high-growth-rate scenario.

Extraction volumes of 4 m^3 ha^{-1} require the forestry project to store at least 157.0–159.0 Mg CO_2e ha^{-1} year^{-1} if the carbon price is USD 4 per Mg CO_2e, or only 7.3–7.4 Mg CO_2e ha^{-1} year^{-1} with a price of 86 USD per Mg CO_2e. In the first case, none of the analyzed sites store more than 157.0 Mg CO_2e ha^{-1} year^{-1}, while all of them store more than 7.3 Mg CO_2e ha^{-1} year^{-1}. Conversely, extraction volumes of 16.8 m^3 ha^{-1} need at least 979.4–981.4 Mg CO_2e ha^{-1} year^{-1} if the carbon price is 4 USD per Mg CO_2e or 45.5–45.6 Mg CO_2e ha^{-1} year^{-1} with a price of 86 USD per Mg CO_2e. Only Pantanos de Centla (Tabasco), Laguna de Términos (Campeche), and Boquilla–La Mancha (Veracruz) attain a maximum of 59.4 Mg CO_2e ha^{-1} year^{-1}, and this occurs only under the high-growth-rate scenario; consequently, blue carbon projects are competitive with wood extraction at 16.8 m^3 ha^{-1} yr^{-1} only when growth rates are high.

4.3.2. Corn vs. Blue Carbon Projects (National Benchmark)

GAP values reported for crops in inland states (presented here as national benchmarks) should not be interpreted as realistic alternatives for mangrove owners in Tabasco, Campeche, Nayarit, Chiapas, or Veracruz. The regional and national figures are used only to contextualize competitiveness at broader scales.

As shown in the Results, corn cultivation remains more profitable than carbon projects under most scenarios. For the annual benefits of a blue carbon project to match those of corn cultivation, the project would need to sequester at least 831.83–833.83 MgCO_2e ha^{-1} year^{-1} under the most favorable corn scenario when the carbon price is at the lowest observed value (4 USD per MgCO_2e), or 18.49–18.58 Mg CO_2e ha^{-1} year^{-1} under the least favorable corn scenario when the carbon price is at the highest observed value (86 USD per Mg CO_2e). The first option is unrealistic because, in the areas analyzed, the sequestration rate is in the range of 5.4–61.8 Mg CO_2e ha^{-1} year^{-1}, whereas the second option is within the range of carbon sequestration in the national context. Thus, high carbon prices are required for conservation projects to be attractive to producers.

In Mexico, the corn production systems with the highest private profitability are found in the states of Sinaloa, Jalisco, Guanajuato, and the state of Mexico, with profits of 1255 USD ha^{-1} [52]. At these sites, the prices of 86 USD per Mg CO_2e require conservation projects that generate at least 15.0 Mg CO_2e ha^{-1} year^{-1}, or 314.0 Mg CO_2e ha^{-1} year^{-1}, with prices of 4 USD per Mg CO_2e; that is, sites with high profitability of the original activity need high prices of CO_2e or for the forestry project to retain high amounts of CO_2e. In this context, where carbon payments are not enough to compete with high-profitability activities, other mechanisms may be necessary, such as a combination of sustainable land-use practices and the inclusion of other ecosystem services in payment-for-services programs. Ecosystems (biodiversity conservation, hydrological services, sustainable land management, cultural services, and climate regulation) constitute an active part of local income [3].

Tabasco is a state with low profitability in the case of low yields from the cultivation of corn, comprising areas with smallholder farmer production systems, simple production of goods, and poverty conditions [82]. This situation makes the implementation of conservation projects attractive because a large improvement in profits is a powerful incentive for farmers to shift from cultivation to conservation or restoration projects to obtain carbon [42]. However, it should be noted that producers might not be able to transform all their plots into blue carbon projects because, in Tabasco, corn is used mainly for self-consumption, such as for the preparation of tortillas, pozol, pinole, atole, tamale de masa and cooked corn, as well as for the feeding of backyard animals such as turkeys, chickens, ducks, and pigs [91].

4.3.3. Beef Cattle vs. Blue Carbon Projects (Regional Comparison/National Benchmark)

The *GAP* for the productive activity of cattle for the sales of meat is in the range of 3167.59 USD ha^{-1} year^{-1} to 3365.71 USD ha^{-1} year^{-1}. Blue carbon projects can compete with cattle production activities; however, they require high carbon prices to be profitable.

In the livestock activity for the sales of meat (classified as a national benchmark), the carbon project must sequester 36.83–36.93 Mg CO_2e ha^{-1} year^{-1} under the worst-case livestock scenario when the carbon price is 86 USD per Mg CO_2e. Prices of USD 4 per Mg CO_2 make blue carbon projects unattractive to livestock producers, owing to the high amounts of carbon needed to store to match their current income. Prices of 86 USD per Mg CO_2e are competitive compared with livestock activity, especially considering that the places with the highest carbon storage capacity, such as Pantanos de Centla in Tabasco and Laguna de Términos in Campeche, reach 61.8 Mg CO_2e ha^{-1} $year^{-1}$ under the high-growth-rate scenario. The livestock activity reflects its role as a reference for economic performance at the national scale. This benchmark allows comparison of carbon projects against typical profitability levels observed across Mexico, providing a broader context for evaluating economic feasibility.

In Tabasco, the economic activity of calf and milk sales (classified as a regional comparison) results in low-level profitability, requiring that a conservation project store 67.43–69.43 Mg CO_2e ha^{-1} $year^{-1}$ with a carbon price of 4 USD per Mg CO_2e. In contrast, if the price increases to USD 86 per Mg CO_2e, then only 3.14–3.23 Mg CO_2e $year^{-1}$ would need to be stored. In this context, carbon projects are a viable alternative for producers to improve their income with blue carbon projects. However, it is necessary for prices to reach at least 15 USD per Mg CO_2e, which would imply the need to store 18.0 Mg CO_2e ha^{-1} $year^{-1}$ so that most of the sites analyzed can be competitive with cattle activity. The regional comparison applied to Tabasco highlights the local variability in production systems and profitability. In this region, cattle raising is often characterized by smaller-scale operations and lower productivity, which makes blue carbon projects relatively more competitive [92]. The distinction between national benchmarks and regional comparisons is therefore essential to understand how carbon prices and storage potential interact with local economic realities. While national benchmarks offer a general reference, regional comparisons reveal the specific conditions under which blue carbon projects can become viable alternatives for producers.

5. Conclusions

This study provides a site-specific, regionally grounded comparison of the economic returns from mangrove carbon conservation versus alternative productive uses (timber extraction, corn cultivation, and extensive livestock) in selected Mexican sites. Below we synthesize the main findings.

Our analysis demonstrates that, under a simplified *GAP* framework and the carbon-price range compiled in our literature review, some mangrove sites—particularly those with high aboveground carbon stocks and favorable growth rates (e.g., sites in Centla, Tabasco; Laguna de Términos, Campeche)—can appear competitive with local productive activities.

Financial viability depends on a combination of factors: (a) sufficiently high carbon prices; (b) site-specific, reliable, and updated measurements of all carbon compartments, including their changes (i.e., growth rate, etc.); (c) low local opportunity costs or restricted alternative uses; and (d) manageable upfront and recurrent project costs. In many cases, one or more of these conditions must be met. The case studies from Tabasco illustrate that blue carbon projects can be feasible under high-price and moderate-income scenarios, but these outcomes are conditional rather than generalizable.

Our analysis does not capture all project-level implementation complexities, including land-tenure negotiations, aggregation costs, social transaction costs, bureaucratic and lengthy certification processes, and evolving market rules. We limited carbon accounting to aboveground biomass under the CAR-based scenarios; soil and sediment carbon—potentially important for blue carbon value—were not credited in the scenarios modeled, and therefore are not reflected in the economic results. Actual payments to producers will depend on project design, chosen standard, and market conditions, so site-level feasibility studies remain essential. Furthermore, this study intentionally uses Gross Annual Benefit (GAB) as a transparent and comparable metric across sites and production activities, but we recognize its limitations for investment decision-making.

Policy instruments and incentive schemes should be informed by full project appraisals and by explicit price and sequestration thresholds that reflect local opportunity costs. Payments should be calibrated using site-specific opportunity-cost analyses that distinguish direct parcel-level alternatives from regional or national benchmarks.

The principal novelty of this work is its applied, regionally contextualized comparison of carbon incomes and alternative livelihoods in Mexican mangrove contexts. By using site-specific data and by distinguishing direct opportunity costs from regional and national benchmarks, the study provides decision-relevant thresholds and a clearer picture of where carbon projects are most likely to be competitive in Mexico. These results offer a practical starting point for site-level feasibility assessments and for designing locally tailored conservation incentives.

In summary, our results show that mangrove carbon projects can be viable under specific, identifiable conditions, but viability is not universal. We therefore caution against generalizing the findings to all mangrove owners and recommend that project proponents and policymakers use the threshold results provided here as a starting point for site-level feasibility assessments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/earth7040136/s1, Supplementary dataset: Detailed carbon price calculations derived from the articles selected in the systematic search.

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References

1. Inoue, T. Carbon Sequestration in Mangroves. In *Blue Carbon in Shallow Coastal Ecosystems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 73–99. [CrossRef]
2. Velázquez-Salazar, S.; Rodríguez-Zúñiga, M.T.; Alcántara-Maya, J.A.; Villeda-Chávez, E.; Valderrama-Landeros, L.; Troche-Souza, C. Manglares de México. Actualización y Análisis de los Datos 2020 (CONABIO)–Agua.Org.Mx. Available online: https://agua.org.mx/biblioteca/manglares-de-mexico-actualizacion-y-analisis-de-los-datos-2020/ (accessed on 3 October 2024).
3. Jakovac, C.C.; Latawiec, A.E.; Lacerda, E.; Leite Lucas, I.; Korys, K.A.; Iribarrem, A.; Malaguti, G.A.; Turner, R.K.; Luisetti, T.; Baeta Neves Strassburg, B. Costs and Carbon Benefits of Mangrove Conservation and Restoration: A Global Analysis. *Ecol. Econ.* **2020**, *176*, 106758. [CrossRef]
4. Kauffman, J.B.; Hernandez Trejo, H.; del Carmen Jesus Garcia, M.; Heider, C.; Contreras, W.M. Carbon Stocks of Mangroves and Losses Arising from Their Conversion to Cattle Pastures in the Pantanos de Centla, Mexico. *Wetl. Ecol. Manag.* **2016**, *24*, 203–216. [CrossRef]

5. McLeod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M.; Lovelock, C.E.; Schlesinger, W.H.; Silliman, B.R. A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO2. *Front. Ecol. Environ.* **2011**, *9*, 552–560. [CrossRef]
6. Banco, M. *Comercio de Emisiones en la Práctica: Manual Sobre el Diseño y la Implementación de Sistemas de Comercio de Emisiones*, 2nd ed.; Banco Internacional de Reconstrucción y Fomento/Banco Mundial: Washington, DC, USA, 2021.
7. World Bank. *State and Trends of Carbon Pricing 2022*; World Bank: Washington, DC, USA, 2022.
8. Ibarra, D.; Escobar, L. Mercados de Bonos de Carbono. *Rev. Tiempo Econ.* **2008**, *3*, 17–38.
9. Lieu, N.T. *Creación del Mercado del Carbono en Vietnam*; Ediciones Nuestro Conocimiento: Dallas, TX, USA, 2023.
10. Ranero, A.; Covaleda, S.; Ranero, A.; Covaleda, S. El Financiamiento de los Proyectos de Carbono Forestal: Experiencias Existentes y Oportunidades en México. *Madera Bosques* **2018**, *24*, e2401913. [CrossRef]
11. Rontard, B.; Reyes, H.; Ii, H.; Aguilar, M.; Iii, R. Pagos Por Captura de Carbono en el Mercado Voluntario en México: Diversidad y Complejidad de su Aplicación en Chiapas y Oaxaca. *Soc. Ambiente* **2020**, *22*, 212–236. [CrossRef]
12. Raihan, A.; Begum, R.A.; Said, M.N.M.; Pereira, J.J. Assessment of Carbon Stock in Forest Biomass and Emission Reduction Potential in Malaysia. *Forests* **2021**, *12*, 1294. [CrossRef]
13. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the Global Value of Ecosystem Services. *Glob. Environ. Change* **2014**, *26*, 152–158. [CrossRef]
14. González, P.; Achinelli, M. Mercado Voluntario de Carbono y su Impacto Socioeconómico en la Colonia La Amistad, Departamento de Itapúa, Paraguay. Periodo: 2010–2015. *Poblac. Desarro.* **2017**, *23*, 45–51. [CrossRef]
15. Pagiola, S. Payments for Environmental Services in Costa Rica. *Ecol. Econ.* **2008**, *65*, 712–724. [CrossRef]
16. Vanderklift, M.A.; Marcos-Martinez, R.; Butler, J.R.A.; Coleman, M.; Lawrence, A.; Prislan, H.; Steven, A.D.L.; Thomas, S. Constraints and Opportunities for Market-Based Finance for the Restoration and Protection of Blue Carbon Ecosystems. *Mar. Policy* **2019**, *107*, 103429. [CrossRef]
17. Angelsen, A. REDD+ as Result-Based Aid: General Lessons and Bilateral Agreements of Norway. *Rev. Dev. Econ.* **2017**, *21*, 237–264. [CrossRef]
18. Reyes, M.; Covaleda, S.; Pérez, M.J.; Paz, F. Ordenamientos Territoriales e Intervenciones a Escala Local en Chiapas en REDD+: Carbono, Costos de Oportunidad y Modelos de Estados y Transiciones. Available online: https://ccmss.org.mx/?s=Ordenamientos+territoriales+e+intervenciones+a+escala+local (accessed on 8 October 2024).
19. Vázquez-González, C.; Moreno-Casasola, P.; Hernández, M.E.; Campos, A.; Espejel, I.; Fermán-Almada, J.L. Mangrove and Freshwater Wetland Conservation Through Carbon Offsets: A Cost-Benefit Analysis for Establishing Environmental Policies. *Environ. Manag.* **2017**, *59*, 274–290. [CrossRef] [PubMed]
20. Pendleton, L.; Donato, D.C.; Murray, B.C.; Crooks, S.; Jenkins, W.A.; Sifleet, S.; Craft, C.; Fourqurean, J.W.; Kauffman, J.B.; Marbà, N.; et al. Estimating Global "Blue Carbon" Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLoS ONE* **2012**, *7*, e43542. [CrossRef] [PubMed]
21. Sapkota, Y.; White, J.R. Carbon Offset Market Methodologies Applicable for Coastal Wetland Restoration and Conservation in the United States: A Review. *Sci. Total Environ.* **2020**, *701*, 134497. [CrossRef] [PubMed]
22. Adame, M.F.; Brown, C.J.; Bejarano, M.; Herrera-Silveira, J.A.; Ezcurra, P.; Kauffman, J.B.; Birdsey, R. The Undervalued Contribution of Mangrove Protection in Mexico to Carbon Emission Targets. *Conserv. Lett.* **2018**, *11*, e12445. [CrossRef]
23. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ* **2021**, *372*, n71. [CrossRef] [PubMed]
24. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Antes, G.; Atkins, D.; Barbour, V.; Barrowman, N.; Berlin, J.A.; Clark, J.; et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
25. Ning, Z.H.; Chambers, R.; Abdollahi, K. Modeling Air Pollutant Removal, Carbon Storage, and CO2 Sequestration Potential of Urban Forests in Scotlandville, Louisiana, USA. *IForest* **2016**, *9*, 860–867. [CrossRef]
26. Tovilla-Hernández, C.; Infante-Mata, D.M.; Ovalle-Estrada, F.; De la Presa-Pérez, J.C.; García-Alfaro, J.R.; De la Cruz-Montes, G. *Informe: Inventario del Manglar y Avance de la Intrusión Salina en el Ejido Úrsulo Galván, Municipio de Jalpa de Méndez, Tabasco, México*; Fondo Institucional de Fomento Regional para el Desarrollo Científico, Tecnológico y de Innovación; El Colegio de la Frontera Sur, Consejo Nacional de Ciencia y Tecnología: Tapachula, Mexico, 2013.
27. Ávila-Acosta, C.R.; Domínguez-Domínguez, M.; Vázquez-Navarrete, C.J.; Acosta-Pech, R.G.; Martínez-Zurimendi, P. Aboveground Biomass and Carbon Storage in Mangrove Forests in Southeastern Mexico. *Resources* **2024**, *13*, 41. [CrossRef]
28. Sol-Sánchez, A.; Sánchez-Díaz, B.; Zapata-Ovando, I.; Hernández-Melchor, G.I. Carbon Storage in the Branchless Trunk of Red Mangrove *Rhizophora mangle* L. in the Mangroves of the Gulf of Mexico. *Agro Product.* **2025**, *18*, 83–91. [CrossRef]
29. Domínguez-Domínguez, M.; Zavala-Cruz, J.; Martínez-Zurimendi, P. *Manejo Forestal Sustentable de los Manglares de Tabasco*; Secretaría de Recursos Naturales y Protección Ambiental, Colegio de Postgraduados: Villahermosa, Mexico, 2011.

30. Vázquez-Vázquez, L.L.; Jiménez-Pérez, N.d.C.; Cruz-Elizondo, Y.D.l.; Rodríguez-Luna, A.R.; Morales-Bautista, C.M. Areas Affected by Defoliator (*Hylesia colimatifex*) in the Mangrove Area of Laguna Mecoacán, Tabasco. *Acta Univ.* **2024**, *34*, 1–11. [CrossRef]
31. CONANP Programa de Manejo de La Reserva de La Biosfera La Encrucijada. Available online: https://www.conanp.gob.mx/datos_abiertos/DGCD/50.pdf (accessed on 13 February 2026).
32. Velázquez-Pérez, C.; Tovilla-Hernández, C.; Romero-Berny, E.I.; De Jesús-Navarrete, A. Estructura del Manglar y su Influencia en el Almacén de Carbono en La Reserva La Encrucijada, Chiapas, México. *Madera Bosques* **2019**, *25*, e2531885. [CrossRef]
33. Sjögersten, S.; de la Barreda-Bautista, B.; Brown, C.; Boyd, D.; Lopez-Rosas, H.; Hernández, E.; Monroy, R.; Rincón, M.; Vane, C.; Moss-Hayes, V.; et al. Coastal Wetland Ecosystems Deliver Large Carbon Stocks in Tropical Mexico. *Geoderma* **2021**, *403*, 115173. [CrossRef]
34. Agraz-Hernández, C.M.; Chan-Keb, C.A.; Chávez-Barrera, J.; Osti-Sáenz, J.; Expósito-Díaz, G.; Alonso-Campos, V.A.; Muñiz-Salazar, R.; Ruiz-Fernández, A.C.; Pérez-Bernal, L.H.; Sánchez-Cabeza, J.A.; et al. Reserva de Carbón en un Ecosistema de Manglar al Norte de México: Cambios Ambientales Durante 35 Años. *Rev. Mex. Biodivers.* **2020**, *91*, e912910. [CrossRef]
35. Sánchez, E.P.; Trejo, H.H. Evaluación Espacio-Temporal de los Manglares de La Reserva de La Biosfera Pantanos de Centla, Tabasco. *Kuxulkab'* **2024**, *30*, e6390. [CrossRef]
36. CONANP Información Espacial de Las Áreas Naturales Protegidas—Formato SHAPE. Available online: https://sig.conanp.gob.mx/Shape (accessed on 31 May 2026).
37. CONABIO División Política Estatal, 1:250,000. Available online: http://geoportal.conabio.gob.mx/metadatos/doc/html/dest_2010gw.html (accessed on 31 May 2026).
38. Gobierno de México Datos Geográficos Perimetrales de los Núcleos Agrarios Certificados, por Estado—Formato SHAPE. Available online: https://www.datos.gob.mx/ (accessed on 27 November 2021).
39. Velázquez-Pérez, C. Cambios en la Estructura del Manglar y Reservorio de Carbono en la Zona Núcleo de La Reserva La Encrucijada. Master's Thesis, El Colegio de la Frontera Sur, Tapachula, Mexico, 2018.
40. Probst, B.S.; Toetzke, M.; Kontoleon, A.; Anadón, L.D.; Minx, J.C.; Haya, B.K.; Schneider, L.; Trotter, P.A.; West, T.A.P.; Gill-Wiehl, A.; et al. Systematic Assessment of the Achieved Emission Reductions of Carbon Crediting Projects. *Nat. Commun.* **2024**, *15*, 9562. [CrossRef] [PubMed]
41. Villalobos-Zapata, G.J.; Yáñez-Arancibia, A.; Day, J.W., Jr.; Lara-Domínguez, A.L. Ecología y Manejo de los Manglares en la Laguna de Términos, Campeche, México. In *Ecosistemas de Manglar en América Tropical*; Yáñez-Arancibia, A., Lara-Domínguez, A.L., Eds.; Instituto de Ecología A.C.: Veracruz, Mexico; UICN/ORMA: Moravia, Costa Rica; NOAA/NMFS: Silver Spring, MD, USA, 1999; pp. 263–274.
42. Jantawong, K.; Kavinchan, N.; Wangpakapattanawong, P.; Elliott, S. Financial Analysis of Potential Carbon Value over 14 Years of Forest Restoration by the Framework Species Method. *Forests* **2022**, *13*, 144. [CrossRef]
43. Román, P.H.; Bueno, D.H.M.; Aguilar, B.U.; Pérez, S.J.M.; Rodríguez, C.M.A.; Koppel, R.E.T. *Manual del Modelo GGAVATT. Campo Experimental la Posta. Folleto Técnico Núm. 27*, 2nd ed.; INIFAP-CIRGOC: Veracruz, Mexico, 2001.
44. Swisher, J.; Masters, G. A Mechanism to Reconcile Equity and Efficiency in Global Climate Protection: International Carbon Emission Offsets on JSTOR. *Ambio* **1992**, *21*, 154–159.
45. Ansari, M.A.; Ravisankar, N.; Shamim, M.; Rani, M.; Prusty, A.K.; Singh, R.; Raghavendra, K.J.; Joshi, H.; Kumar, S.; Panwar, A.S.; et al. Accounting of Carbon Sequestration and Tradeoff under Various Climatic Scenarios in Alternative Agricultural System: A Comprehensive Framework toward Carbon Neutrality. *Front. Sustain. Food Syst.* **2024**, *8*, 1371255. [CrossRef]
46. Missbach, L.; Steckel, J.C.; Ward, H. Assessing Distributional Effects of Carbon Pricing in Israel. *Energy Policy* **2023**, *180*, 113672. [CrossRef]
47. Chimdi, A.; Gurmessa, E. Effects of Land Use on Selected Soil Properties and Carbon Sequestration in the Gurra Watershed: The Case of Chalia District, West Shoa Zone, Oromia, Ethiopia. *S. Afr. J. Bot.* **2023**, *156*, 21–28. [CrossRef]
48. Alpaidze, L.; Salukvadze, J. Green in the City: Estimating the Ecosystem Services Provided by Urban and Peri-Urban Forests of Tbilisi Municipality, Georgia. *Forests* **2023**, *14*, 121. [CrossRef]
49. Hong, M.; Song, C.; Kim, M.; Kim, J.; Lee, S.G.; Lim, C.H.; Cho, K.; Son, Y.; Lee, W.K. Application of Integrated Korean Forest Growth Dynamics Model to Meet NDC Target by Considering Forest Management Scenarios and Budget. *Carbon Balance Manag.* **2022**, *17*, 5. [CrossRef] [PubMed]
50. Carhart, M.; Litterman, B.; Munnings, C.; Vitali, O. Measuring Comprehensive Carbon Prices of National Climate Policies. *Clim. Policy* **2022**, *22*, 198–207. [CrossRef]
51. Debanshi, S.; Pal, S. Assessing the Role of Deltaic Flood Plain Wetlands on Regulating Methane and Carbon Balance. *Sci. Total Environ.* **2022**, *808*, 152133. [CrossRef] [PubMed]
52. Koricho, H.H.; Seboka, A.D.; Fufa, F.; Gebreyesus, T.; Song, S. Study on the Ecosystem Services of Urban Forests: Implications for Climate Change Mitigation in the Case of Adama City of Oromiya Regional Sate, Ethiopia. *Urban Ecosyst.* **2021**, *25*, 575–584. [CrossRef]

53. Alvis-Ccoropuna, T.; Francisco Villasante-Benavides, J.; Anthony Pauca-Tanco, G.; Del Pilar Quispe-Turpo, J.; César, Y.; Luque-Fernández, R. Cálculo y Valoración del Almacenamiento de Carbono del Humedal Altoandino de Chalhuanca, Arequipa (Perú). *Rev. Investig. Altoandinas* **2021**, *23*, 139–148. [CrossRef]
54. Habib, S.; Al-Ghamdi, S.G.; Casazza, M.; Kenawy, A.; Li, W. Estimation of Above-Ground Carbon-Stocks for Urban Greeneries in Arid Areas: Case Study for Doha and FIFA World Cup Qatar 2022. *Front. Environ. Sci.* **2021**, *9*, 635365. [CrossRef]
55. Stankovic, M.; Ambo-Rappe, R.; Carly, F.; Dangan-Galon, F.; Fortes, M.D.; Hossain, M.S.; Kiswara, W.; Van Luong, C.; Minh-Thu, P.; Mishra, A.K.; et al. Quantification of Blue Carbon in Seagrass Ecosystems of Southeast Asia and Their Potential for Climate Change Mitigation. *Sci. Total Environ.* **2021**, *783*, 146858. [CrossRef] [PubMed]
56. Delgado-Paredes, G.E.; Zuñe-Da Silva, F.; Vasquez-Diaz, C.d.C.; Esquerre-Ibañez, B.; Fuluy-Chung, J.A.; Rojas-Idrogo, C. Biomasa Arbórea y Valoración Económica de Carbono del Cerro Tres Puntas de Pilasca (Salas-Motupe, Lambayeque, Perú). *Rev. Cuba. Cienc. For.* **2020**, *8*, 456–467.
57. Ngo, D.T.; Le, A.V.; Le, H.T.; Stas, S.M.; Le, T.C.; Tran, H.D.; Pham, T.; Le, T.T.; Spracklen, B.D.; Langan, C.; et al. The Potential for REDD+ to Reduce Forest Degradation in Vietnam. *Environ. Res. Lett.* **2020**, *15*, 074025. [CrossRef]
58. Cameron, C.; Hutley, L.B.; Friess, D.A.; Brown, B. High Greenhouse Gas Emissions Mitigation Benefits from Mangrove Rehabilitation in Sulawesi, Indonesia. *Ecosyst. Serv.* **2019**, *40*, 101035. [CrossRef]
59. Shiau, Y.J.; Burchell, M.R.; Krauss, K.W.; Broome, S.W.; Birgand, F. Carbon Storage Potential in a Recently Created Brackish Marsh in Eastern North Carolina, USA. *Ecol. Eng.* **2019**, *127*, 579–588. [CrossRef]
60. Dong, H.; Dai, H.; Geng, Y.; Fujita, T.; Liu, Z.; Xie, Y.; Wu, R.; Fujii, M.; Masui, T.; Tang, L. Exploring Impact of Carbon Tax on China's CO2 Reductions and Provincial Disparities. *Renew. Sustain. Energy Rev.* **2017**, *77*, 596–603. [CrossRef]
61. Rahman, M.M.; Kabir, M.E.; Imran, A. Protected Areas for Climate Change Mitigation and Livelihood Option: A Case Study of the Bangladesh Sundarbans Mangrove Forest. In *Participatory Mangrove Management in a Changing Climate. Disaster Risk Reduction*; DasGupta, R., Shaw, R., Eds.; Springer: Tokyo, Japan, 2017; pp. 119–136. ISBN 978-4-431-56481-2.
62. Wu, R.; Dai, H.; Geng, Y.; Xie, Y.; Masui, T.; Tian, X. Achieving China's INDC through Carbon Cap-and-Trade: Insights from Shanghai. *Appl. Energy* **2016**, *184*, 1114–1122. [CrossRef]
63. Park, H.C.; Oh, C.H. Potential Effects of Future Adoption of the REDD Mechanism as a Preventive Measure against Deforestation and Forest Degradation in North Korea. *J. Mt. Sci.* **2016**, *13*, 1645–1651. [CrossRef]
64. Zapfack, L.; Noiha, V.N.; Tabue, M.R.B. Economic Estimation of Carbon Storage and Sequestration as Ecosystem Services of Protected Areas: A Case Study of Lobeke National Park. *Commer. Important Seaweed Resour. Their Cultiv.* **2016**, *28*, 406–415.
65. Chen, Z.M.; Liu, Y.; Qin, P.; Zhang, B.; Lester, L.; Chen, G.; Guo, Y.; Zheng, X. Environmental Externality of Coal Use in China: Welfare Effect and Tax Regulation. *Appl. Energy* **2015**, *156*, 16–31. [CrossRef]
66. Wang, P.; Dai, H.C.; Ren, S.Y.; Zhao, D.Q.; Masui, T. Achieving Copenhagen Target through Carbon Emission Trading: Economic Impacts Assessment in Guangdong Province of China. *Energy* **2015**, *79*, 212–227. [CrossRef]
67. Rickels, W.; Rehdanz, K.; Oschlies, A. Economic Prospects of Ocean Iron Fertilization in an International Carbon Market. *Resour. Energy Econ.* **2012**, *34*, 129–150. [CrossRef]
68. De Koning, F.; Olschewski, R.; Veldkamp, E.; Benítez, P.; López-Ulloa, M.; Schlichter, T.; De Urquiza, M. The Ecological and Economic Potential of Carbon Sequestration in Forests: Examples from South America. *AMBIO J. Hum. Environ.* **2005**, *34*, 224–229. [CrossRef]
69. Lewis, C.J.E.; Carnell, P.E.; Sanderman, J.; Baldock, J.A.; Macreadie, P.I. Variability and Vulnerability of Coastal 'Blue Carbon' Stocks: A Case Study from Southeast Australia. *Ecosystems* **2017**, *21*, 263–279. [CrossRef]
70. Thanh, D.T.; Ying, Z.; Huyen, T.T.; Nguyen, N.T.T.; Thanh, D.T.; Ying, Z.; Huyen, T.T.; Nguyen, N.T.T. Assessing the Economic Benefits of Forest Carbon Reservoirs in Vietnam: Implications for Forest Carbon Trading Market Development. *J. Anim. Plant Sci.* **2024**, *34*, 1054–1064. [CrossRef]
71. Hintural, W.P.; Jeon, H.J.; Kim, S.Y.; Go, S.; Park, B.B. Quantifying Regulating Ecosystem Services of Urban Trees: A Case Study of a Green Space at Chungnam National University Using i-Tree Eco. *Forests* **2024**, *15*, 1446. [CrossRef]
72. Climate Action Reserve Cost Benefit Analysis V2.2. Available online: https://www.climateactionreserve.org/wp-content/uploads/2020/11/Cost-Benefit-Analysis_V2.2.xlsx (accessed on 4 January 2024).
73. World Agroforestry Tree Functional Attributes and Ecological Database. Available online: https://www.worldagroforestry.org/output/tree-functional-and-ecological-databases (accessed on 9 February 2024).
74. Secretaría de Agricultura y Desarrollo Rural. Maíz Blanco o Amarillo es Cultivo de Tradición y Desarrollo. Available online: https://www.gob.mx/agricultura/articulos/maiz-blanco-o-amarillo-es-el-cultivo-de-tradicion-y-desarrollo (accessed on 10 January 2024).
75. Secretaría de Agricultura y Desarrollo Rural. Boletín Bimestral Balanza Disponibilidad-Consumo. Available online: https://www.gob.mx/cms/uploads/attachment/file/666190/Balanza_Disponibilidad_consumo_sep_6.pdf (accessed on 10 January 2024).

76. Ayala-Garay, A.V.; Schwentesius-Rindermann, R.; de la O-Olán, M.; Preciado-Rangel, P.; Almaguer-Vargas, G.; Rivas-Valencia, P. Análisis de Rentabilidad de la Producción de Maíz en la Región de Tulancingo, Hidalgo, México. *Agric. Soc. Desarro.* **2013**, *10*, 381–395. [CrossRef]
77. Guzmán-Soria, E.; de la Garza, C.M.T.; González, F.J.P.; Hernández, M.J. Análisis de los Costos de Producción de Maíz en la Región Bajío de Guanajuato. *Anál. Econ.* **2014**, *29*, 145–156.
78. González-Estrada, A.; Alferes-Varela, M. Competitividad y Ventajas Comparativas de la Producción de Maíz en México. *Rev. Mex. Cienc. Agric.* **2010**, *1*, 381–396.
79. Fuentes-Domínguez, I.; Vázquez-Vázquez, L.L.; Ojeda-Morales, M.E.; Córdova-Bautista, Y.; Vargas-Rodríguez, S.C.; Morales-Bautista, C.M. Caracterización y Validación Estadística de Muestras de Suelo Libre de Petróleo para Pruebas en Laboratorio. *J. Energy Eng. Optim. Sustain.* **2024**, *8*, 99–104. [CrossRef]
80. Maas, E.V.; Hoffman, G.J. Crop Salt Tolerance: Current Assessment. *J. Irrig. Drain. Div.* **1977**, *103*, 115–134. [CrossRef]
81. Servicio de Información Agroalimentaria y Pesquera. Población Ganadera. Available online: https://nube.siap.gob.mx/poblacion_ganadera/ (accessed on 17 February 2024).
82. SEMARNAT Compendio de Estadísticas Ambientales 2020. Available online: https://apps1.semarnat.gob.mx:8443/dgeia/compendio_2020/dgeiawf.semarnat.gob.mx_8080/ibi_apps/WFServlet87e3.html (accessed on 17 January 2024).
83. Servicio de Información Agroalimentaria y Pesquera Carne en Canal por Estado. Available online: http://infosiap.siap.gob.mx/anpecuario_siapx_gobmx/CarneenCanal.do (accessed on 21 October 2024).
84. Calderón, R.R.C.; Hernández, V.J.O.; Olazarán, J.S.; Ramírez, G.M.; Rosete, F.J.V.; Ríos, U.A.; Galavíz, R.J.R.; Vega, M.V.E.; Lagunes, L.J.; Aguilar, B.U.; et al. *Manual Ilustrado Para el Manejo de la Lechería Tropical Especializada con Bovinos. Sitio Experimental las Margaritas. Campo Experimental la Posta*; INIFAP-CIRGOC: Puebla, Mexico, 2007.
85. Brambila-Paz, J.J.; Mora-Flores, S.; Rojas-Rojas, M.M.; Pérez-Cerecedo, V. El Precio Mínimo al Productor Primario de Leche para Reducir las Importaciones de Lácteos en México. *Agrociencia* **2013**, *47*, 511–522.
86. Hernández, M.J.; Rebollar, R.A.; Mondragón, A.J.; Guzmán, S.E.; Rebollar, R.S. Costos y Competitividad en la Producción de Bovinos Carne en Corral en el Sur del Estado de México. *Investig. Cienc. Univ. Autón. Aguascalientes* **2016**, *69*, 13–20. [CrossRef]
87. Granados-Rivera, L.D.; Quiroz-Valiente, J.; Maldonado-Jáquez, J.A.; Granados-Zurita, L.; Díaz-Rivera, P.; Hernandez, J. Oliva Caracterización y Tipificación del Sistema Doble Propósito en la Ganadería Bovina del Distrito de Desarrollo Rural 151, Tabasco, México. *Acta Univ.* **2018**, *28*, 47–57. [CrossRef]
88. Sánchez-Medina, A.P.; Herrera-Haro, J.G.; Ramírez-Bribiesca, J.E.; Ortega-Cerrilla, M.E.; Mendoza-Nazar, P.; Dorantes-Jiménez, J. Evaluación Económica del Sistema de Producción Lechera Familiar. *Agroproductividad* **2018**, *11*, 111–118.
89. OECD. *Effective Carbon Rates 2021: Pricing Carbon Emissions Through Taxes and Emissions Trading*; OECD Series on Carbon Pricing and Energy Taxation; OECD Publishing: Paris, France, 2021.
90. Griscom, B.W.; Adams, J.; Ellis, P.W.; Houghton, R.A.; Lomax, G.; Miteva, D.A.; Schlesinger, W.H.; Shoch, D.; Siikamäki, J.V.; Smith, P.; et al. Natural Climate Solutions. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 11645–11650. [CrossRef] [PubMed]
91. Ramírez, J.S. Evaluación de Sistemas de Producción de Maíz (*Zea mays* L.) en Transición a Orgánico y Convencional en El Ejido las Piedras, Huimanguillo, Tabasco, México. Master's Thesis, Colegio de Postgraduados, Tabasco, Mexico, 2009.
92. Valenzuela-Que, F.G.; Villanueva-López, G.; Alcudia-Aguilar, A.; Medrano-Pérez, O.R.; Cámara-Cabrales, L.; Martínez-Zurimendi, P.; Casanova-Lugo, F.; Aryal, D.R. Silvopastoral Systems Improve Carbon Stocks at Livestock Ranches in Tabasco, Mexico. *Soil Use Manag.* **2022**, *38*, 1237–1249. [CrossRef]