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Agricultural Policy Planning for Carbon Emission Reduction in Taiwan

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ABSTRACT

The greenhouse effect drives climate change and extreme weather, threatening environmental sustainability, human survival, food security, economic stability. Reducing atmospheric carbon dioxide (CO_2) and decoupling greenhouse gas (GHG) emissions from economic growth are global priorities. To stabilize GHG concentrations and prevent further climate disruption, the Paris Agreement requires countries to set Nationally Determined Contributions (NDCs) for climate action. Nature-based Solutions (NbS), including green carbon stored in trees(forest), yellow carbon in soil, and blue carbon in marine ecosystems, are increasingly recognized for their dual role in mitigating GHGes and enhancing human well-being and ecosystem services. Although Taiwan's agriculture sector accounted for only 1.17% (29 kt CO_2 e) of the nation's total GHG emissions in 2020, their remains the only measurable sector for carbon sink evaluation, making it pivotal to Taiwan's Net-Zero Emission goals. On World Earth Day, 22 April 2021, the Government of Taiwan announced its commitment to achieving net-zero emissions by 2050. Subsequently, in March 2022, Taiwan formally unveiled "Taiwan's Pathway to Net-Zero Emissions in 2050." The four major transition strategies encompass "energy transition," "industrial transition," "lifestyle transition," and "social transition," while the two major governance foundations focus on "technological research and development" and "climate legislation." Therefore, the Ministry of Agriculture will accomplish the goal of net-zero emissions by 2040 and has set out 19 strategies and 59 measures under the four major aspects of "reduction of carbon emission," "enhancement of carbon sink," "circular agriculture," and "green trend." Moreover, the Green Payments Program, Organic Agriculture Promotion Act, Regulations for Subsidies Program of Organic Agricultural Production and so on are used to reach the goal. As the Taiwan Agricultural Research Institute of the Ministry of Agriculture hosts the "Internationalization Mechanism Coordination and Establishment Project for Taiwan's Agricultural Carbon Credits," three "Agricultural Carbon Reduction Methodology Seminars" were organized, and draft methodologies were presented. This study reviews relevant literature and official documents to analyze the agricultural sector's strategic plan, technology, policy, and incentives for reducing GHG emissions. Consequently, this study proposes recommendations for Taiwan's future policy planning. These recommendations encompass improving GHG emission inventories, planning recommendations for carbon credit trading within the agricultural sector, emission reduction in rice planting and the livestock industry, increasing agricultural land emission reduction, forest carbon credits, reducing emissions in fisheries, and conducting an inventory of agricultural GHG emissions. However, trading carbon credits from these sinks offers a lucrative business model for agricultural carbon reduction. Furthermore, increasing soil carbon sequestration, organic farming, and sustainable practices are crucial not only for reducing GHG emissions but also for sustainable agricultural production. The government is incentivizing agricultural carbon reduction through carbon credit programs. The Taiwan Carbon Solution Exchange (TCX), established in August 2023, facilitates carbon credit trading. Current

credits primarily come from non-agricultural sources. To stay competitive, Taiwan must enhance its agricultural carbon credit systems and align with international markets. Developed countries' carbon regulations encourage improvements and protect local enterprises. Taiwan needs robust carbon credit certification and trading systems to integrate into the global market.

Keyword: Net-Zero Emissions, Agricultural Policy, Carbon-negative Strategies, Nature-based Solutions.

INTRODUCTION

The rapid advancement of industry and technology has yielded favorable outcomes for economic expansion and the enhancement of human convenience. However, akin to water's dual nature as a blessing in the desert yet a curse to a drowning individual, these advancements have engendered adverse environmental consequences. These include extensive exploitation and depletion of natural resources, degradation of the Earth's ecosystem, exacerbation of the greenhouse effect, and resultant global warming. As delineated in the Sixth Assessment Report (AR6) by the United Nations Intergovernmental Panel on Climate Change (IPCC) (2023), the greenhouse effect poses significant threats to environmental equilibrium, human sustenance, food security, and socioeconomic progress. Consequently, initiatives aimed at mitigating the escalating concentration of CO_2 in the atmosphere and decoupling economic growth from greenhouse gas (GHG) emissions (Oberle *et al*. 2019) have emerged as imperative global concerns.

According to the Republic of China's (Taiwan's) national GHG inventory report (Ministry of Environment, 2024), the total GHG emission from 1990 to 2022 is between 250 and 300 Mt CO_2e (Figure 1). The energy sector has the highest emissions, followed by the industrial process & product use sector. However, these two sectors are closely tied to national economic development, and reducing carbon emissions could impact the nation's economy and people's livelihoods. Carbon reduction measures within these sectors alone cannot achieve the goal of net-zero emissions. A broader strategic approach is needed. On the other hand, the LULUCF (Land Use, Land-Use Change, and Forestry) sector continues to provide a carbon sink of approximately 22Mt CO_2e annually, demonstrating the carbon reduction potential of NbS. Currently, in the national GHG inventory report, only forest carbon sinks are calculated (Ministry of Environment, 2024), while agricultural land carbon sinks are not yet included in the accounting. This not only leads to an underestimation of carbon sequestration in the LULUCF sector but also overlooks the potential carbon sink enhancement through improved agricultural management practices that could contribute to achieving net-zero emissions.

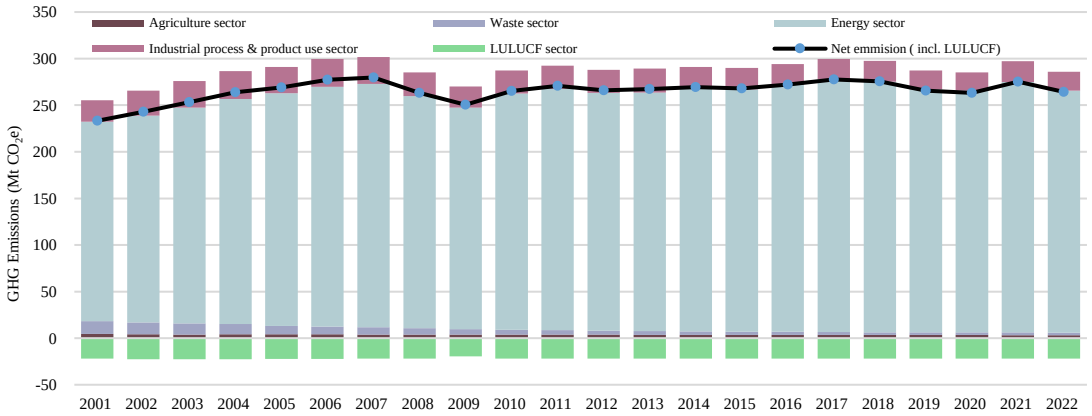

Figure 1. Taiwan's GHG Emissions by Sector from 1990 to 2022
Data source: Ministry of Environment (2024)

In response to the Nature-based Solutions (NbS) initiative introduced by the World Bank (WB) in 2008 as a means to mitigate GHG emissions and address climate change, the International Union for Conservation of Nature (IUCN) proposed the IUCN Global Standard for Nature-based Solutions. This standard delineates NbS as strategies encompassing the conservation, sustainable utilization, management, and restoration of natural ecosystems, while also emphasizing their role in addressing societal challenges and effectively enhancing human well-being and biodiversity. Concurrently, NbS has garnered recognition in the Glasgow Climate Pact as a pivotal approach for mitigating the impacts of the greenhouse effect.

Aligned with this global trajectory, Taiwan announced on the 2021 World Earth Day its commitment to achieving net-zero emissions by 2050 (Executive Yuan, 2023). Subsequently, in March of the following year, Taiwan formally unveiled "Taiwan's Pathway to Net-Zero Emissions in 2050," providing a comprehensive roadmap and actionable steps toward achieving this ambitious goal (National Development Council, 2022b). Furthermore, by year-end, Taiwan released 12 Key Strategies (National Development Council, 2022a) focusing on energy, industry, and lifestyle transitions to proactively address significant sectors and formulate concrete action plans for realizing the objectives of the Net-Zero Transition.

This study presents recommendations aimed at addressing the challenges related to national GHG inventories and carbon offsetting within Taiwan's agriculture sector. The primary objective is to achieve a reduction in agricultural GHG emissions to achieve net-zero emission targets while simultaneously safeguarding food security.

POLICIES AND INCENTIVE MECHANISMS FOR REDUCING EMISSIONS AND INCREASING CARBON SINK

In 2020, Taiwan's agriculture sector contributed 1.17% (29 kt CO_2 e) of the nation's total GHG emissions (Figure 2). Despite the relatively low proportion of GHG emissions originating from agriculture, the imperative to address carbon reduction within this sector is underscored by considerations of food security (Kim *et al*., 2021). Additionally, the GHG Inventories report highlights that the agriculture sector stands out as the sole measurable sector for carbon sink evaluation. Consequently, maximizing the agricultural sector's capacity to serve as a carbon sink is paramount. Developing a low-carbon agriculture industry to augment its capacity for carbon sequestration is crucial in advancing towards the country's net-zero emissions goal. Leveraging the inherent advantages of agriculture to enhance carbon sinks represents a pivotal strategy for Taiwan to navigate towards achieving net-zero emissions.

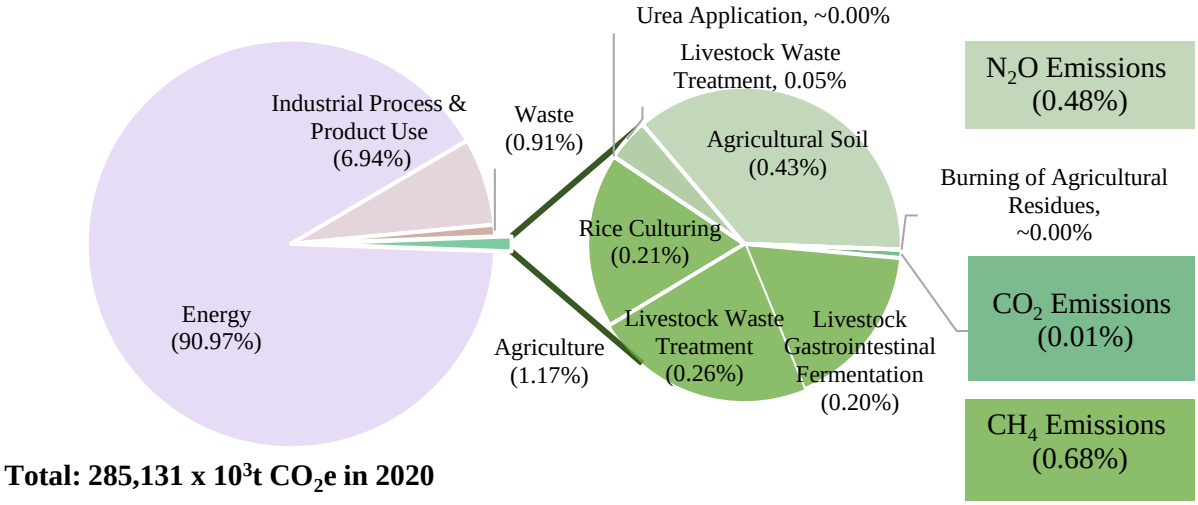

Figure 2. Taiwan's GHG emissions per sector in 2020
Data source: Ministry of Environment (2022)

Superior plan

Taiwan's commitment to achieving net-zero carbon emissions has been embedded in the second phase of the National Climate Change Adaptation Action Plan since 2013. On March 10, 2022, Taiwan officially unveiled "Taiwan's Pathway to Net-Zero Emissions in 2050," delineating four major transition strategies and two governance foundations as the cornerstone for achieving net-zero emissions (National Development Council, 2022b). Subsequently, in December of the same year, "12 Key Strategies for Taiwan's 2050 Net-Zero Transition" was released (National Development Council, 2022a). These strategies elucidate the essential pathways derived from the four major transition strategies and two

governance foundations, serving as a comprehensive master plan to guide Taiwan toward its net-zero emissions target by 2050.

The 1st National Climate Change Adaptation Action Plan (2013-2017)

The first phase of the National Climate Change Adaptation Action Plan was dedicated to establishing a robust foundation for climate change adaptation in Taiwan. It entailed the evaluation of climate change risks, formulation of adaptation plans, and promotion of these plans particularly in high-risk regions. This comprehensive action plan is comprised of various sector-specific initiatives including the Disaster Action Plan, Basic Infrastructure Action Plan, Water Resources Action Plan, Land Action Plan, Coastal Action Plan, Energy Supply and Industry Action Plan, Agricultural Production and Biodiversity Action Plan, and Public Health Action Plan. Within the realm of agricultural production and biodiversity, the focus was on conducting vulnerability analyses, assessing impacts, and devising eight distinct adaptation strategies. These strategies were supplemented with specific adaptation measures outlined within the action plans. Agricultural production encompassed activities related to the domestic cultivation and provisioning of crops, livestock, fisheries, and forestry resources. Biodiversity considerations extend to the preservation of species diversity and genetic resources of living organisms, along with the ecosystems crucial for their sustenance. This included various ecosystems such as forests, river and freshwater wetlands, coastal and saltwater wetlands, and marine environments.

The 2nd National Climate Change Adaptation Action Plan (2018-2022)

The second phase of the National Climate Change Adaptation Action Plan is primarily anchored in the framework provided by the Greenhouse Gas Reduction and Management Act, leveraging insights gleaned from the outcomes of the initial National Climate Change Adaptation Action Plan (2013-2017). This phase places greater emphasis on capacity building, encompassing a more holistic approach to fortify the country's overall readiness to address climate change. Within this phase, the focus on agricultural production and biodiversity not only continues from the previous phase but is also augmented by efforts to enhance long-term monitoring and early warning systems. Additionally, there is an integration of technological advancements to bolster response capabilities. Furthermore, efforts are directed towards the refinement of disaster relief and insurance systems. Concurrently, the phase aims to strengthen food security measures and bolster initiatives aimed at conserving biodiversity.

Taiwan's pathway to net-zero emissions in 2050

On March 10, 2022, Taiwan's government introduced "Taiwan's Pathway to Net-Zero Emissions in 2050," which outlines four primary transition strategies and two key governance foundations to guide the nation toward achieving net-zero emissions. The four major transition strategies include Energy Transition, Industrial Transition, Lifestyle Transition, and Social Transition, while the two major governance foundations refer to Technological Research and Development, and Climate Legislation. The four transition strategies encompass Energy Transition, which focuses on transforming the energy system to renewable sources; Industrial Transition, which promotes green manufacturing and circular economy in the manufacturing sector, the commercial sector, the building sector, and the transportation sector; Lifestyle Transition, which encourages sustainable consumption patterns and low-carbon living; and Social Transition, which is to build a social support system to realizing just transition and civic engagement. These strategies are supported by two crucial governance foundations: Technological Research and Development, which drives innovation in clean energy and carbon reduction technologies, and Climate Legislation, which establishes the necessary legal framework and carbon pricing mechanisms (National Development Council, 2022b). In particular, it is pointed out that in order to achieve net-zero carbon emissions and to take into account the country's economic development, the carbon emissions that are difficult to reduce must be offset by forest carbon sinks and carbon-negative technologies. Notably, the pathway emphasizes the necessity of offsetting carbon emissions that are challenging to mitigate while also considering the country's economic development. Forest carbon sinks and carbon-negative technologies are highlighted as crucial means to achieve this offsetting. Although agriculture is not explicitly mentioned within the delineated transitions, it remains an essential sector in the pursuit of net-zero emissions.

The 12 key strategies for Taiwan's net-zero transition

The 12 Key Strategies derived from the four major transition strategies and the two governance foundations encompass a range of initiatives including wind/solar photovoltaic (PV), hydrogen, innovative energy, power systems and energy storage, energy saving and efficiency, Carbon Capture, Utilization & Storage (CCUS), carbon-free & electric vehicles, resource recycling & zero waste, natural carbon sinks, green lifestyle, green finance, and just transition (National Development Council 2022a).

Among these strategies, resource recycling & zero waste and natural carbon sinks are categorized under agricultural net-zero strategies. Under resource recycling & zero waste, 190,000 tons of agricultural waste generated from farming, livestock production, and fisheries are allocated to biomass, organic chemicals, metals and chemicals, and inorganic recycled pellets. This approach facilitates waste recycling, thus contributing to a circular economy by reusing, fueling, and fertilizing of agricultural by-products.

Regarding natural carbon sinks, the focus is on enhancing the efficiency of carbon sequestration across three primary domains: forests/green carbon, soils/yellow carbon, and marine/blue carbon. Forest carbon sequestration strategies entail increasing forest area, improving forest management practices, and maximizing the utilization of domestic timber products. The forest coverage expansion strategy aims to achieve 12,600 hectares of afforestation and increase CO_2 absorption by 107,000 metric tons annually by 2030 through three main approaches: implementing afforestation on slope land and low-profit farmland, promoting agroforestry to incentivize participation, and developing urban forests to enhance carbon sinks and ecological environments. Then, the forest management strategy targets 16,400 hectares of forest and 30,000 hectares of bamboo areas by 2030, aiming to increase CO_2 absorption by 454,000 metric tons annually through degraded forest restoration, artificial forest management, and bamboo cultivation optimization that combines carbon sequestration with economic benefits. Moreover, Taiwan aims to achieve 5% timber self-sufficiency by 2030 by producing 200,000 m^3 of domestic timber and increasing CO_2 carbon stock by 197,000 metric tons, focusing on bamboo industry development for both construction materials and bioenergy products to reduce dependency on timber imports and on reducing carbon emissions in long-distance timber transportation. On the other hand, Taiwan's soil management strategy focuses on two key approaches: enhancing soil management and implementing carbon-negative farming. The plan aims to develop effective soil management techniques to increase organic matter content, establish soil carbon monitoring, reporting and verification (MRV) mechanisms, and assess carbon stock distribution patterns. For carbon-negative farming, the initiative will implement practices such as greenhouse cultivation, carbon-negative crop varieties, and incorporating harvested straws into soil across 119,000 hectares to remove 199,000 metric tons of CO_2 by 2030. Additionally, the strategy includes reusing agricultural resources and applying microorganisms across 300,000 hectares to remove an additional 60,000 metric tons of CO_2, bringing the total carbon reduction to 259,000 metric tons by 2030. Additionally, marine carbon sequestration strategies encompass developing measurement methodologies for oceans and wetlands, implementing management measures to enhance ocean carbon sinks, promoting aquatic plant restoration, and advancing complex aquaculture operation models. By 2030, the plan aims to restore 6,325 hectares of marine habitats, projecting to increase carbon absorption by 340,000 metric tons CO_2e annually, with seagrass beds contributing 270,000 metric tons, mangroves 64,000 metric tons, and salt marshes 6,000 metric tons per year, while also expanding wetland conservation areas by 5 hectares by 2030 and 10 hectares by 2050 (National Development Council 2022a).

Net-zero strategies of the Ministry of Agriculture

In September 2021, the Ministry of Agriculture formally established the Office of Climate Change Adaptation and Net-Zero Emission Project, announcing that the Ministry of Agriculture would accomplish the goal of net-zero emission by 2040, and would set out 19 strategies and 59 measures under the four major aspects. These four major aspects are: 1) reduction of carbon emission - establishing comprehensive agricultural production carbon monitoring and transitioning to low-carbon production models to effectively reduce GHG emissions; 2) enhancement of carbon sink - increasing forest carbon sequestration through improved forest management, enhancing productivity, and strengthening coastal and wetland carbon sink management; 3) circular agriculture - optimizing agricultural resource efficiency through energy conservation, resource utilization, and material recycling while promoting agricultural circular technology development; and 4) Green Trends - developing energy self-sufficient fishing villages, implementing carbon pricing and trading mechanisms, and promoting agricultural green finance and consumption for sustainable development (Ministry of Agriculture, 2024).

In the first phase of the Ministry of Agriculture GHG Emission Control Action Plan (2016-2020) it achieved significant results across multiple sectors. In agriculture, organic farming incentives expanded environmentally friendly farming to 15,754 hectares, reducing emissions by 9,600 metric tons CO_2e, while green payment measures covered 438,000 hectares. In livestock, biogas power generation from pig farming involved 2.5 million pigs, reducing emissions by 58,890 metric tons CO_2e annually, while maintaining self-sufficiency rates of over 90% for pork, 100% for eggs, and 80% for poultry. The fisheries sector's vessel buyback program retired 8 boats and 116 rafts, reducing 7,770 metric tons CO_2e, while the fishing moratorium program involving 50,817 vessels reduced 408,570 metric tons CO_2e. Forestry initiatives included new afforestation of 3,207 hectares sequestering 23,860 metric tons CO_2e, and enhanced forest management across 3,790 hectares removing an additional 10,180 metric tons CO_2e. These achievements were supported by ongoing policies including green payments, organic farming promotion, fertilizer optimization, bamboo industry development, sustainable forestry programs, and livestock industry revitalization focusing on biogas generation and manure reuse (Climate Change Administration, Ministry of Environment, 2024).

Furthermore, the Ministry of Agriculture has established comprehensive GHG emission control targets, aiming for 5.006 $MtCO_2e$ by 2025 and 27.814 $MtCO_2e$ for the second phase (2021-2025), supported by strategic initiatives across four key sectors. These strategies include promoting environmentally friendly farming with organic practices and green incentives in the agricultural sector, advancing low-carbon livestock practices with biogas utilization in the livestock sector, enhancing fishing resource efficiency through vessel management and energy conservation in the fisheries sector, and strengthening forest resource management to increase carbon sequestration in the forestry sector. Together, these measures aim to establish a sustainable and carbon-efficient agricultural system while maintaining domestic production capacity and environmental protection (Ministry of Agriculture, 2024).

Green Payments

The Ministry of Agriculture launched the Green Payment in 2018 to effectively restructure the rice farming industry while incorporating organic and eco-friendly farming practices. Through an area-based subsidy mechanism, the program incentivizes agricultural land utilization, enhances crop quality, and promotes environmentally friendly farming methods, ultimately achieving sustainable agricultural development while safeguarding farmers' earnings. The green payments program is structured into two phases, each with distinct objectives and approaches. The primary objectives of the first phase of the program are to reconfigure the agricultural industry's structure, ensure optimal use of farmlands, enhance domestic food self-sufficiency, secure food supply, conserve farmland resources, underscore the multifunctional value of the agricultural sector, and promote eco-friendly farming practices. These objectives are geared towards ensuring the sustainable management of the agricultural industry. The payment mechanism employed in the first phase follows a "stacked subsidy measure," which involves different stages of payment linked to farmland utilization, cultivation, production, marketing, and environmental protection activities. In contrast, the focus of the second phase of the program shifts towards facilitating basic agricultural and environmental benefits, crop incentives, and eco-friendly subsidies. This phase aims to assist farmers in adapting their farming practices in response to climate change while adopting a stacked and value-added approach to enhance production value. Additionally, it seeks to foster a high-quality crop environment, preserve the ecology of farmlands, and maximize the multiplier effect of incentivizing farmland cultivation to achieve the overarching goal of farmland preservation. As of 2023, the green payment program covered an area of 437,000 hectares. The promotion of green manure crops covered an area of 79,000 hectares, reducing CO_2e emissions by 22,100 metric tons (Climate Change Administration, Ministry of Environment, 2024).

Farming methods of organic and eco-friendly

Since 2017, efforts have been made to foster the sustainable development of organic agriculture and enhance the quality of organic agricultural products. This includes extending counseling services to eco-friendly farming practitioners alongside certified organic farmers, facilitating the sharing of resources pertinent to organic agriculture. In addition to maintaining incentives and subsidies for ecological conservation in organic agricultural production, support is provided to organic and eco-friendly farmers to stabilize their operations. This support encompasses subsidies for organic certification and inspection fees, assistance for acquiring organic agricultural greenhouse facilities, establishment of simple composting facilities, and provision of organic agricultural tools and processing equipment. Furthermore, counseling services are offered to assist in the establishment of organic and eco-friendly farmers' markets,

and financial aid in the form of loans for agricultural and food-related operations is available. To incentivize farmers to reduce the usage of chemical fertilizers, the "Domestic Organic Fertilizer Promotion Program" has been in effect since 2004. Additionally, the "Organic Agriculture Applicable Fertilizer Promotion Plan" has been implemented specifically for organic farmers who have attained accreditation for their organic agricultural products. Under this plan, organic farmers are incentivized and subsidized for utilizing recommended applicable organic fertilizers. As of 2023, this project reached an area of 24,114 hectares, reducing CO_2e emissions by 28,900 metric tons (Climate Change Administration, Ministry of Environment, 2024). These measures collectively aim to encourage the adoption of sustainable practices within the agricultural sector and promote the transition towards organic and eco-friendly farming methods.

Fertilizer optimization and stabilization of supply and demand

Aligned with the new agriculture promotion program and the national net-zero emission policy, the Ministry of Agriculture has embarked on initiatives outlined in the "Regulations for Subsidies Program of Organic Agricultural Production," "Operation Guidelines for Domestic Organic and Microbial Fertilizers for Farmland Fertility," "Operation Guidelines for Crop Biological Control," and "Operation Guidelines for Materials of Eco-friendly Plant Protection." Efforts are directed towards promoting subsidies for various types of fertilizers including organic fertilizers, microbial fertilizers, organic compound fertilizers, and slow-release compound fertilizers. Additionally, subsidies for eco-friendly plant protection materials and crop biological control are being incentivized. These measures are complemented by the promotion of rational fertilization practices and the cultivation of green manure crops. The overarching aim is to enable domestic farmers to leverage diverse fertilizer materials to enhance farmland fertility, optimize fertilizer utilization efficiency, and encourage a reduction in reliance on chemical fertilizers and pesticides. By diminishing the usage of chemical pesticides and fostering rational fertilization practices, the initiative not only supports the development of organic and eco-friendly farming methods but also contributes to the mitigation of carbon emissions from farmlands. Furthermore, by promoting soil health and maintaining farmland soil, the initiative aids in increasing soil carbon sequestration, thereby aligning with the broader objective of enhancing soil carbon sinks.

AGRICULTURAL CARBON REDUCTION METHODOLOGY

In terms of technological methodologies for agricultural carbon reduction in Taiwan, current methods mainly revolve around small-scale reduction approaches such as the "AR-TMS0001 Reforestation and Afforestation Carbon Sequestration Project." This initiative involves planting trees and nurturing them to increase carbon storage, thus making it applicable to reforestation projects with an area larger than 0.5 hectares and an annual average removal quantity of less than 16,000 metric tons of CO_2e, initiated after January 1, 2000. As the Taiwan Agricultural Research Institute of the Ministry of Agriculture hosted the "Internationalization Mechanism Coordination and Establishment Project for Taiwan's Agricultural Carbon Credits," three "Agricultural Carbon Reduction Methodology Seminars" were organized in September 2023. Following international voluntary carbon reduction certification regulations, stakeholders were invited to these seminars where draft methodologies were presented, including:

Methodology 1: Application of Biochar in Soil and Non-Soil (Proposed)
The production of biochar from waste biomass through a clean process, followed by its application in soil or suitable non-soil contexts for long-term end use to retain carbon.

Methodology 2: Utilization of Aquatic Plants or Microorganisms for Sequestering CO_2 from Flue Gas and Converting it to Biomass Fuel (Proposed)
Utilizing aquatic plants or microorganisms to capture CO_2 from flue gas and converting to biomass for application in existing stationery and transportation biomass fuel production.

Methodology 3: Reduction of Emissions from Livestock Wastewater through Reuse Methods (Proposed)
Reducing methane emissions by reducing the volume of livestock wastewater in treatment processes through reuse methods.

Methodology 4: Methane Emission Reduction through Composting (Proposed)
Utilizing biomass or other organic matter through controlled biological treatment processes, including aerobic treatment and appropriate compost soil application, to increase soil organic carbon for long-term carbon sequestration purposes.

Methodology 5: Agricultural Land Management Methodology (Proposed)
Modifying one or more existing agricultural management measures, including introducing new measures, discontinuing, or adjusting existing measures, to reduce GHG emissions and/or increase GHG removal.

Methodology 6: Reduction of GHG Emissions by Reducing Nitrogen Fertilizer Application (Proposed)
Reducing GHG emissions from agricultural or grassland areas by reducing excessive nitrogen fertilizer application during production and application processes.

Methodology 7: Substitution of Waterlogged Fallow Farmland with Azolla as Green Manure to Reduce GHG Emissions (Proposed)
Replacing waterlogged fallow farmlands with Azolla as green manure to reduce GHG emissions from paddy fields.

POLICY PLANNING SUGGESTIONS

After conducting a literature review and analyzing agricultural net-zero carbon emission policies, while considering the unique characteristics of Taiwan's agricultural development, this study proposes recommendations for Taiwan's future policy planning.

Carbon sink in the agriculture sector

Presently, Taiwan's assessment of land use, land use change, and forestry primarily concentrates on carbon sequestration within the forestry sector, thus overlooking the potential contributions from other carbon sinks. Furthermore, the country's GHG emissions inventory lacks comprehensive data pertaining to grasslands, wetlands, and agricultural lands. To address this discrepancy, it is recommended to incorporate parameters derived from established frameworks such as those provided by the IPCC (2023) or comparable international standards to estimate carbon sinks. Alternatively, localized scientific research endeavors could be pursued to develop methodologies for the assessment of soil and ocean carbon sinks.

Regarding agricultural production, rice cultivation and livestock operations are identified as principal contributors to GHG emissions in Taiwan, underscoring the necessity for effective management strategies. Taiwan possesses considerable potential for fostering forest, soil, and ocean carbon sinks, advocating for their prioritization in carbon credits trading initiatives. Additionally, surplus agricultural resources significantly impact carbon emissions. Embracing a circular economy paradigm entails accurate categorization of agricultural surplus resources and harnessing scientific and technological innovations to minimize agricultural waste while maximizing resource utilization and value.

Carbon credit trading in the agricultural sector

The predominant approach in advanced countries regarding natural carbon credits revolves around domestic offsets, aligning with the global trend towards localization and reducing carbon leakage. Moreover, advanced nations incentivize companies to prioritize offsets and bolster domestic green investment through government compensation mechanisms. In instances of priority projects, international carbon sinks are only procured if domestic quotas are insufficient, underscoring the significant role of domestic carbon offset systems for enterprises. Carbon sinks must undergo verification procedures by the Carbon Offset Mechanism before being converted into carbon credits.

For Taiwan's agricultural sector, a crucial aspect to address is the verification of the carbon offset mechanism, particularly concerning forest management and regenerated agricultural soil. Oversight of projects involving carbon sinks, such as management and marine wetland conservation, should fall under the purview of relevant professional competent authorities.

Using agriculture and forestry as exemplars, the existing legal framework, regulations, and scientific understanding of agriculture and forestry management are not as comprehensive as desired. Thus, it is preferable for the Ministry of Agriculture to serve as the competent authority for converting carbon credits from natural carbon sinks, while the Ministry of Environment should be responsible for issuing these credits. In terms of procedures, reliance should be placed on project applications confirmed by a third party, with provisions for random or on-site inspections to mitigate misjudgments of

agricultural and forest carbon credits. Additionally, the government should strategize to establish procedures and methods in accordance with two major international carbon inspection standards, namely the Verified Carbon Standard (VCS) and the Gold Standard (GS).

The prevailing practice in various countries emphasizes aiding domestic natural carbon credits to provide offsets for domestic enterprises. Consequently, it is recommended Taiwan's government to limit the lifespan of forest carbon sinks to 20-30 years, while agricultural (soil) carbon sinks should endure for 8-16 years. Given that a significant portion of Taiwan's agricultural land is managed by small-scale farmers, often overseeing areas of less than 0.5 hectares, effective integration of private small farmers or forest farmers through integrated management is advised to encourage their participation in carbon credits trading.

Carbon Reduction Management Model for Rice Industry

Rice is a crucial agricultural crop in Taiwan. In 2021, the total agricultural planting area was 735,000 hectares, with rice cultivation accounting for 224,000 hectares. Chiang *et al*., (2013) conducted a carbon footprint analysis of Wufeng rice, revealing that fertilization and field emissions contributed 74.79% of total carbon emissions, primarily from CH_4 and N_2O. Based on these findings, this study identifies key areas for carbon reduction in the rice industry: fertilizer management, fertilizer utilization efficiency improvement, and reduction of field GHG emissions.

Multiple strategies can be implemented to reduce field GHG emissions. First, aerobic microorganisms can be added during compost preparation to reduce CH_4 emissions, while complete nitrifying bacteria can replace unstable nitrite-oxidizing bacteria to decrease N_2O emissions. Second, green manure crops can be planted before cultivation as base fertilizer, combined with precision fertilization and slow-release fertilizers to minimize GHG emissions from excess fertilizer application.

Adjusting rice drainage cycles is a crucial research direction internationally and serves as a domestic agricultural reduction methodology in many countries. Taiwan has developed smart intermittent irrigation systems for rice (Lin *et al*., 2021), while Japan has established customized cultivation calendars based on geographical location, environment, and climate characteristics to optimize water management, growth duration, and fertilization timing. This indicates the necessity for location-specific carbon reduction management models in rice cultivation. This study recommends conducting large-scale trials in collaboration with agricultural research stations, utilizing precision agriculture technologies such as IoT (Internet of Things), satellite imagery, aerial photography, and drones for monitoring and feedback to establish optimal cultivation parameters for farmers' reference. Regarding paddy field management, the government has long promoted fallow, crop conversion, and rotation policies to regulate supply-demand balance and promote efficient land resource utilization. While Academia Sinica's Agricultural Policy Proposal 2.0 recommends reducing rice cultivation areas and increasing artificial forest coverage, landowners show limited willingness to convert agricultural land to forestry. In response to decreasing spring rainfall and increasing drought periods in Taiwan, agricultural authorities have planned a "three-out-of-four" rice planting policy, allowing only three growing seasons over two years, with recommendations for drought-resistant crops in the remaining season or withdrawal of public grain purchase support.

In conclusion, carbon reduction in the rice industry requires comprehensive approaches from planting through harvesting to processing, integrating precision agricultural technologies with local characteristics to establish sustainable and feasible carbon reduction models. Through the integration and implementation of diverse strategies, the rice industry's carbon emissions can be effectively reduced, contributing to sustainable agricultural development.

Animal husbandry emissions reduction

Common measures to reduce GHG emissions in animal husbandry can be categorized into two main areas: addressing emissions from fermentation in the gastrointestinal tract and implementing effective manure treatment methods. To mitigate emissions from fermentation in the gastrointestinal tract, improvements can be made starting from the feed aspect. Enhancing the nutritional balance of feed can optimize animal nutrition and production efficiency while simultaneously reducing methane emissions from livestock and poultry. In terms of manure treatment, when composting is utilized to manage animal

waste, it is advisable to regularly aerate the compost to enhance decomposition and effectively reduce methane production.

In Taiwan's livestock industry, carbon reduction management efforts have focused on initiatives such as using green corn feed and implementing biogas recovery and management systems. Kums (2002) suggests that incorporating high-quality corn silage into livestock diets can lead to a reduction in methane production by 10% to 12%. However, a common challenge faced in practice is the prevalence of small-scale operations among livestock farmers. To address this challenge and promote more efficient management practices, livestock farmers need to be integrated into coordinated management systems.

Reducing and increasing emissions from agricultural land

Taiwan has delineated three key directions for the advancement of soil carbon sinks, focusing on (a) enhancing soil management practices, (b) adjusting crop farming patterns, and (c) harnessing soil biological resources, primarily through the adoption of regenerative agriculture practices. Given that a majority of agricultural land in Taiwan is managed by small-scale farmers, with relatively limited land area and low levels of mechanization, it becomes imperative to tailor strategies for increasing soil carbon sinks while considering regional variations in production.

In regions characterized by lower productivity, the adoption of no-till or fallow methods can significantly enhance the value of ecosystem services and bolster productivity levels. Conversely, in areas dedicated to food production, the implementation of crop rotation not only fosters soil carbon sequestration but also conserves water resources, mitigates methane emissions, and prevents rice overproduction. Given that farmland represents the most intensively managed land use, it presents a significant opportunity for actively managing its vital carbon pool. When estimating soil carbon content, striking a balance between carbon sequestration and emissions is essential. This necessitates thorough consideration of various factors such as agricultural practices, land management techniques, and regional characteristics to ensure accurate and effective carbon accounting.

Forest carbon credits

Forest carbon credits present an opportunity for the forestry industry to align with corporate social responsibility (CSR) guidelines, particularly within the framework of environmental, social, and governance (ESG) considerations. By actively engaging in afforestation efforts, the industry can rapidly enhance forest carbon sinks, thereby underscoring the significance of forestry in economic development. Specifically, forested land must be planted with trees and consistently maintained to qualify as part of the forest carbon sink. The entire process, from initial planning to the sale of forest land carbon credits, requires a minimum of eight years. Even after the commencement of carbon credit sales, ongoing monitoring and management of forest land for up to ten years are necessary to prevent diversion from the intended business model and ensure sustainability.

Since the carbon sequestration capacity that accompanies tree growth is not a linear relationship, the carbon sequestration capacity gradually decreases and plateaus at forest ages of 20-30 years. Therefore, in addition to the current policy of new afforestation, the government should consider sustainable forestry economic development for the limitation of the forest land area constraints in Taiwan. Trees aged 20-30 years can be made into Harvested Wood Products (HWP) for long-term carbon storage, and HWP is also a kind of carbon sink in IPCC Good Practice Guidance (Penman *et al*., 2003). Furthermore, the government should increase incentives for forest stand improvement, transforming forests with poor stand conditions and declining vitality into forests with vigorous growth.

However, the current methodology for measuring carbon sinks is hindered by practical limitations. Measurement primarily focuses on the aboveground portion of forests, overlooking the underground component, often resulting in an underestimation of forest carbon sinks. Additionally, there is a scarcity of skilled professionals capable of implementing quantitative data analysis, and the costs associated with monitoring and inspection are prohibitive. Therefore, there is an urgent need to focus on talent development through university training programs and establish more cost-effective methodologies rooted in scientific research foundations. Such efforts are crucial for expediting the promotion of Taiwan's forest carbon credits and maximizing their potential impact.

CONCLUSION

As the global drive for net-zero emissions intensifies, natural carbon sinks, such as forests, soils, and marine environments--have become a key strategy for carbon reduction. Nature-based Solutions (NbS) are particularly attractive for carbon credit trading, presenting significant business opportunities in agricultural carbon reduction. The Ministry of Agriculture in Taiwan aims to reduce net emissions by 10% compared to 2005 levels by 2025, with a target of achieving net-zero emissions by 2040. To support this goal, the government has introduced various policies, including incentives for green farming practices and organic agriculture. Notably, converting 1,000 hectares to organic and eco-friendly farming, results in a reduction of approximately 1,800 metric tons of chemical fertilizer reduction is achieved, equating to a reduction of 612 metric tons of CO_2e emissions.

In August 2023, Taiwan established the Taiwan Carbon Solution Exchange (TCX) to facilitate carbon credit trading. However, the current trading market is primarily dominated by non-agricultural sources, with forest carbon sinks representing the only agricultural component. This limited scope contrasts with advanced countries which are actively developing agricultural carbon credits linked to trade policies. As global trade increasingly adapts to carbon reduction mandates, developed countries are imposing carbon border tariffs and emissions restrictions on imports. To enhance industrial export competitiveness and align with international standards, Taiwan must strengthen its agricultural carbon credit system and expand and broaden its carbon trading market, particularly in agricultural carbon reduction credits.

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The co-authors have collectively contributed to the completion of this article. Chia-Chi Chang served as the first author to make contributions to conceptualizing the research framework, developing the main conceptual ideas, and editing the manuscript. Wan-Yu Liu is listed as the second author and contributed to devising the project, outlining the research, conducting data analysis, and drafting the manuscript. She is also the corresponding author during the review, editing, results confirmation, and submission process. Tian-Yuh Lee is acknowledged as the third author, providing guidance on the research framework, reviewing and proofreading the entire article.

COMPETING INTERESTS

Chia-Chi Chang, Wan-Yu Liu, and Tian-Yuh Lee declare no conflict of interest.