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CH_4 emissions in Vietnamese Rice Agriculture: Benchmarking process-based model approaches (Tier 3) against Tier 1/2 Estimates

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Rice cultivation is the largest source of methane (CH_4) emissions in Vietnam's agricultural sector, making accurate quantification of these emissions critical for national GHG inventories and the design of mitigation policies. Currently, for UNFCCC GHG reporting, Vietnam primarily employs IPCC Tier 2 approaches using national emission factors combined with Tier 1 scaling factors. With the implementation of large-scale mitigation projects and Vietnam's ambition to achieve Net Zero by 2050, Methane Global Pledge commitment by 2030, and joining international carbon markets, there is an urgent need to transition towards higher-tier methodologies. However, also process-based model (Tier 3) outputs are associated with uncertainty, which needs to be benchmarked first with established Tier 1 and 2 emission estimates.

In this study, CH_4 emission data from 13 Vietnamese field experiments are split into two groups—one with comprehensive management information (sufficient data) and one with sparse information (limited data)—to test IPCC Tier methods under different activity data conditions. Furthermore, for Tier 3, an inter-comparison is conducted between two biogeochemical models, DNDC and LandscapeDNDC. The evaluation focuses on the performance in estimating rice yields, seasonal CH_4 emissions, and daily flux dynamics, while also analyzing the impact of different model parameterization and simulation setups.

Our evaluation shows that Tier 1 significantly underestimates CH_4 emissions, whereas Tier 2 provides a substantial improvement and remains robust across varying soil and management conditions. In contrast, Tier 3 outperforms Tier 2 only when comprehensive management data is available, reflecting its distinctive capacity to represent daily emission dynamics and management-driven peaks. Consequently, while Tier 2 remains a practical choice for national inventories, Tier 3 is essential for high-resolution mitigation assessments, particularly for large-scale emission reduction evaluations where detailed management data are comprehensively collected and systematically organized. The process-based model comparison reveals that while DNDC and

LandscapeDNDC show similar performance under continuous flooding, they diverge significantly under Alternate Wetting and Drying (AWD) regimes. These discrepancies are primarily attributed to the models' different concepts of representing water table fluctuations.

Building on these results, the Tier-3 approach of LandscapeDNDC was integrated into the web-based LUI-RICE platform (https://ldndc.online/rice/). This makes GHG quantification for Vietnamese rice cultivation directly accessible to local stakeholders and policymakers, translating the scientific findings of this study into a practical decision-support application.