

ASSESSMENT OF GREENHOUSE GAS EMISSIONS FROM
POST-HARVEST RICE-STRAW BURNING IN TRIPLE- AND
DOUBLE-CROP SYSTEMS IN THE UPPER VIETNAMESE
MEKONG DELTA

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Abstract

Rice farming is a major contributor to greenhouse gas (GHG) emissions in the agricultural sector, especially in the Vietnamese Mekong Delta (VMD). We surveyed 202 rice-farming households (382.9 ha) in Dong Thap Province (Upper VMD) and estimated CO₂, CH₄, and N₂O emissions from post-harvest rice-straw burning using IPCC (2006) Tier-2 methods. In 2024, straw was burned on 333.9 ha (87% of the surveyed area) and removed off-field on 49.0 ha. Total emissions were 415.14 t CO₂e, dominated by CH₄. Emission intensity was higher in triple-crop systems (1.26–1.55 t CO₂e·ha⁻¹·yr⁻¹) than in the double-crop system (1.03 t CO₂e·ha⁻¹·yr⁻¹). Reducing in-field burning through straw utilization (incorporation/composting, mushroom cultivation, livestock feed) and, where feasible, moderating cropping intensity can lower emissions while maintaining soil fertility. The study provides important data to support policy development and encourages farmers to adopt low-emission alternatives for post-harvest residue management.

Key words: GHG, crop residues, rice straw, open burning, Mekong delta, climate change, emission factors

Introduction. Climate change poses one of the greatest challenges to global food systems, while agriculture itself remains a significant contributor to GHG

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emissions [1]. According to the Intergovernmental Panel on Climate Change (IPCC) agriculture, forestry, and land use collectively account for approximately 13–21% of global total anthropogenic GHG emissions in the period 2010–2019 [2]. In Vietnam, the agricultural sector contributes around 65.09 million tons of CO₂-equivalent, representing 43.1% of the country's total GHG emissions [3, 4]. Notably, rice cultivation is the dominant source within this sector, responsible for 57.5% of total agricultural emissions [5].

Among the major emission sources in rice farming are methane emissions from flooded fields and the open burning of rice straw after harvest. The latter is a widely practiced yet highly polluting method of residue management in many rice-producing regions [6–8]. Rice straw burning releases a substantial volume of CO₂, along with other harmful gases such as carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO_x), and sulphur dioxide (SO₂), contributing to air pollution and climate change [9, 10].

In Asia, outdoor biomass burning contributes an estimated 1100 million tons of CO₂, 67 million tons of CO, 3.1 million tons of CH₄, 2.8 million tons of NO_x, and 0.37 million tons of SO₂ annually [3, 11]. Specifically, emissions from agricultural residue burning alone account for 379 million tons of CO₂ and nearly 0.68 million tons of CH₄ [12]. In Vietnam, it is estimated that the burning of rice straw produces between 1.2 to 4.7 million tons of CO₂ per year, depending on the proportion of straw treated [10]. Furthermore, studies have shown that triple-crop rice models emit significantly more GHGs compared to single or double-crop models [13, 14].

The VMD, one of the world's most productive rice-growing regions, plays a vital role in national and global food security. Dong Thap Province is located in the Upper VMD and is a key rice-production area characterized by extensive floodplain landscapes and intensive cultivation. In recent decades, large wetland areas have been converted to rice farming, resulting in widespread double- and triple-cropping systems [15]. This intensification increases straw generation and shortens the turnaround time between harvest and land preparation, which can encourage open-field burning and associated greenhouse-gas (GHG) emissions. Comparing double- and triple-cropping systems is therefore important for climate-change mitigation because cropping intensity influences both the volume of residues and the potential magnitude of emissions [12, 16–18]. Such comparisons can inform mitigation options through improved residue management and, where feasible, moderation of cropping intensity.

Accordingly, this study aims to assess GHG emissions from post-harvest rice-straw burning in the Upper VMD. Specifically, we address: (1) current straw-management practices and burning areas across districts and cropping systems; (2) the resulting CO₂, CH₄, and N₂O emissions and CO₂-equivalent totals; and (3) differences in emission intensity between double- and triple-cropping systems.

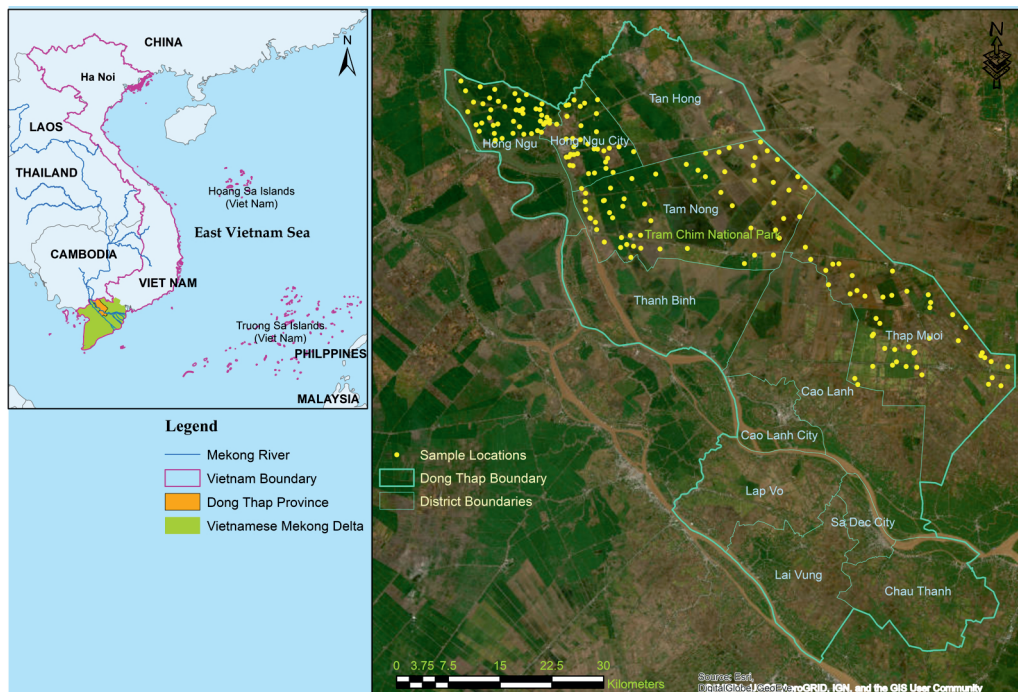


Fig. 1. Location of the study area and sampling sites. (Note: On 12 June 2025, the National Assembly of Viet Nam issued Resolution No. 202/2025/QH15, which altered certain administrative boundaries effective 1 July 2025. Throughout this study, provincial and district names/boundaries are presented as they existed prior to that Resolution to ensure consistency across historical datasets)

Materials and methods. Study area and survey design. The study was conducted in the upper region of the VMD, focusing on three representative rice-producing districts in Dong Thap Province: Thap Muoi, Tam Nong, and Hong Ngu. Historically dominated by extensive wetlands that have been largely converted to rice cultivation over the past three decades, these districts are now characterized by intensive rice farming with both double- and triple-cropping models [15].

We employed a stratified random sampling design by district and cropping system (double vs. triple). Households within each stratum were selected at random from district farmer lists. The final sample comprised 202 households – Thap Muoi ($n = 38$, triple-crop; 92.05 ha), Tam Nong ($n = 40$, triple-crop; 98.65 ha), and Hong Ngu ($n = 124$, 37 triple-crop; 62.8 ha; 87 double-crop; 129.4 ha) – covering 382.9 ha in total. This allocation provides broad spatial coverage across strata for district- and system-level descriptive comparisons.

Data collection. Secondary data on socio-economic conditions, rice production areas, and statistical records of Dong Thap Province were gathered from provincial statistical yearbooks and relevant governmental reports. In parallel, pri-

mary data was obtained through household surveys and key informant interviews with local agricultural officers. The questionnaires were designed to capture both quantitative and qualitative aspects of rice cultivation and straw-management practices.

GHG emission estimation from straw burning. We estimated CO₂, CH₄, and N₂O from rice-straw burning using the IPCC (2006) Tier-2 approach. Gas-specific emission factors (EFs) from the IPCC defaults [19] – 1.515 g·kg⁻¹ (CO₂), 2.7 g·kg⁻¹ (CH₄), and 0.07 g·kg⁻¹ (N₂O) – were applied; these Tier-1 values are not calibrated to Vietnam and may differ under local combustion efficiency, straw moisture, and field-burning practices. Vietnamese studies (e.g., LE et al. [9]; NGUYEN [10]) suggest discrepancies between field measurements and IPCC estimates, underscoring the need for Tier-2 or country-specific EFs.

Emissions were calculated as $\text{Emissions_GHG (t\cdot yr}^{-1}) = A \times MB \times CF \times \text{GEF} \times 10^{-3}$, where A is the burned area (ha), MB is the biomass burned (t·ha⁻¹), CF is the combustion factor, GEF is the gas-specific EF (g·kg⁻¹), and the 10⁻³ conversion yields emissions in t·yr⁻¹.

To account for global-warming impact, emissions were converted to CO₂-equivalents (CO₂e) using Global Warming Potential – GWP₁₀₀₀ (CO₂ = 1, CH₄ = 25, N₂O = 298); all CO₂e values follow this convention [19, 20].

Data analysis. Survey data were compiled and analyzed using descriptive statistics. Emission calculations were validated through cross-referencing with EFs and biomass-burning models. Comparative analyses assessed differences in GHG emissions between cropping models (double vs. triple rice) and among districts. Results are presented using summary tables to support discussion and interpretation.

Statistical analysis. Survey data were compiled in Microsoft Excel and analyzed in SPSS Statistics. Descriptive statistics (means, totals, and proportions) were summarized by district and cropping system. Differences among the three districts were evaluated using one-way ANOVA, and differences between double- and triple-cropping systems were tested using an independent-samples *t*-test (two-tailed), with statistical significance set at $p < 0.05$.

Results. Post-harvest residue-management practices. In Thap Muoi District, 50% of farmers burned rice straw after harvest (covering ~ 67.5 ha), while the remaining 50% adopted alternative practices such as in-situ incorporation with microbial additives, selling straw to collectors, or removing it for mushroom production, livestock feed, or composting. Tam Nong showed a similar pattern: approximately 45% burned straw and 55% removed or reused it off-field. By contrast, in Hong Ngu District, virtually all surveyed households reported on-site straw burning.

Yields and residue volumes. The total cultivated area surveyed was 92.05 ha in Thap Muoi, 98.65 ha in Tam Nong, and 192.2 ha in Hong Ngu (including triple and double crops). In 2024, total paddy yield across all sites reached

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Surveyed rice area, straw management (burned vs. removed off-field), and paddy yield/straw volume in 2024

Study site	Rice model	Total surveyed area (ha)	Burned in-field (ha)	Removed off-field (ha)	Total yield (t)	Mean yield ($\text{t}\cdot\text{ha}^{-1}$)	Total straw (t)
Thap Muoi	triple-crop	92.05	67.5	24.55	627.58	6.9	564.82
Tam Nong	triple-crop	98.65	74.2	24.45	650.23	6.72	585.2
Hong Ngu	triple-crop	62.8	62.8	0	548.78	7.1	451.13
Hong Ngu	double-crop	129.4	129.4	0	1067.91	8	929.43
Total		382.9	333.9	49	2894.5	–	2530.58

Note: Yield and straw totals are reported for the total surveyed area; “burned” and “removed off-field” indicate how straw was managed within that surveyed area

2894.5 tons, with a corresponding straw volume of 2530.58 tons (Table 1). Average yields in triple-crop models ranged $6.72\text{--}7.10\text{ t}\cdot\text{ha}^{-1}$, while the double-crop model averaged $8.0\text{ t}\cdot\text{ha}^{-1}$. Table 1 summarizes the total surveyed area by district and cropping system and its breakdown into fields where straw was burned in-field versus removed off-field, together with paddy yield and straw volume in 2024.

Current practices and burning areas. Post-harvest straw volumes are substantial yet under-utilized. In 2024, straw was burned on ~ 333.9 ha versus only ~ 49.0 ha removed off-field – about 87% vs. 13% of the surveyed area. By district: in Thap Muoi and Tam Nong (both triple-crop), burning covered 67.5 and 74.2 ha, with ~ 24.55 and ~ 24.45 ha removed off-field, respectively. That corresponds to burning shares of about 73–75% within each district. In Hong Ngu, both systems relied almost entirely on burning – 62.8 ha in the triple-crop and 129.4 ha in the double-crop model – with no off-field removal reported (Table 1). Figure 2 illustrates typical practices: Fig. 2(a) shows in-field burning immediately after harvest, whereas Fig. 2(b) shows a rice field cleared of straw after harvest.



Fig. 2. (a) In-field burning of rice straw; (b) Rice field cleared of straw after harvest.
(Source: authors’ field photographs)

GHG emissions from straw burning. Emissions from post-harvest burning were quantified for CO₂, CH₄, and N₂O using IPCC (2006) Tier-2 methods with local inputs. In 2024, district-level CH₄ was 2.72, 2.82, and 2.62 t·yr⁻¹ for Thap Muoi, Tam Nong, and Hong Ngu (triple-crop), with CO₂ of 1.52, 1.58, and 1.44 t·yr⁻¹ and N₂O ~ 0.07 t·yr⁻¹ per triple-crop district. Using GWP₁₀₀ (CO₂ = 1, CH₄ = 25, N₂O = 298) [19, 20], CO₂e totals for triple-crop systems were 90.43, 93.75, and 97.31 t CO₂e·yr⁻¹ (i.e., 1.34, 1.26, 1.55 t CO₂e·ha⁻¹·yr⁻¹). The Hong Ngu double-crop model showed lower intensity (1.03 t CO₂e·ha⁻¹·yr⁻¹) despite a larger area, totalling 133.65 t CO₂e·yr⁻¹ (Table 2). Overall emissions were 415.14 t CO₂e·yr⁻¹ (mean 1.24 t CO₂e·ha⁻¹·yr⁻¹).

T a b l e 2

Greenhouse-gas emissions from rice-straw burning activities (2024)

Study site	Rice model	Burning area (ha)	Total yield (t)	CO ₂ (t·yr ⁻¹)	CH ₄ (t·yr ⁻¹)	N ₂ O (t·yr ⁻¹)	Total CO ₂ e (t·yr ⁻¹)	CO ₂ e intensity (t·ha ⁻¹ ·yr ⁻¹)
Thap Muoi	triple-crop	67.5	627.58	1.52	2.72	0.07	90.43	1.34 ^a
Tam Nong	triple-crop	74.2	650.23	1.58	2.82	0.07	93.75	1.26 ^a
Hong Ngu	triple-crop	62.8	548.78	1.44	2.62	0.07	97.31	1.55 ^a
Hong Ngu	double-crop	129.4	1067.91	2.25	4.02	0.10	133.65	1.03 ^b
Total		333.9	2565.39	7.00	12.18	0.32	415.14	5.18

Note: ^{a,b,c} in the same column denote statistically significant differences among rice-cropping models in various provinces ($p < 0.05$)

Discussion. Open-field burning remained the dominant residue-management practice across the surveyed sites (Table 1). In Thap Muoi and Tam Nong, a measurable share of straw was removed off-field, whereas in Hong Ngu both triple- and double-crop systems relied almost entirely on burning. Farmer interviews indicated that burning is favoured because it is fast and low-cost, supports rapid field turnover between crops, and is perceived to reduce pests and weeds. However, open burning wastes organic carbon resources and releases particulate matter and gases (CO₂, CO, CH₄, SO₂, NO_x) that degrade air quality and human health [12].

The emission intensities estimated here are consistent with published values for rice-based systems in the region. Reported ranges include 1.1–1.7 t CO₂e·ha⁻¹·yr⁻¹ in Thailand [13], and ~ 1.0–1.6 t CO₂e·ha⁻¹·yr⁻¹ in Vietnam (Red River delta [10] and the VMD (Can Tho) [11]). Similar ranges (1.2–1.5 t CO₂e·ha⁻¹·yr⁻¹) have been reported for intensive rice systems in China [14]. This alignment supports the plausibility of the present estimates and reinforces the need for mitigation in intensive rice-growing areas.

Replacing burning with composting, in-situ incorporation (with microbial additives), mushroom cultivation, or collection for livestock feed can reduce emissions substantially; diversion of rice straw away from open burning can cut CH₄

by up to $\sim 90\%$ [12]. Given current practice patterns, scaling such options across triple-crop areas could reduce emissions by more than $200 \text{ t CO}_2\text{e}\cdot\text{yr}^{-1}$, especially if paired with moderated cropping intensity where feasible.

Uncertainties and limitations. Although Tier-2 IPCC procedures were used, three uncertainties remain. First, straw-to-grain ratios and recoverable fractions vary with season, cultivar, water regime, harvest method, and moisture; applying generic ratios (0.8–1.0) can over- or under-state burnable biomass. Second, management shares are self-reported and prone to recall/social-desirability bias (e.g., underreporting of burning), which can bias burned-area, and thus emission estimates. Third, default IPCC emission and combustion factors may not reflect local burning conditions (heaped vs. scattered residues; smoldering vs. flaming; weather), potentially shifting CH_4 and N_2O yields [19].

Conclusion. Open-field rice-straw burning was the dominant post-harvest practice in the three upstream districts surveyed in Dong Thap, the Upper VMD, occurring on 333.9 ha (87% of 382.9 ha) in 2024. Using IPCC Tier-2 calculations, straw burning emitted $415.14 \text{ t CO}_2\text{e}$, with CH_4 as the main contributor; triple-crop fields showed higher emission intensity ($1.26\text{--}1.55 \text{ t CO}_2\text{e}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$) than the double-crop system ($1.03 \text{ t CO}_2\text{e}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$). Mitigation should prioritize residue collection and reuse (incorporation/composting, mushroom cultivation, livestock feed) and consider reducing cropping intensity where practical, supported by extension and incentives.

REFERENCES

- [1] IPCC (2022) Global Warming of 1.5°C : IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, Cambridge University Press, NY, USA, <https://doi.org/10.1017/9781009157988>.
- [2] IPCC (2023) Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team (eds H. Lee and J. Romero)], IPCC, Geneva, Switzerland, 1–34.
- [3] CHU S. H., V. T. MAI, V. H. CAO et al. (2020) Study on green house gas emission of rice soils in Thai Binh Province, Vietnam J. Agric. Sci., **18**(2), 113–122, (in Vietnamese with English abstract).
- [4] HUYNH T. L. H. (2020) Potential assessment of greenhouse gas emission reductions when implementing climate change adaptation in agriculture, Vietnam J. Hydrometeorol., **719**(11), 26–37.
- [5] TRINH M. V., M. TESFAI, A. BORRELL et al. (2017) Effect of organic, inorganic and slow-release urea fertilisers on CH_4 and N_2O emissions from rice paddy fields, Paddy Water Environ., **15**(2), 317–330, <https://doi.org/10.1007/s10333-016-0551-1>.

- [6] JAMIR T., U. S. DE (2013) Trend in GHG emissions from Northeast and West Coast regions of India, *Environ. Res. Eng. Manag.*, **63**(1), 37–47, <https://doi.org/10.5755/j01.ere.m.63.1.2739>.
- [7] MACCARTHY D. S., R. B. ZOUGMORÉ, P. B. I. AKPONIKPÈ et al. (2018) Assessment of greenhouse gas emissions from different land-use systems: a case study of CO₂ in the Southern Zone of Ghana, *Appl. Environ. Soil Sci.*, **2018**, 1–12, <https://doi.org/10.1155/2018/1057242>.
- [8] VO T. B. T., R. WASSMANN, A. TIROL-PADRE et al. (2018) Methane emission from rice cultivation in different agro-ecological zones of the Mekong river delta: seasonal patterns and emission factors for baseline water management, *Soil Sci. Plant Nutr.*, **64**(1), 47–58, <https://doi.org/10.1080/00380768.2017.1413926>.
- [9] LE H. A., T. T. H. NGUYEN, T. L. LE (2013) Estimated gas emission from burning rice straw in open fields in Thái Bình province, *VNU J. Sci. Earth Environ. Sci.*, **29**(2), 26–33.
- [10] NGUYEN M. D. (2012) An estimation of air pollutant emissions from open rice straw burning in the Red River delta, *Vietnam J. Agric. Sci.*, **10**(1), 190–198.
- [11] NGUYEN T. H. D., V. H. T. NGUYEN, M. M. DO et al. (2024) Estimating the greenhouse gas agricultural emission: a case study at O Mon district, Can Tho city, *Dong Thap Univ. J. Sci.*, **13**(2), 13–21, <https://doi.org/10.52714/dthu.13.2.2024.1229>.
- [12] GADDE B., S. BONNET, C. MENKE, S. GARIVAIT (2009) Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines, *Environ. Pollut.*, **157**(5), 1554–1558, <https://doi.org/10.1016/j.envpol.2009.01.004>.
- [13] ARUNRAT N., C. WANG, N. PUMIJUMNONG (2016) Alternative cropping systems for greenhouse gases mitigation in rice field: a case study in Phichit province of Thailand, *J. Clean. Prod.*, **133**, 657–671, <https://doi.org/10.1016/j.jclepro.2016.05.137>.
- [14] FENG J., C. CHEN, Y. ZHANG et al. (2013) Impacts of cropping practices on yield-scaled greenhouse gas emissions from rice fields in China: A meta-analysis, *Agric. Ecosyst. Environ.*, **164**, 220–228, <https://doi.org/10.1016/j.agee.2012.10.009>.
- [15] NGUYEN H., T. DINH, P. PHAN-VAN, H. NGUYEN-QUOC (2025) Transformation and fragmentation of wetlands in Mekong delta floodplains: A case study in Dong Thap province, Vietnam, *C. R. Acad. Bulg. Sci.*, **78**(2), 207–215, <https://doi.org/10.7546/CRABS.2025.02.06>.
- [16] SAHU S. K., P. MANGARAJ, G. BEIG et al. (2021) Quantifying the high resolution seasonal emission of air pollutants from crop residue burning in India, *Environ. Pollut.*, **286**, 117165, <https://doi.org/10.1016/j.envpol.2021.117165>.
- [17] STREETS D. G., K. F. YARBER, J.-H. WOO, G. R. CARMICHAEL (2003) Biomass burning in Asia: Annual and seasonal estimates and atmospheric emissions, *Glob. Biogeochem. Cycles*, **17**(4), 2003GB002040, <https://doi.org/10.1029/2003GB002040>.
- [18] VAN ZANDVOORT A., D. R. LAPEN, I. D. CLARK et al. (2017) Soil CO₂, CH₄, and N₂O fluxes over and between tile drains on corn, soybean, and forage fields under tile drainage management, *Nutr. Cycl. Agroecosystems*, **109**(2), 115–132, <https://doi.org/10.1007/s10705-017-9868-4>.

- [19] IPCC 2006 (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Institute for Global Environmental Strategies, Hayama, Japan.
- [20] ZERBE M., D. MÖRLEIN, S. J. HÖRTENHUBER (2025) Towards climate neutrality: Comparison of mitigation strategies for agricultural emissions using GWP₁₀₀ and GWP* metrics, Environ. Chall., **18**, 101060, <https://doi.org/10.1016/j.envc.2024.101060>.

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