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CO_2 And CH_4 Gas Emissions From Peatlands In An Tuc And O Lam Under Agricultural Land Conversion

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Abstract: *This study investigates greenhouse gas (GHG) emissions of CO_2 and CH_4 from two peatland sites in An Tuc and O Lam, An Giang Province, Vietnam—areas notable for their peat deposits that play a critical role in carbon storage. However, land-use changes, particularly the drainage of peatlands for agricultural purposes, have led to significant GHG emissions, contributing to global climate change. The objective of the study is to quantify CO_2 and CH_4 emissions from these two peatlands and assess the impact of land-use changes, especially the conversion of wetlands to agricultural land, on greenhouse gas emissions. The results show that the peat deposit in An Tuc has greater thickness, area, and volume than in O Lam, indicating differences in resource potential and management needs. CO_2 emissions showed no significant difference across land-use phases or between the study sites, suggesting that CO_2 emissions are less influenced by location or cultivation method. However, CH_4 emissions varied significantly by phase and location. Notably, during the land reclamation phase, CH_4 emissions in An Tuc were significantly higher ($p < 0.05$), reflecting the influence of site-specific soil, hydrological, and cultivation factors. The land reclamation phase is a CH_4 emission hotspot that requires targeted mitigation measures. These findings emphasize the need to understand the interactions between cultivation stages, local conditions, and greenhouse gas emissions to design effective land, water, and agricultural waste management strategies. The study provides essential scientific insights for developing sustainable agricultural policies on peatlands, especially appropriate land preparation techniques, smart farming practices, and strict control of straw burning to reduce GHG emissions and preserve the ecological integrity of the Mekong Delta.*

Keywords: *Greenhouse gas emissions, CO_2, CH_4, peatland, land-use change, O Lam, An Tuc.*

INTRODUCTION

Peat-land are formed through the accumulation and incomplete decomposition of plant residues under prolonged waterlogged and anaerobic conditions. This process is influenced by various factors, including hydro-logical conditions, microclimate, microbial activity, and especially the duration of inundation (Reddy & DeLaune, 2008; Nguyen Van Tiep & Nguyen Van Bo, 2005). Depending on the environmental conditions and the degree of organic matter decomposition, peat exhibits considerable variation in chemical composition, structure, color, moisture content, ash content, and other physico-chemical properties (Joosten & Clarke, 2002; Tran Kim Tung, 2006). Additionally, studies in the Đong Thap Muoi region have shown that unsustainable exploitation and use of peat soils can lead to land degradation and negative impacts on the ecological environment (Lê Quang Tri, Nguyen Huu Hop & Nguyen Huu Chien, 2013).

Globally, peatlands cover only about 3% of the Earth's land area, yet they store between 600 to 650 Gt of carbon, which accounts for approximately 30-44% of the global soil organic carbon pool. This makes peatlands contain more carbon than all the terrestrial biomass combined (Page et al., 2011; IPCC, 2014; Leifeld & Menichetti, 2018). As a result, peatlands play a crucial role as a natural "carbon sink" in regulating global climate and conserving biodiversity.

However, peatland ecosystems are increasingly under pressure from human activities, particularly land-use changes for agriculture, forestry, and infrastructure development. Drainage, biomass burning, mechanical cultivation, and resource extraction disrupt the anaerobic conditions, leading to the oxidation of organic matter and the release of large amounts of greenhouse gases, primarily CO_2, which accounts for over 90% of the total greenhouse gases emitted from degraded peatland ecosystems (Hooijer et al., 2010; Dommain et al., 2014). It is estimated that greenhouse gas emissions from drained and unsustainably managed peatlands contribute to about 5% of global anthropogenic emissions, despite the relatively small area they cover (IPCC, 2014).

In Southeast Asia, which accounts for approximately 70% of the global tropical peatland area (~27 million hectares), the conversion of peatlands to agricultural use—particularly for oil palm, rice, and pineapple cultivation—and for plantation forests (such as acacia, eucalyptus, and melaleuca) is occurring at an accelerated pace. Studies in Indonesia and Malaysia, the two countries with the largest peatland areas in the region, have shown that CO_2 emissions from peatlands converted for oil palm cultivation can reach 60-100 tons of CO_2 per hectare per year, while rice or pineapple farming may emit 30-70 tons of CO_2 per hectare per year (Hooijer et al., 2012; Jauhiainen et al., 2012). Particularly concerning is the large amount of methane (CH_4) and nitrous oxide (N_2O) released from peatlands when they are burned during land clearance. These gases have a global warming potential (GWP) 28-265 times higher than CO_2 (IPCC AR5, 2014).

In Vietnam, the area of peatlands is estimated to be around 84,000 hectares, distributed across 28 locations nationwide, but primarily concentrated in the Mekong Delta region (MDR), including U Minh Hạ, U Minh Thượng, Đồng Tháp Mười, and parts of An Giang Province (Đặng Ngọc Vấn et al., 2004; Southern Institute of Water Resources Planning, 2015). The peatland areas in the MDR are being used for various purposes, including melaleuca plantation, rice, vegetable, and pineapple farming, aquaculture, or a combination of agriculture and forestry. However, improper exploitation practices (such as digging deep drainage ditches, planting upland crops on flooded land, and burning biomass) have led to rapid degradation and significant greenhouse gas emissions.

Many studies have shown that land use types directly affect the emission levels from peatlands. In the Indonesian peatland regions, CO_2 emissions from natural forests range from -2 to +3 tons CO_2 per hectare per year (due to some carbon sequestration), while plantation forests show an average emission of 10–35 tons CO_2 per hectare per year. Agricultural practices, especially the cultivation of upland crops such as maize, cassava, or double-cropping rice, can result in emissions of up to 60–80 tons CO_2 per hectare per year (Jauhiainen et al., 2012; Page et al., 2011; Warren et al., 2017). Additionally, methane (CH_4) and nitrous oxide (N_2O) emissions significantly increase when water management is poor or when high doses of chemical fertilizers are used.

In the context of Vietnam's commitment to achieving net-zero emissions by 2050 (COP26, 2021), accurately assessing greenhouse gas emissions from sensitive areas such as peatlands–especially with the changing land-use patterns–is critically important. Currently, data on greenhouse gas (GHG) emissions from peatlands under actual land-use conditions in Vietnam remains limited, particularly concerning carbon storage and emissions from agricultural and forestry models on peatland-based landscapes.

Therefore, this study is conducted to evaluate GHG emissions (CO_2, CH_4) from the primary land-use types–agriculture (rice cultivation) and forestry (*Melaleuca plantations*) – in the peatland areas of An Giang and Ca Mau provinces. The aim is to propose appropriate peatland land management solutions that can reduce emissions and contribute to the sustainable development of agriculture and forestry.

This study is particularly relevant as Vietnam strives to meet its climate goals, and addressing the impact of land-use changes in peatland areas can significantly help in carbon sequestration and emission reduction efforts (COP26, 2021).

METHODOLOGY

Characteristics of the Study Area

The selected study sites are An Tuc and Ô Lam communes in Tri Ton District, An Giang Province—an area characterized by semi-mountainous terrain interspersed with low mountain ranges such as Núi Cam, Núi Dài, and To mountain, alongside low-lying wetlands and depressions (Figure 1). These geomorphological conditions have fostered the formation of alluvial flats, swamps, and permanently inundated zones—favorable environments for organic matter accumulation and peat soil development.

According to the Southern Institute for Water Resources Planning (2020), the peat layer in this region ranges from 0.5 to 1.5 meters in thickness, with a very high organic matter content (> 40%), low pH (3.5–4.5), and a high potential for greenhouse gas emissions if drained or mismanaged.

Historically, land in this area was not intensively cultivated due to seasonal flooding. However, in recent years, peatlands in An Tuc and O Lam have been increasingly converted to agricultural land, particularly for rice cultivation. This land-use conversion requires surface water drainage, which initiates organic matter mineralization processes, resulting in the release of greenhouse gases such as CO_2 and CH_4.

Given their natural characteristics, soil conditions, and land-use transitions, An Tuc and O Lam represent ideal peatland sites for studying greenhouse gas emissions.

Figure 1: Land preparation for rice cultivation on peat soil in Tri Tôn District

DATA COLLECTION

To collect field data, we employed a set of specialized equipment, including a handheld GPS device to determine measurement locations and synchronize spatial data; a specialized manual coring tool to measure peat layer depth; and a static chamber specifically designed for greenhouse gas sampling under field conditions typical of peatlands.

This study aims to estimate peat reserves, assess carbon storage capacity, and quantify greenhouse gas (CH_4 and CO_2) emissions from peat soils under different land-use types in two peat mining sites in Tri Ton District, An Giang Province. The land-use types investigated include: (i) peat soils under rice cultivation–covering soil preparation, post-harvest straw burning, and the main cultivation phase; (ii) bare peatlands.

The gas collection chamber was constructed from PVC, with a cylindrical upright shape, 40 cm in height and 15 cm in radius (Figure 2). The chamber base is open-bottomed and firmly fixed to the soil surface to minimize leakage and disturbance during sampling. The top cover is made of transparent material, allowing for direct observation of the sampling process, equipment monitoring, and light penetration during daytime measurements. Inside the chamber, a small fan system ensures uniform mixing of air within the chamber volume, and an electronic thermometer is mounted to record temperature conditions during sampling. A plastic gas outlet tube extends from the center of the chamber to the outside through a specialized seal, allowing for gas extraction into sampling bags or tubes for CH_4 and CO_2 concentration analysis in the laboratory.

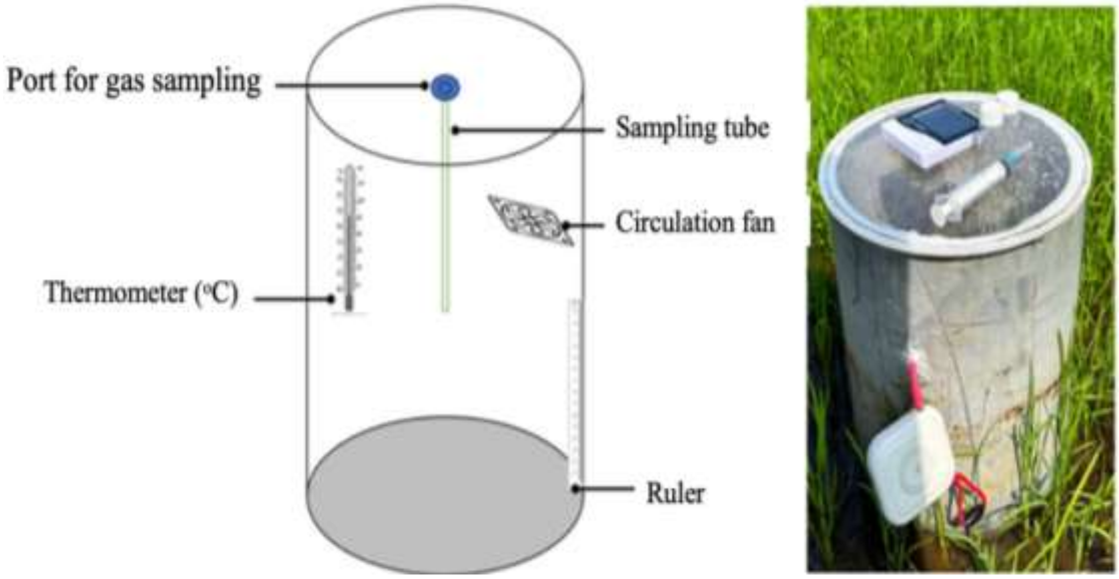

Figure 2: Structure of the Gas Sampling Chamber

Method for Measuring Greenhouse Gas Emissions: Greenhouse gas emissions (CH_4 and CO_2) from peat soil surfaces were measured using the closed static chamber technique. Gas samples were collected at three time intervals (0, 15, and 30 minutes after chamber closure) using a 20 ml syringe and then injected into pre-evacuated 15 ml glass vials. These samples were analyzed using a Gas Chromatography (GC) system in the laboratory.

Calculation of CH_4 and CO_2 Emission Rates: The emission rates of greenhouse gases were calculated based on the slope of the linear regression line describing the change in gas concentration over time. The gas flux was calculated using the following formula: (Smith, K. A., & Conen, F, 2004).

$$f = \left\{\frac{\Delta C}{\Delta T}\right\} * \left\{\frac{v}{A}\right\} * \left\{\frac{M}{V}\right\} * \left\{\frac{P}{P_0}\right\} * \left\{\frac{\mathrm{To}}{T}\right\}$$

Where:

F: Gas emission rate ($mg/m^2/h$)

$\Delta C/\Delta t$: Rate of change in gas concentration inside the chamber (ppm/h)

v: Volume of the gas sampling chamber (m^3)

A: Surface area in contact with the soil (m^2)

M: Molar mass of the gas (CH_4: 16 g/mol, CO_2: 44 g/mol)

V: Molar volume of gas at standard conditions (22.4 liters/mol)

P/P_0: Ratio of atmospheric pressure at the time of sampling to standard pressure (1.013 mbar)

T: Average chamber temperature in Kelvin (T = 273 + T_avg) The average chamber temperature

(T_avg) is calculated as the mean of three consecutive temperature readings during sampling: **T_avg =**

(T_1 + T_2 + T_3)/3.

Estimation of peat reserves: Peat volume (m^3) = Area of peatland (m^2) × Average peat thickness (m). The peat volume is estimated as follows: Rm=Rv×D. Where Rm: Peat volume by mass (tons). D: Average density (dry weight) of peat, in tons/m^3. The average dry weight of peat is about 0.715 tons/m^3.

Data Analysis: The Duncan's multiple range test in ANOVA was used to compare differences in greenhouse gas emission levels among different peatland land use types.

RESULTS AND DISCUSSION

Peatland Characteristics and Reserves in An Tuc and O Lam Sites

In the Mekong Delta, particularly in the Long Xuyen Quadrangle, peat deposits are primarily found in low-lying, waterlogged areas such as swamps, former ponds, and along canal banks. These peatlands are typically formed through alluvial deposition along riverbeds and are strongly influenced by microtopography and the region's hydrological history. As a result, they often appear in narrow, elongated forms or scattered patches (Thai Thanh Luom & Tran Trong Toan, 2013).

Surveys at the An Tuc and O Lam peat sites revealed peat layer thickness ranging from 0.3 m to 1.2 m, based on 20 boreholes drilled to a depth of 3 meters (Table 1). The An Tuc site had a slightly higher average thickness (1.36 m) compared to O Lam (1.27 m). However, both are thinner than many other peat deposits in the Mekong Delta. For instance, Nguyen, V. H., et al. (2016) reported that peat in Ca Mau typically ranges from 1.5 to 2.5 meters thick, and some areas in U Minh Thuong National Park can reach up to 3.0 meters. Internationally, peat deposits can be significantly thicker: in Nong Kham (Thailand), some peat layers reach 3.8 meters (G.M.T. Corporation Cp., Ltd., 1984), while in Poland, large marshes like Rospuda and Biebrza have peat layers exceeding 20 meters in depth (Paprocka & Podstolski, 1996). Peat thickness is closely related to the time of accumulation, reflecting the geological and ecological development of the area. Although no radiocarbon dating (^14C) has been conducted at the study sites, Glaser & Belyea (2011) suggest that peat layers between 1 and 2 meters thick are typically 700–1,000 years old (Sinskul, 1998). This implies that the An Tuc and O Lam peatlands likely formed during the late Holocene, shaped by historical hydrological changes in the Long Xuyen Quadrangle.

The shapes and boundaries of both peat sites are clearly defined (Fig 3 and 4). The O Lam peat site spans approximately 946.55 meters in width and 1,691.9 meters in length, with a total area of 158.95 hectares. In comparison, the An Tuc site is larger, with a width of 1,343.06 meters, an average length of 1,728.84 meters, and a total area of 204.07 hectares. Although An Tuc is larger within the local context, both sites are relatively small compared to other peatlands in the Mekong Delta. For example, the U Minh Ha peatland was reported to cover 20,167 hectares in 1976 (Phan Truong Khanh, 2019), though this area had decreased to approximately 2,654 hectares by 2022 (WRI Indonesia, 2025).

In terms of reserves, the An Tuc peat site holds an estimated volume of 2,775.36 m^3, equivalent to 1,984.39 tons of dry peat. Meanwhile, the O Lam site contains around 2,018.68 m^3, or 1,443.35 tons of dry peat. These quantities are significantly lower than the reserves at larger sites such as U Minh Ha, which has an estimated 4 million tons of peat.

Table 1. Peat Thickness, Area, and Reserves at Two Sites in Tri Tôn District.

No	Peatland Site Name	Thickness (m)	Area (ha)	Reserves (dry tons)
1	An Tuc	**1.36**±0.28	158,951	1,984.39
2	O Lam	**1.27**±0.32	204,071	1.443,35

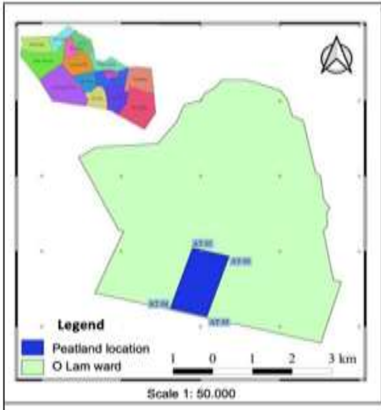

Fig 3. Location of the O Lam peat site

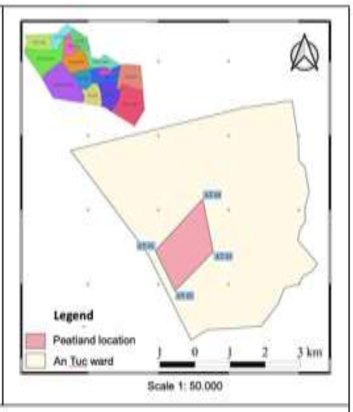

Fig 4: Location of the An Tuc peat site

CO_2 Emissions at the An Tuc and O Lam Peat Site

Table 2 presents the CO_2 emission rates (measured in $mgCO_2/m^2/h$) across different land use types at the An Tuc peatland site, including rice cultivation land, rehabilitated land, burned land, and abandoned land. The results reveal significant differences among land use types. Notably, burned land exhibited the highest CO_2 emission rate, reaching approximately 750 $mgCO_2/m^2/h$, which was significantly higher than the other types and marked with the letter **b** (indicating a statistically significant difference at $P < 0.05$). In contrast, the rice fields, rehabilitated land, and abandoned land showed similar emission levels, ranging from 250 to 300 $mgCO_2/m^2/h$, with no statistically significant differences among them (all labeled with the letter **a**). Variability within each land use category is illustrated by the error bars, reflecting fluctuations in field-measured data.

Table 2: CO_2 Emission Levels from the An Tuc and O Lam Peat Sites during different land use phases in rice cultivation. ***Unit:*** $mgCO_2/m^2/h$

Land use phase	An Tuc	O Lam
Bare peatland	$217,46^{a} \pm 115,84$	$403,47^{a} \pm 231,75$
Peatland reclamation	$204,94^{a} \pm 128,50$	$367,38^{a} \pm 184,09$
Rice cultivation on peatland	$267,48^{a} \pm 97,62$	$229,26^{a} \pm 143,94$
Burning straw on peatland	$736,39^{b} \pm 110,89$	$728,18^{b} \pm 54,76$

The results align with previous studies indicating that activities such as burning and disturbing peatland soil lead to a significant increase in CO_2 emissions due to the oxidation of organic matter when exposed to the atmosphere. According to Jauhiainen et al. (2008), peatlands in Southeast Asia subjected to human intervention, particularly surface burning, can emit CO_2 levels ranging from 600 to 1,200 $mgCO_2/m^2/h$. Similarly, Hooijer et al. (2010) reported that drained and burned peatlands in Indonesia emitted CO_2 at rates much higher than natural wetlands, with emissions exceeding 200 $mgCO_2/m^2/h$. In contrast, CO_2 emissions from rice fields and abandoned land in An Tức were closer to the lower range typically found in well-preserved peatlands, aligning with findings by Khalil et al. (2013) in Malaysian peatland areas.

Furthermore, rice cultivation also resulted in relatively high CO_2 emissions, which could be attributed to the use of chemical fertilizers, pesticides, and irrigation practices. However, ANOVA analysis revealed no significant statistical difference in CO_2 emissions between the three land use stages—rice cultivation, land reclamation, and unused land.

Similarly, at the O Lam peatland site, CO_2 emissions recorded during the burning phase ranged from 691.15 to 791.09 $mgCO_2/m^2/h$, with an average of 728.18±54.76 $mgCO_2/m^2/h$, which was significantly higher than other stages. Emissions during abandoned land, land reclamation, and rice cultivation phases showed no significant differences, with average emissions of 403.47±231.75 $mgCO_2/m^2/h$, 367.38±184.09 $mgCO_2/m^2/h$, and 229.26±143.94 $mgCO_2/m^2/h$, respectively.

A T-Test comparison of CO_2 emissions across the land use stages between the two study areas showed no significant statistical difference, suggesting that CO_2 emissions during rice farming on peatlands at both An Tức and O Lâm are comparable.

These findings conclude that agricultural activities on peatlands result in significant variability in CO_2 emissions, particularly during straw burning, which causes a sharp increase in emissions. Therefore, it is essential to implement effective management practices for post-harvest straw disposal to minimize greenhouse gas emissions, protect the environment, and promote sustainable peatland utilization.

CH_4 Emissions at the An Tuc and O Lam Peat Site

The table compares methane (CH_4) emissions across different land use phases in two study areas: An Tuc and O Lam.

During **rice cultivation on peatland**, CH_4 emissions in An Tuc were 67.31±18.56 $mgCH_4/m^2/h$, higher than in O Lam at 38.04±12.44 $mgCH_4/m^2/h$. This difference may be attributed to variations in soil characteristics, water management practices, and environmental conditions between the two areas.

In the **peatland reclamation** phase, emissions in An Tuc were significantly higher (92.22±37.43 $mgCH_4/m^2/h$) compared to O Lam (5.38±2.50 $mgCH_4/m^2/h$). This suggests that land preparation activities in An Tuc may have created more anaerobic conditions favorable for methane production, whereas O Lam may have implemented more effective soil and water management techniques.

For **burning straw on peatland**, both areas showed very low CH_4 emissions, with 0.41±0.16 $mgCH_4/m^2/h$ in An Tuc and 0.37±0.06 $mgCH_4/m^2/h$ in O Lam. This indicates that burning rice straw on peatland contributes minimally to methane emissions in both locations.

The highest CH_4 emissions were observed in **bare peatland**, particularly in An Tuc, with 283.33±107.09 $mgCH_4/m^2/h$, compared to 31.81±8.52 $mgCH_4/m^2/h$ in O Lam. This significant difference may be due to variations in water table levels, organic matter content, or microbial activity in unmanaged peat soils.

In summary, CH_4 emissions were generally higher in An Tuc across most land use phases, especially in bare peatland and during land reclamation, highlighting the influence of land use practices and environmental conditions on greenhouse gas emissions from peatland areas.

Table 3: CO_2 Emission Levels from the An Tuc and O Lam Peat Sites during different land use phases in rice cultivation. ***Unit***: $mgCH_4/m^2/h$

Land use phase	An Tuc	O Lam
Rice cultivation on peatland	67,31±18,56	38,04±12,44
Peatland reclamation	92,22±37,43	5,38±2,50
Burning straw on peatland	0,41±0,16	0,37±0,06
Bare peatland	283,33±107,09	31,81±8,52

CONCLUSION

This study reveals notable differences in peatland characteristics and greenhouse gas emissions from agricultural practices between the two study areas: An Tuc and O Lam.

In terms of morphology and scale, the peat deposit in An Tuc has a greater area, thickness, and volume compared to that in O Lam. This suggests a higher potential for exploitation and highlights the need for more comprehensive resource management strategies in An Tuc than in O Lam.

Regarding **CO_2 emissions**, no significant differences were observed between the land use phases or between the two sites. However, for **CH_4 emissions**, substantial differences were recorded, particularly during the **land reclamation phase**, where emissions at An Tuc were significantly higher than at O Lam. In other phases—such as rice cultivation, straw burning, and bare peatland—CH_4 emissions did not differ significantly between the two locations.

The following are some key findings identified in the study:

1. Distinct peatland characteristics: The peat deposit in An Tuc has greater thickness, area, and volume than that in O Lam, reflecting differing levels of resource potential and management needs.
2. **CO_2 emissions showed no significant difference** across land use stages or between study areas, indicating that CO_2 emissions are less influenced by location or cultivation method.
3. **CH_4 emissions varied significantly by phase and location**: Notably, CH_4 emissions during the land reclamation phase were significantly higher at An Tuc ($p < 0.05$), indicating the influence of site-specific soil, hydrological, and cultivation factors.
4. **The land reclamation phase is a CH_4 emission hotspot**, requiring targeted mitigation efforts.
5. **Effective resource use and emission reduction must be site-specific**: Understanding the interactions between cultivation phases, local conditions, and emissions is crucial to designing effective soil, water, and agricultural waste management strategies.

These findings provide essential scientific insights for developing sustainable agriculture policies on peatlands. In particular, appropriate land preparation techniques, smart agricultural practices, and strict control of straw burning are recommended to minimize greenhouse gas emissions and protect the ecological integrity of the Mekong Delta.

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