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Article

Driving sustainable agroforestry through carbon credit-based policies: Realities and perspectives

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Abstract: Carbon credit-based policies are important to driving sustainable practices worldwide. These policies have in the past focused mainly on wetlands, forests, and other ecosystems, neglecting agroforestry—which is a climate-smart and agroecological practice. This paper therefore seeks to examine how carbon credit-based policies can drive sustainable agroforestry through an in-depth empirical review of literature. It was found that the most common carbon credit-based policies and schemes are government-led, including the CCER (China Certified Emissions Reduction), ETS (EU Emissions Trading System), and the California Global Warming Solutions Act in the United States of America. These schemes focus on heavy emitters such as transportation, steel, and cement. Carbon credits guiding carbon credit-based policy formulation and implementation are mainly: Credits from avoided emissions (not cutting down trees); credits from reduced emissions (energy-efficient technologies); and credits from removed emissions (tree planting and carbon capture tech). Factoring in these 03 main types of carbon credits into the carbon credit policy framework will drive sustainable agroforestry across the world in general and the developing world in particular, as smallholder agroforestry farmers will be encouraged to practice agroforestry. One of the main stumbling blocks to the practice of agroforestry is the financial cost involved in its establishment and management, which the carbon credit scheme would offset. Besides driving sustainable agroforestry, carbon credit-based policies in the domain of agroforestry would provide other co-benefits such as employment generation; technology transfer; improved energy security and access to energy services; improved livelihoods; improved air, water, or soil quality; and infrastructure development.

Keywords: smallholders; farmers; climate change; carbon emissions; governance

1. Introduction

Carbon policies, such as carbon taxes and cap-and-trade systems, are widely promoted to mitigate greenhouse gas emissions. However, these policies come with notable downsides, particularly for developing countries, and face technical challenges in implementation. Carbon policies can disproportionately affect developing nations. These countries often rely on fossil fuels for energy and industrial growth, and imposing carbon taxes or emission caps may hinder economic development. Aldy et al. [1] and Stern and Stiglitz [2] argue that carbon pricing mechanisms often fail to account for historical emissions, placing an undue burden on nations with lower per capita emissions. Developing economies may lack the financial resources and technological infrastructure to transition rapidly to low-carbon alternatives, exacerbating inequalities. Carbon policies are not the sole mechanism to reduce emissions. Alternative strategies, such as technology transfer, reforestation projects, and sector-specific energy efficiency programs, may offer more tailored and equitable

solutions. Levenda et al. [3] highlight that integrating renewable energy subsidies and international cooperation can yield significant reductions without disproportionately impacting vulnerable populations. The technical challenges of carbon credit accounting undermine the efficacy of these policies. Issues such as double counting, lack of standardized measurement frameworks, and verification difficulties create barriers to the transparent and accurate implementation of carbon markets. Michaelowa et al. [4] emphasize the problem of "hot air" credits (where countries claim reductions without actual mitigation) leading to weakened environmental outcomes. While carbon policies have merits, their drawbacks, particularly for developing nations, necessitate complementary approaches. Policymakers must address technical accounting challenges and ensure equitable global participation to achieve effective and fair climate action.

Agroforestry is one of the foremost nature-based solutions (NbS) with enormous potential to enhance carbon sequestration, thereby mitigating climate change and providing additional income to agroforestry practitioners through carbon credits [5–7]. Leakey [8] defined agroforestry as a dynamic, ecologically based, natural resource management system that involves the integration of trees in farmland rangeland, diversifies, and sustains smallholder production for increased social, economic, and environmental benefits. Carbon credits in agroforestry systems are an incentive to farmers to take up the practice. Carbon credits have emerged as a critical market-based mechanism to address climate change by incentivizing the reduction of greenhouse gas (GHG) emissions. Essentially, a carbon credit represents the right to emit one metric ton of carbon dioxide equivalent (CO_2e). These credits are integral to both voluntary and compliance-based carbon markets, enabling businesses and governments to achieve their climate goals. In recent years, carbon credit projects in agroforestry systems in both the developed and developing worlds have been used increasingly as a means to increase farmers adoption of agroforestry systems for the provision of environmental benefits such as carbon sequestration and reduced pressure on primary forests [9–11]. These carbon credit-based projects have focused on agroforestry systems such as agrisilvicultural, silvopastoral, and agrisilvipastoral, which are reputed for their provision of different environmental services that can enable agroforestry practitioners to join the carbon market and sell the carbon credits derived from their agroforestry systems [12–13]. For these agroforestry systems to provide substantial carbon credits to farmers and agroforestry practitioners, there is an absolute need for favorable carbon credit-based policies that ease access to the carbon market. The combined efforts of external and internal institutions are needed to place farmers and agroforestry practitioners at the forefront of these carbon credit policies [14].

However, there are few countries globally, namely Canada, the US, and Australia, which have specific carbon credit-based policies [15–23]. These policies aim to decrease agricultural emissions by storing carbon in various sustainable land use systems, such as agroforestry. Farmers adopting and implementing different carbon farming practices, notably agroforestry, benefit from carbon credits under carbon credit-based initiatives/policies [24]. Currently, various carbon projects in East Africa aim to assist farmers and especially those practicing agroforestry in their efforts to mitigate climate change through carbon farming. Examples of these projects include

Livelihoods-Mount Elgon, CARE's Sustaining Agriculture through Climate Change (SACC), Trees for Global Benefits Program, Kenya Agricultural Carbon Project (KACP), Emiti Nibwo Bulora, International Small Group and Tree Planting Program (TIST), and the Humbo Assisted Regeneration Project [25–27].

Among these carbon initiatives, KACP (the Kenya Agricultural Carbon Project) stands out as the pioneering agriculture-based carbon project in Africa. It successfully showcased that adopting and practicing carbon farming methods significantly contributes to greenhouse gas reduction. Moreover, it enhances the resilience of farmers and agroforestry practitioners to climate change at both individual and group levels. Additionally, KACP demonstrates potential benefits such as increased income for farmers and agroforestry practitioners, as well as improved agricultural productivity within agroforestry systems [28–33]. These initiatives have provided financial compensation to farmers and agroforestry practitioners who implement sustainable carbon farming practices on their land. Additionally, some of these projects are involved in REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiatives, along with other renewable energy projects like improved cookstoves [34,35]. Most of the initiatives work mainly with individual farmers/agroforestry practitioners necessitating carbon projects that work with farmers/agroforestry practitioners organized in cooperatives. East Africa, particularly Kenya and Uganda, are working hard to get into the carbon market and obtain carbon credits by promoting carbon farming practices such as agroforestry, which contributes significantly to carbon sequestration and the mitigation of climate change [36]. Better carbon credit-based policies are vital for obtaining maximum carbon credits from agroforestry systems. In light of the foregoing, this study therefore seeks to examine how carbon credit-based policies can drive sustainable agroforestry.

2. Methodology

This study employs a systematic review of empirical literature to explore the realities and perspectives of driving sustainable agroforestry through carbon credit-based policies. The research focuses on synthesizing findings from a diverse set of studies to understand the potential, challenges, and outcomes of integrating carbon credits into agroforestry systems. A total of 150 empirical research papers were selected for inclusion in the study. The literature search was conducted across three primary databases: Google Scholar, Web of Science, and Scopus. These platforms were chosen due to their extensive coverage of peer-reviewed articles, reports, and conference proceedings relevant to the topic. The search process was carried out exclusively in English, using a combination of keywords such as "agroforestry", "carbon credits", "sustainability", "climate policy", and "carbon sequestration". Articles were screened based on their empirical focus, relevance to carbon credit-based agroforestry systems, and availability of sufficient data or insights. Studies were excluded if they lacked a clear empirical basis or focused solely on theoretical or hypothetical frameworks. Key information was extracted from the selected studies, including the geographical focus, methodological approach, key findings, and policy implications. This information was analyzed thematically to identify recurring patterns, contradictions, and gaps in the literature. Special attention was given to

studies that provided insights into real-world applications of carbon credit mechanisms in agroforestry systems, as well as those that evaluated socio-economic and environmental outcomes. The methodology has certain limitations. First, the exclusive use of English-language studies introduces a language bias, potentially omitting valuable insights from non-English publications; Second, reliance on three databases may have resulted in the exclusion of relevant research indexed in other platforms or regional databases; Third, the scope of this review is limited to empirical studies, potentially neglecting theoretical or conceptual work that might provide complementary perspectives; Lastly, the synthesis of findings from diverse contexts may obscure localized nuances and variations in the implementation of carbon credit-based agroforestry policies. Despite these limitations, the study provides a robust foundation for understanding the realities and potential of leveraging carbon credits to promote sustainable agroforestry practices.

3. National Agroforestry Policies: The case of India and Nepal

3.1. National Agroforestry Policy of India

India was the first country in the world to craft and implement a National Agroforestry Policy in 2014, which came to complement the National Forestry Policy implemented in 1988 [37]. The necessity for an agroforestry policy in India arose due to several factors: insufficient institutional mechanisms and a dedicated national policy, absence of integrated farming approaches, restrictive regulatory frameworks, non-liberalization of regulations, inadequate capacity building, research, and extension services, scarcity of quality planting material, limited institutional insurance and financial support, restricted access to markets for agroforestry products, and sub-optimal functioning of wood-based industries that could otherwise support agroforestry initiatives [38–40]. The challenging environment for agroforestry prompted the Indian government and stakeholders in agriculture, forestry, and environmental sectors to develop and implement the National Agroforestry Policy.

India's National Agroforestry Policy aims to establish a National Agroforestry Board or National Agroforestry Mission to effectively implement its objectives. These include enhancing rural livelihoods, productivity, income, and employment opportunities while meeting the growing demand for timber, fiber, food, fertilizer, fodder, and fuel, alongside ensuring environmental protection and sustainability. The policy also focuses on expanding and promoting tree planting in agricultural and livestock systems to boost productivity, livelihoods, and employment while conserving ecosystems and promoting climate-resilient farming practices. It aims to reduce wood imports, meet raw material needs for wood-based industries, and alleviate pressure on natural forests by increasing production of agroforestry products like non-timber forest products, fuelwood, small timber, and fodder. Additionally, the policy targets enhancing ecological stability through increased forest and tree cover, and strengthening research and capacity building in agroforestry.

To achieve the objectives of India's National Agroforestry Policy, various strategies have been implemented. These include establishing national-level institutions (such as missions or boards within the Ministry of Agriculture, with participation from entities like the South Asian Office of the World Agroforestry

Centre, Ministry of Environment and Forest, National Rainfed Area Authority, Ministry of Rural Development, Planning Commission, Ministry of New and Renewable Energy), along with representatives from non-governmental organizations, state governments, industry, agricultural universities, and the National Bank for Agriculture and Rural Development (NABARD). Other strategies involve simplifying regulatory mechanisms to facilitate the harvesting and transportation of agroforestry products within states. This includes integrating decentralized local governance institutions such as Joint Forest Management Committees, GramSabhas, and Eco-Development Committees into the regulatory framework.

Efforts also focus on developing robust information systems and databases, particularly concerning land tenure security and agroforestry systems. Investments are made in capacity building, research, and extension services, coordinated by the National Research Centre for Agroforestry (NRCAF). Access to high-quality planting materials for farmers is enhanced through the certification of seeds, nurseries, and planting materials, including involvement from the private sector. Institutional-level insurance and credit are provided to support agroforestry, particularly through farmers' organizations. Industries engaged in agroforestry products, especially wood-based industries, are integrated into Corporate Social Responsibility programs. Other initiatives/strategies include establishing marketing infrastructure to facilitate farmers' access to tree product markets, increasing private sector participation, and promoting agroforestry adoption through incentives, primarily facilitated through farmers' organizations. Emphasis is also placed on promoting sustainable agroforestry for renewable biomass energy, focusing on planting fast-growing trees on degraded and marginal lands [41].

The pathways to achieving India's National Agroforestry Policy goals include integrating agroforestry into agriculture strategies and policies, establishing a fund to leverage resources from various programs and schemes, simplifying legislation related to forestry, land tenure, and land use to create a supportive environment, identifying the 20 most commonly grown tree species on farmlands to streamline regulatory frameworks, ensuring land tenure security nationwide, fostering public-private partnerships in agroforestry, providing certified planting material locally, improving data collection on agroforestry systems and products, boosting research in both private and government sectors, upgrading national agroforestry centers, expanding extension services, incorporating agroforestry into school curricula to promote youth engagement in tree planting and conservation, empowering the National Bureau of Plant Genetic Resources (NBPGR) to manage agroforestry species, enhancing marketing infrastructure and market information systems, offering more incentives and insurance for agroforestry farmers and their products, establishing carbon credit schemes for agroforestry, and encouraging wood-based and food-based industries to support agroforestry initiatives [42,43].

3.2. National Agroforestry Policy of Nepal

In the wake of India's National Agroforestry Policy in 2014, Nepal crafted and implemented her own National Agroforestry Policy in 2019 [44]. Nepal's National Agroforestry Policy was influenced by existing strategies and policies within the

country, such as the Forestry Sector Strategy (2016–2025), the Agriculture Development Strategy (implemented in 2014), and the National Forestry Policy (implemented in 2018). Various challenges in Nepal's agroforestry sector prompted the government to develop and implement this policy. Key challenges included insufficient technological expertise, limited land ownership among families, inadequate adoption of advanced technologies, predominance of small and medium-scale farmers, absence of livelihood-oriented farming systems, soil fertility decline, scarcity of quality seeds and planting materials, limited research and extension on suitable agroforestry species, lack of technical and financial support, challenges in selecting site-specific agroforestry species, difficulties in developing, protecting, and promoting agriculture in protected and forest adjacent areas, issues related to livelihood and food security, rural migration especially among young people, limited employment opportunities, gender disparities, and complex procedures for harvesting, transporting, and marketing trees grown outside forest areas [45–47].

These challenges prompted the formulation of Nepal's National Agroforestry Policy. This policy aims to simplify procedures for planting, harvesting, transporting, and marketing tree species grown outside forests. It seeks to integrate agroforestry throughout Nepal, promote a participatory approach involving various programs, policies, and stakeholders; enhance research and extension services in agroforestry; expand agroforestry systems across different agroecological zones in Nepal; improve livelihoods for farmers in general and those practicing agroforestry in particular; provide technical and financial support to advance agroforestry and its products; increase the availability of high-quality planting materials for agroforestry; enhance market infrastructure and value chains while encouraging agroforestry-based industries; and facilitate agroforestry-based credit and insurance schemes.

The vision of Nepal's National Agroforestry Policy is to contribute towards developing, expanding, and marketing agroforestry products, thereby enhancing national prosperity [48]. The primary goals of the policy include boosting the production of livestock, agricultural, and forest products while promoting the versatile use of land. It aims to conserve biodiversity and the environment to alleviate pressure on natural forests and enhance ecosystem resilience to climate change. Additionally, the policy seeks to generate income, livelihoods, and employment opportunities, ensuring food security through the promotion of agroforestry. It aims to contribute to sustainable development and economic growth by creating marketing and investment opportunities in agroforestry. Furthermore, the policy aims to enhance capacity building and research in the field of agroforestry.

To achieve the objectives of Nepal's National Agroforestry Policy, several strategies have been implemented. These include focusing on commercial activities in agroforestry through specialized programs in landscapes without natural forests, establishing cooperatives, and improving infrastructure for transportation and distribution of agroforestry products. Additionally, efforts are underway to enhance research on value chains and farmers' access to markets by developing business plans and promoting cooperatives, particularly for non-timber forest products derived from agroforestry. The policy also aims to boost agroforestry-based industries by promoting the use of local agroforestry products and establishing information networks for raw materials. Financial incentives are provided to the agroforestry sector through

initiatives such as distributing quality planting material, offering loan and insurance schemes, providing low-interest and concessional loans, and exempting interest on loans.

There is a focus on prioritizing agroforestry systems on degraded, barren, and fallow lands by developing site-specific models, selecting appropriate agroforestry species, managing information systems, facilitating registration processes, and streamlining establishment procedures. Site-specific agroforestry models are also being developed to enhance the production of cereals, fruit trees, pulses, fisheries, livestock, oilseed crops, tea, coffee, and systems for flood and landslide control. Capacity building, research, and dissemination of agroforestry systems are emphasized through training, technical support services, and awareness campaigns. Budget planning, monitoring, and evaluation programs are being developed to oversee agroforestry initiatives at national, provincial, and local levels [49]. The strategies outlined in Nepal's National Agroforestry Policy are executed through the Agroforestry Inter-Ministerial Coordination Committee (AFIMCC), led by relevant ministries like the Ministry of Agriculture and Livestock Development and the Ministry of Forests and the Environment. The policy is supported by financial commitments and legal frameworks that ensure its comprehensive implementation.

4. General overview and typology of carbon credit-based policies for emissions trading schemes

Carbon credits have emerged as a critical market-based mechanism to address climate change by incentivizing the reduction of greenhouse gas (GHG) emissions. Essentially, a carbon credit represents the right to emit one metric ton of carbon dioxide equivalent (CO_2e). These credits are integral to both voluntary and compliance-based carbon markets, enabling businesses and governments to achieve their climate goals. The concept of carbon credits is rooted in the Kyoto Protocol of 1997 and later expanded under the Paris Agreement of 2015, both of which underscore the global commitment to reducing emissions [50–51]. Carbon credits are designed to create economic incentives for reducing GHG emissions. The principle relies on the idea that it is often more cost-effective for some entities to reduce emissions than others. By purchasing carbon credits, organizations unable to reduce their emissions can finance projects elsewhere that achieve the same environmental benefit [52]. This approach aligns with the concept of "additionality", meaning the reductions would not have occurred without the credit-financed intervention [53]. Carbon credits can be used in two main markets, which are compliance markets and voluntary carbon markets. Compliance markets are regulated by governments or international agreements. Examples include the European Union Emissions Trading System (EU ETS) and the California Cap-and-Trade Program. Entities are given or must purchase allowances, and if they exceed their caps, they must buy credits or face penalties [54]. Meanwhile, voluntary carbon markets are unregulated markets where companies or individuals voluntarily purchase credits to offset their emissions. Voluntary markets are driven by corporate social responsibility goals or consumer pressure [55].

Carbon credits can be obtained through various mechanisms, which involve either creating or purchasing them. The most prominent of these mechanisms are

emission reduction projects, carbon removal projects, purchasing credits, and participating in compliance schemes. In the case of emission reduction projects, organizations can develop projects that directly reduce or avoid GHG emissions. Common examples include renewable energy installations (solar or wind), methane capture from landfills, and energy efficiency programs [56]. Credits from these projects must undergo rigorous verification by third-party certifiers such as Verra or the Climate Action Reserve. Carbon removal projects involve actively removing CO_2 from the atmosphere. Techniques include afforestation, reforestation, and soil carbon sequestration. Emerging technologies like direct air capture (DAC) are also gaining traction [57]. For purchasing credits, companies can buy carbon credits directly from project developers or through brokers and exchanges like the Chicago Climate Exchange (CCX) or the AirCarbon Exchange (ACX). Meanwhile, for participation in compliance schemes, entities in jurisdictions with cap-and-trade systems can acquire credits through auctions, trading, or government allocation. Despite their potential, carbon credits face challenges, including concerns over double counting, lack of standardization, and questions about the permanence of carbon sequestration projects [58,59]. However, advancements in digital tools, such as blockchain, and growing regulatory oversight aim to address these issues. Carbon credits, therefore, represent a dynamic tool for climate mitigation, offering both opportunities and complexities. As the global community strives to meet the 1.5 ℃ target, these mechanisms will likely play a pivotal role in aligning economic activities with environmental sustainability.

The predominant carbon credit policies are typically initiated by governments and center around emissions trading schemes, including the China Certified Emissions Reduction (CCER) program, the California Global Warming Solutions Act in the United States, and the EU Emissions Trading System (ETS) (**Table 1**). Many countries in the world are now operating country-based carbon credit schemes. These schemes focus on heavy emitters such as transportation, steel, and cement. However, there are also carbon credit-based policies/schemes that are a mix of government- and non-government-led, such as the Clean Development Mechanism (CDM).

Table 1. Typology of carbon credit-based policies for emissions trading schemes.

Type of emissions trading scheme	Type of carbon credit-based policy	Country/Region	References
Programs based on credits to reduce carbon dioxide (CO_2) emissions from existing power plants	Government led	The United States of America	[60]
Credit-based incentive mechanism (CBIM)	Non-government led	Global	[61]
Green credit	Government-led	China	[62]
Voluntary United States-based CO_2 offset trades	Non-government led	The United States of America	[63]
Canadian ETS	Government led	Canada	[64]
Clean Development Mechanism (CDM)	Government and non-government led	Global	[65]
Green credit	Government led	China	[66]
Carbon capture and utilization (CCU) projects that encompass various initiatives such as the regional greenhouse gas initiative, 45Q tax credit, loan guarantee programs, green bonds, and low carbon fuel standards	Government led	United States of America	[67]
The dual-credit policy (DCP)	Government and non-government led	Global	[68]

Table 1. (*Continued*).

Type of emissions trading scheme	Type of carbon credit-based policy	Country/Region	References
Clean Development Mechanism (CDM)	Government and non-government led	Global	[69]
Output-based carbon credits	Government led	Global	[70]
ETS	Government led	Global	[71]
ETS	Government led	United States of America	[72]
EU ETS	Government led	EU	[73]
Clean Development Mechanism (CDM)	Government and non-government led	Global	[74]
EU ETS	Government led	EU	[75]
The tradable credit scheme (TCS)	Government led	Global	[76]
Green credit	Government led	China	[77]
Green credit	Government led	China	[78]
EU ETS	Government led	Finland	[79]

Good policies are key to the proper functioning of emissions trading schemes. However, Policy makers must formulate and implement policies that factor in the following: carbon pricing policies, including emissions trading systems and carbon taxes, which incentivize investments in clean technology, effectiveness, and cost-effectiveness, are the best instruments; require proper designing, taking into cognizance the policy's comprehensiveness, its ability to raise revenue, capacity for use in socially productive ways, a fluid credit trading market, and price stability provisions for emissions trading systems; are extremely challenging to implement carbon pricing policies owing partly to burdens on trade-sensitive industries and households; and require careful design of packages of regulations as a reasonable alternative in the absence of carbon pricing. The regulations packages should exploit mitigation opportunities across all sectors and must ensure extensive credit trading to limit costs and circumvent the need for credit trading by combining several feebates (subsidy/tax policies); isolated policies such as renewable mandates are not a good substitute for comprehensive feebate/regulatory packages or carbon pricing.

Thus, the main alternative policy instruments to mitigate carbon dioxide emissions include carbon taxes; cap-and-trade systems; excise taxes on electricity, vehicles, and individual fuels such as coal; energy efficiency standards; emissions standards; incentives for renewable fuels; feebates; and regulatory combinations. However, Policy makers must consider the following when resorting to these alternative policy instruments to mitigate carbon dioxide emissions: effectiveness, economic costs, ability to deal with uncertainty, distributional impacts across industries and income groups, and the promotion of clean technology development and deployment.

A case-by-case study of government-led carbon credit-based policies/schemes for emissions trading schemes across the world, particularly in China, the EU, and the United States of America, reveals that these schemes are the right path to take for an effective net zero transition (**Table 2**).

Table 2. Government led carbon credit-based policies for emissions trading schemes.

Government-led carbon credit-based policy/schemes	Country/Region	References
The China Certified Emissions Reduction (CCER) scheme	China	[80] [81] [82] [83] [84] [85] [86] [87] [88] [89] [90] [91] [92] [93] [94] [95] [96] [97] [98] [99]
EU ETS	European Union	[100] [101] [102] [103] [104] [105] [106] [107] [108] [109] [110] [111] [112] [113] [114] [115] [116] [117] [118]
The California Global Warming Solutions Act in the United States of America	United States of America	[119] [120] [121] [122] [123] [124] [125] [126] [127] [128] [129] [130] [131] [132] [133] [134] [135]

China's carbon market is primarily characterized by the national emission trading scheme, which became fully operational in 2021, and the CCER, which started

operating in 2012. The National ETS and the CCER work in synergy and mainly target projects in energy-efficient improvements, forestry, methane capture, and renewable energy. The main financial institution that provides infrastructure for registration, listing, trading, and settlement of CCER is the China Beijing Green Exchange (CBGEX). In July 2023, China's Ministry of Ecology and Environment approved multiple initiatives, including the "Administrative Measures for the Greenhouse Gas Voluntary Emission Reduction Trading," which has bolstered confidence in the CCER program.

The EU ETS was formally implemented in 2005 and has since become a pivotal tool for cost-effectively reducing greenhouse gas emissions within the EU, playing a leading role in the region's efforts to combat climate change. It was the world's first major carbon market and currently ranks alongside China's CCER as the largest carbon market globally. The EU ETS operates across all European Union countries and includes the EEA-EFTA states of Iceland, Norway, and Liechtenstein. It requires polluters to pay for their greenhouse gas emissions, facilitating emission reductions while generating revenue to fund the EU's green transition. Starting in 2024, the EU ETS will also encompass maritime transport emissions, alongside emissions from approximately 10,000 installations in the manufacturing and energy sectors [136]. The scheme also covers aircraft operators flying within the EU and to the United Kingdom and Switzerland, which collectively account for about 40% of emissions in the EU [137].

The California Global Warming Solutions Act, enacted in 2006 in the United States, aims to enhance cost savings for California households and improve energy efficiency. It also strives to reduce greenhouse gas emissions, foster the creation of green jobs, and increase investments in clean technologies. The Act specifically targets various greenhouse gases emitted in California, including Sulfur hexafluoride (SF_6), Hydrofluorocarbons (HFCs), Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Perfluorocarbons (PFCs), and Nitrogen trifluoride (NF_3). Implementation of the Act is primarily overseen by the California Air Resources Board (CARB), supported by the Climate Action Team, which comprises multiple state agencies such as the California Transportation Agency, California Public Utilities Commission, and California Environmental Protection Agency, among others. In addition to the California Global Warming Solutions Act, key assembly and senate bills and policies addressing climate change issues in California include Assembly Bill 341, Assembly Bill 1493, Senate Bill X1-2, Senate Bill 375, and Senate Bill 535.

5. Carbon credit systems guiding carbon credit-based policy formulation and implementation

The types of carbon credits guiding carbon credit-based policy formulation and implementation include credits from avoided emissions (not cutting down trees), credits from reduced emissions (energy-efficient technologies), and credits from removed emissions (tree planting and carbon capture technologies) (**Table 3**).

Table 3. Carbon credit systems guiding carbon credit-based policy formulation and implementation.

Type of carbon credit system guiding credit-based policy formulation and implementation	Country/Region	References
Credits from avoided emissions (not cutting down trees)	United States of America	[138]
Credits from removed emissions (tree planting and carbon capture technologies)	Global	[139]
Credits from reduced emissions (energy-efficient technologies)	China	[140]
Credits from reduced emissions (energy-efficient technologies)	European Union	[141]
Credits from reduced emissions (energy-efficient technologies)	Global	[142]
Credits from reduced emissions (energy-efficient technologies)	Global	[143]
Credits from removed emissions (tree planting and carbon capture technologies)	United States of America	[144]
Credits from removed emissions (tree planting and carbon capture technologies)	China	[145]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies); Credits from reduced emissions (energy efficient technologies)	EU and China	[146]
Credits from reduced emissions (energy-efficient technologies)	China	[147]

As shown in **Table 3**, carbon credits that guide policy formulation and implementation are credits from avoided emissions, credits from reduced emissions, and credits from removed emissions. Carbon avoidance is an action geared towards preventing the occurrence of carbon-emitting activities, e.g., by not cutting down trees. Carbon reduction is an action geared towards decreasing greenhouse gas emissions compared to prior practices, e.g., through the use of energy-efficient technologies. Carbon removal encompasses activities focused on extracting carbon dioxide from the atmosphere and storing it for extended periods, ranging from decades to millennia. Examples include tree planting and employing carbon capture technologies such as chemical absorption (e.g., amine-based solvents); physical absorption (e.g., pressure swing adsorption); membranes for gas separation; physical solvents (e.g., Selexol or Rectisol); adsorption techniques; membrane separation; cryogenic air separation units; CO2 compression and purification units; chemical absorbents (e.g., hydroxides); solid sorbents; Emerging DAC companies: Climeworks, Carbon Engineering; industrial carbon capture; afforestation and reforestation; soil carbon sequestration; biochar application; Bioenergy with Carbon Capture and Storage (BECCS); as well as carbon mineralization.

6. Carbon credit-based schemes/policies and the promotion of agroforestry

Factoring in these carbon credits into the carbon credit policy framework will drive sustainable agroforestry across the world in general and the developing world in particular, as smallholder agroforestry farmers will be encouraged to practice agroforestry (**Table 4**). One of the main stumbling blocks to the practice of agroforestry is the financial cost involved in its establishment and management, which the carbon credit scheme would offset [148]. Besides driving sustainable agroforestry, carbon credit-based policies in the domain of agroforestry would provide other co-benefits such as employment generation; technology transfer; improved energy

security and access to energy services; improved livelihoods; improved air, water, or soil quality; and infrastructure development.

Table 4. Carbon credit-based schemes/policies and the promotion of agroforestry.

Type of carbon credit schemes/policies	Type of agroforestry system promoted	Country/region	References
Credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Ghana	[149]
Credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	United States of America	[150]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	India	[151]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Teak woodlots	Laos, Thailand, and Vietnam	[152]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Kenya	[153]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Costa Rica	[154]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[155]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[156]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[157]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	India	[158]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Canada	[159]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[160]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[161]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	China	[162]
Credits from reduced emissions (energy-efficient technologies); credits from avoided emissions (not cutting down trees)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[163]

Table 4. (*Continued*).

Type of carbon credit schemes/policies	Type of agroforestry system promoted	Country/region	References
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Global	[164]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	India	[165]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	Nepal	[166]
Credits from avoided emissions (not cutting down trees); credits from removed emissions (tree planting and carbon capture technologies)	Agrisilvicultural, silvipastoral and agrisilvopastoral systems	European Union	[167]

7. Conclusion

This study investigates the potential of carbon credit-based policies to promote sustainable agroforestry, a critical yet often overlooked climate-smart and agroecological practice. While such policies have historically concentrated on wetlands, forests, and other ecosystems, agroforestry remains underutilized in the global push for climate resilience. This paper underscores the need to integrate agroforestry into the framework of carbon credit schemes to realize its vast environmental, social, and economic benefits. The study highlights that carbon credit-based policies, such as the CCER (China Certified Emissions Reduction), ETS (EU Emissions Trading System), and California's Global Warming Solutions Act, have primarily targeted heavy emitters like transportation and industrial sectors. These policies derive their effectiveness from three main types of carbon credits: those from avoided emissions (e.g., preventing deforestation), reduced emissions (e.g., energy-efficient technologies), and removed emissions (e.g., afforestation and carbon capture). Incorporating these credit types into agroforestry-focused policies could encourage smallholder farmers, especially in developing countries, to adopt agroforestry practices by offsetting the financial barriers associated with their establishment and management. While the findings point to significant co-benefits, including employment generation, technology transfer, enhanced energy access, improved livelihoods, and better environmental quality, several challenges persist. These include limited financial resources, inadequate policy frameworks, and a lack of robust monitoring and verification systems for agroforestry-related carbon sequestration. Moreover, there is a need to bridge the gap between smallholder farmers and global carbon markets to ensure equitable participation and benefits. To address these challenges, researchers and policymakers must prioritize the development of inclusive carbon credit mechanisms tailored to agroforestry. Future research should focus on quantifying the carbon sequestration potential of various agroforestry systems and identifying scalable models that integrate local ecological and socio-economic contexts. Policymakers should work towards simplifying access to carbon markets, enhancing financial support, and establishing transparent monitoring frameworks to build trust and participation among stakeholders.

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