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Calculating the carbon footprint of rice production in Vietnam and formulating a proposal for mitigation options

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Abstract:

This study aims to develop a method for calculating the carbon footprint of rice during its life cycle by combining Life Cycle Assessment (LCA) and the 2006 Guideline of the Intergovernmental Panel on Climate Change (IPCC) for National Greenhouse Gas Inventories (GL 2006) for paddy rice grown in Phu Luong commune, Dong Hung district, Thai Binh province, Vietnam. In the course of the study, a LCA survey that included activities in the upstream processes, the agricultural process, and the post-farm stage was conducted based on interviews with three groups of 30 farmer households that apply the conventional practice of rice production, the system of rice intensification (SRI), or the wide-narrow row method. These cultivation practices are applied for both the winter-spring crop and summer-autumn crop seasons. The emissions were calculated by multiplying the activity data by the default emission factors in GL 2006 or in other relevant studies. The emission factors of methane (CH_4) from rice cultivation and nitrous oxide (N_2O) from agricultural soil were adjusted using actual measurement results from the Institute of Agricultural Environment (IAE) in 2016. The results of the calculations show that the main sources of the emissions that constitute the carbon footprint of rice include: (i) CH_4 emissions from rice cultivation; (ii) electricity generation for irrigation; (iii) diesel combustion for the operation of agricultural machinery, and (iv) fertiliser production. Emissions from other activities were negligible. The carbon footprint of spring rice is 2.69 kgCO$_2$e/kg of rice grown using the conventional paddy cultivation method, 2.35 kgCO$_2$e/kg for rice grown using the SRI method, and 2.29 kgCO$_2$e/kg for rice grown using the wide-narrow row method. In summer, the carbon footprint for rice grown using the conventional method is 3.72 kgCO$_2$e/kg of rice, 3.56 kgCO$_2$e/kg of rice using SRI, and 3.3 kgCO$_2$e/kg of rice using the wide-narrow row method. Three mitigation options are proposed: integrated crop management for rice; alternate wetting and drying; and the substitution of urea fertiliser ($CO(NH_2)_2$) with ammonium sulphate ($(NH_4)_2SO_4$).

Keywords: **carbon footprint, greenhouse gas, LCA, mitigation, rice.**

Classification number: **5.2**

Introduction

The term *carbon footprint* is defined as "the quantity of GHGs (greenhouse gases) expressed in terms of CO$_2$e, emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary" [1]. The scope of a carbon footprint depends on the range of activities to be taken into account, including Tier 1 (on-site emissions), Tier 2 (emissions embodied in purchased energy), and Tier 3 (all other indirect emissions not covered under Tier 2) [2, 3]. The choice of direct or indirect emissions is incompatible across the different studies. In most cases, including all indirect emissions in the calculation is very complex; therefore, many studies of carbon footprints calculate only direct emissions or indirect emissions at Tier 2 but not include indirect emissions at Tier 3. However, indirect emissions may account for the majority of the carbon footprints of many activities and products.

Carbon-footprint calculations can be undertaken based on a product-based approach or an activity-based approach, that is, GHG emissions from the activities of individuals, groups, or organisations. The carbon footprints of activities are the annual GHG emission inventories of individuals,

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groups, organisations, companies, and governments. National GHG inventories are based on emissions from activities within the territories of countries. This means that production, transport, and other activities occurring in countries, such as international transport and emissions from imported products, are excluded. However, the product carbon footprint (PCF) refers to the LCA of the whole or part of the product or the service life cycle; this means that all GHG emissions from every activity involved in providing a product or service to consumers should be included. This is the more comprehensive and fairer approach, since consumers would be made "responsible" for emissions. For example, in this study, the GHG emissions from imported fertiliser or pesticides that are used in rice cultivation must become part of the life-cycle analysis, though such emissions should not be included in the national inventory.

One of the guidelines for calculating GHG emissions using the activity-based approach is the GL 2006 of the Intergovernmental Panel on Climate Change (IPCC). Since 2009, government agencies and international organisations have made significant strides in developing standards and guidelines for calculating PCFs [4]. At present, three PCF calculation guidelines are universally accepted: PAS 2050 of the British Standards Institute [2], the GHG Protocol of the World Resources Institute and the World Business Council for Sustainable Development [1], and ISO 14067 [5]. All these standards are based on the LCA method specified in ISO 14040 and ISO 14044. Apart from those of the IPCC, most publications on LCA in Vietnam are also based on the Vietnamese Standard TCVN ISO 14040:2009 on environmental management, life-cycle assessment, and principles and framework. In 2017, the Food and Agriculture Organization (FAO) developed guidelines for calculating GHG emissions from major agricultural products such as corn, wheat, barley, cassava, and soybeans [6].

Study area

Phu Luong commune is located in the northwest of Dong Hung district in Thai Binh province (Fig. 1). It comprises 4.77 km^2. Most rural households in Phu Luong commune depend on agriculture. It includes five villages: Duyen Tuc, Duyen Giang, Duyen Phu, Duyen Trang Dong, and Duyen Trang Tay. In 2017, Phu Luong commune had 2,608 households with 8,202 inhabitants [7].

According to IAE (2016) [7], Phu Luong has a total planted paddy rice area of 299.04 ha; the winter crop covers 137.9 ha; the spring, summer, and autumn cereals cover 23.25 ha. The spring rice yield reaches 7.3 tons/ha, and the summer yield reaches 6.3 tons/ha.

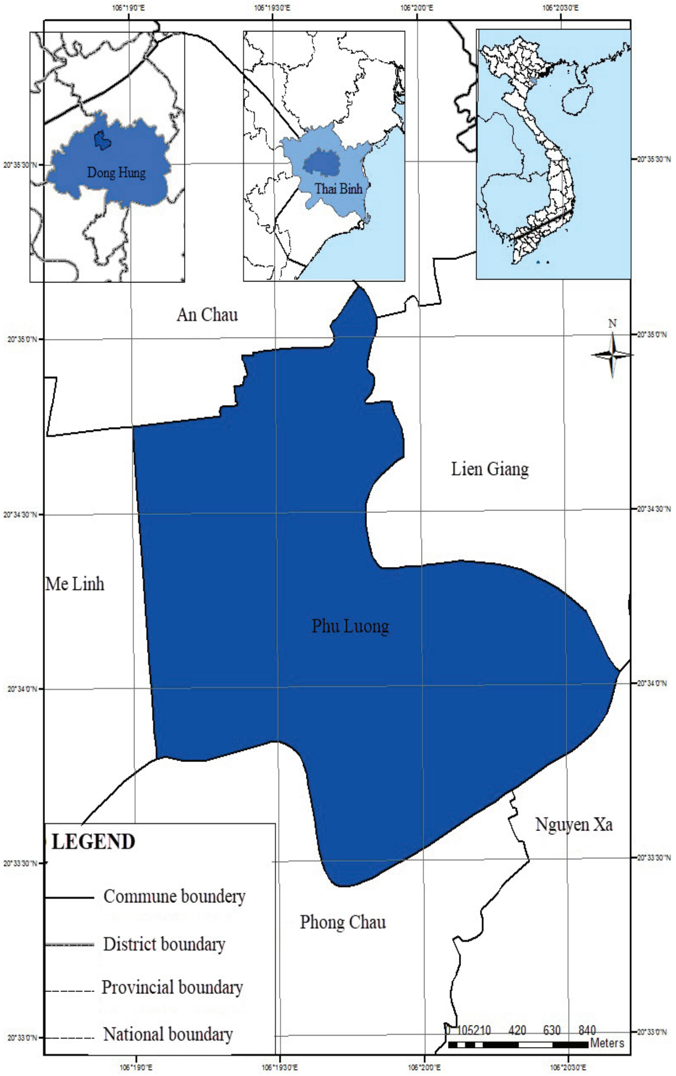

Fig. 1. Geographical location of Phu Luong commune.

Material and methodology

Data collection

Activity data such as cultivated land area, crop variety, the growth duration of rice, the capacity and frequency of the use of agricultural machinery, the amount of fertiliser and pesticide used, crop productivity, and the method used to treat straw (burying or burning) are taken from the results of interviews with 90 farmer households in Phu Luong commune. Three types of cultivation are used: the conventional one, the wide-narrow row method, and the system of rice intensification (SRI) for the spring and season crops. Emission factors are taken from GL 2006 [8], FAO [6], and other relevant studies.

Methodology

The methodology of this study is based on combining LCA and GL 2006 [8] and other studies (Fig. 2).

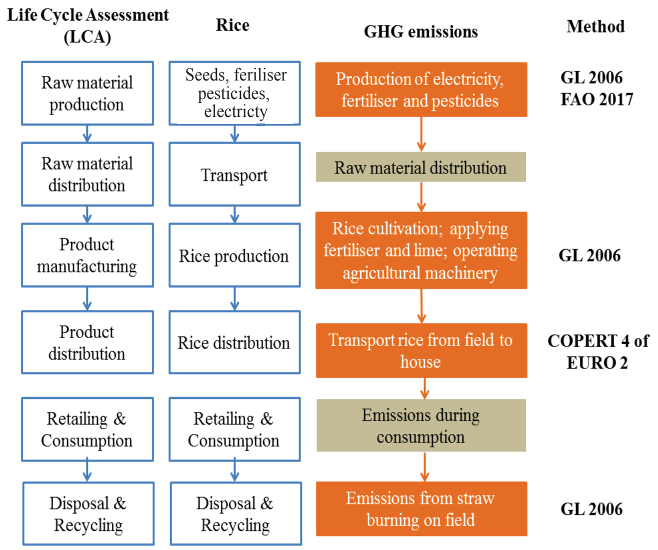

Fig. 2. Methodology for the calculation of the carbon footprint for rice.

The procedure for calculating the carbon footprint for rice involves five steps:

Step 1: select the GHGs in terms of the regulations of the Kyoto Protocol, including CO_2, nitrous oxide (N_2O), and methane (CH_4).

Step 2: determine the scope of the calculation: GHG emissions from upstream processes (electricity generation and the production of fertiliser, lime, and pesticides); rice production (rice cultivation, diesel combustion for the operation of agricultural machinery, and the application of fertiliser and lime), and the post-production of rice (transporting rice from farms to households and on-site straw burning).

Step 3: collect activity data.

Activity data were collected by means of questionnaires provided to 90 farmer households in Phu Luong commune. The households interviewed were selected based on stratified random sampling.

Step 4: calculate the carbon footprint.

Calculation of GHG emissions/removals:

Table 1 presents the formulas used for the calculation in the study.

Table 1. Summary of formulas used to compute the carbon footprint of rice.

Stage	Activity	Source	Tier
Upstream processes	1. Electricity generation for the operation of agricultural machinery	Formula 2.1, Vol. 2, GL 2006 [8], p.2.11	Tier 2
	2. Fertiliser production	FAO [6], p.13	Tier 1
	3. Lime production	Formula 2.8, Vol. 3, GL2006 [8] p.2.22	Tier 1
	4. Pesticide production	FAO [6], p.13	Tier 1
Rice production	5. Methane emissions from rice cultivation	Formula 5.1, Vol. 4, GL 2006 [8], p.5.45	Tier 2
	6. Diesel combustion for the operation of agricultural machinery	Formula 2.1, Vol. 2, GL 2006 [8], p.2.11	Tier 1
		FAO [6], Nemecek and Kagi [9]	
	7. Lime application	Formula 11.12, GL 2006 [8], p. 11.27	Tier 1
	8. CO_2 emissions from urea application	Formula 11.12, GL 2006 [8], p.11.27	Tier 1
	9.1. Direct N_2O emissions from agricultural soil	Formula 11.1, Vol. 4, GL 2006 [8]	Tier 2
	9.2 N_2O indirect emission from agricultural soil	Formula 11.9, Vol. 4, GL 2006 [8]	Tier 1
Post-farm	10. Transport rice from farms to houses	Computer programme to calculate emissions from road transport (COPERT 4) of the European	Tier 1
	11. On-site straw burning	Formula 2.27, GL 2006 [8], p.2.42	Tier 1
		Gadde, et al. 2009 [10]	

Calculating the carbon footprint:

The global warming potential (GWP) of all tiers is calculated individually using the IPCC's conversion factor. According to the IPCC's Fifth Assessment Report (AR5) [11], the GWP value of CH_4 is 28 and that of N_2O is 265. The formula for calculating the GWP of $tier_i$ ($i = 1, 2,$ or 3) is as follows:

GWP ($tier_i$) = emission/removal of CH_4 x 28 + emission/removal of N_2O x 265 + emission/removal of CO_2

where GWP is measured in kg CO_2e/ha.

The carbon footprint is calculated by summing the GWP of all tiers; its value can be presented as spatial or yield-scaled carbon footprints, which are calculated as follows:

$$CF_s = \sum_{i=1}^{3} [GWP(tier_i)]$$

$$CF_y = \frac{CF_s}{Grain\ yield}$$

where CF_s is the spatial carbon footprint (kg CO_2e/ha) and CF_y is the yield-scaled carbon footprint (kg CO_2e/yield).

This study uses the carbon footprint by both yield and spatial unit, that is, kg CO_2e/kg rice and kg CO_2e/ha.

Step 5: analysis of uncertainty (optional).

Uncertainty regarding the results of the calculation usually stems from uncertainty regarding the model and of the data. The results of GHG-emission calculations cannot avoid uncertainty.

Results and discussion

The GHG emissions for each activity in life cycle of rice in the spring and summer seasons are presented in Table 2.

It can be seen from Table 2 that the carbon footprint of spring rice is 2.69 kg CO_2e/kg of rice for the conventional practice, 2.35 kg CO_2e/kg of rice for the SRI method, and 2.29 kg CO_2e/kg of rice for the wide-narrow row method. In the summer season, the carbon footprint of rice is 3.72 kg CO_2e/kg of rice for thee conventional practice, 3.56 kg

Table 2. Carbon footprint of rice in Phu Luong commune.

No.	Sources of GHG emissions	GHG	GHG emissions (kg CO_2e/ha)					
			Spring rice			*Summer rice*		
			Conventional	*SRI*	*Wide-narrow row*	*Conventional*	*SRI*	*Wide-narrow row*
1	Electricity generation for the operation of agricultural machinery		3,143.10	3,143.09	3,143.09	2,619.25	2,619.25	2,619.25
2	Fertiliser production	CO_2	1,842.77	1,718.23	1,735.17	1,777.48	1,709.03	1,674.15
2.1	N-fertiliser	CO_2	*526.35*	*457.68*	*655.14*	*513.77*	*450.21*	*640.20*
2.2	P-fertiliser	CO_2	*8.08*	*13.27*	*14.10*	*7.94*	*13.27*	*13.52*
2.3	K-fertiliser	CO_2	*57.66*	*63.57*	*63.50*	*54.14*	*61.84*	*63.13*
2.4	NPK	CO_2	*1,250.68*	*1,183.70*	*1,002.44*	*1,201.64*	*1,183.70*	*957.30*
3	Lime production	CO_2	23.15	0.00	12.76	23.15	0.00	12.76
4	Pesticide production	CO_2	3.83	3.83	3.83	3.83	3.83	3.83
5	Methane emissions from rice cultivation	CH_4	7,870.93	5,765.76	5,556.19	10,646.16	10,110.0	8,990.94
6	Fertiliser application		506.58	414.20	497.65	548.42	431.31	538.53
6.1	CO_2 emissions from urea application	CO_2	*81.55*	*63.39*	*78.44*	*81.55*	*88.31*	*85.75*
6.2	Direct N_2O emissions from agricultural soil	N_2O	*425.04*	*350.81*	*419.21*	*466.87*	*343.00*	*452.77*
7	Lime application	CO_2	3.70	0.00	2.04	3.70	0.00	2.04
8	Diesel combustion for the operation of agricultural machinery		2,642.20	2,816.43	2,717.66	2,688.90	2,816.43	2,662.07
8.1	Tractor	CO_2	*1,940.87*	*1,940.87*	*1,940.87*	*1,940.87*	*1,940.87*	*1,940.87*
		N_2O	*4.68*	*4.97*	*8.42*	*4.79*	*4.97*	*8.32*
8.2	Combine harvester	CO_2	*694.97*	*852.44*	*750.46*	*694.97*	*852.44*	*694.97*
		N_2O	*1.68*	*2.06*	*1.81*	*1.68*	*2.06*	*1.81*
9	Transporting rice from farm to house	CO_2	3.46	5.37	3.72	3.46	5.85	3.67
10	On-site straw burning	CH_4	49.59	0.00	106.69	689.47	516.09	602.22
		N_2O	3.43	0.00	7.37	47.63	35.65	41.60
	Total (kg CO_2e/ha)		**16,092.74**	**13,866.90**	**13,786.17**	**19,051.44**	**18,247.45**	**17,151.04**
	Carbon footprint of rice (kg CO_2e/kg of rice)		**2.69**	**2.35**	**2.29**	**3.72**	**3.56**	**3.3**

CO_2e/kg of rice for the SRI method, and 3.3 kg CO_2e/kg of rice for the wide-narrow row method.

Proposal for mitigation options

Selection criteria

Vietnam submitted its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) on 29 September in 2015. In its NDC, Vietnam committed that with domestic resources, by 2030 Vietnam will reduce its GHG emissions by 8% compared to the Business-As-Usual (BAU scenario). The above-mentioned 8% contribution could be increased to 25% given receiving international support. The implementation of NDC will contribute to the global efforts to achieve the Paris Agreement, reaching the goal of limiting the average temperature increase less than 2^0C in 2100.

Based on the criteria for selecting the preferred GHG-emission mitigation options in Vietnam's NDC [12], the criteria that are developed include:

- Harmony with strategies and planning for agricultural and rural development.

- Mitigation cost (USD/ton CO_2e).

- Mitigation potential.

- Mitigation potential according to the results of the calculation of the carbon footprint of rice.

- Availability of technology.

- And co-benefits: bringing benefits to the economy, society, and environment and climate-change adaptation.

Selection of prioritised mitigation options

Based on the results of the calculations, it can be observed that the largest source of GHG emissions is from methane from rice cultivation in both the spring and summer seasons and in all three forms of cultivation; followed by electricity production for operating agricultural machinery; burning diesel for operating farm machinery; and fertiliser production.

According to Vietnam's NDC [12], 15 mitigation options in the agricultural sector have been developed based on agriculture and land use software. Of the 15 mitigation options for agriculture, five are selected in this study for rice production (Table 3). The option of 'biogas development' was not selected as farmers in Phu Luong commune mostly apply chemical fertilisers and very little farmyard manure.

Table 3. Mitigation costs and co-benefits of mitigation options for rice production in Phu Luong commune.

Option	Mitigation cost ($/t.$CO_2e$)	Co-benefit
A1. Reuse of agricultural residues	63.0	- Increase organic content in soil
A2. Alternate wetting and drying	88.0	- Reduce water volume for irrigation
A3. Introduction of biochar	75.0	- Reduce GHG emissions
A4. Integrated crop management (ICM) for rice	20.0	- Reduce cost of seeds and fertiliser
A5. Substitution of urea ($CO(NH_2)_2$) fertiliser by ammonium sulphate ($(NH_4)_2SO_4$)	30.0	- Reduce costs of seeds and fertiliser

Source: MONRE [12].

Mitigation options were assessed based on the criteria by scoring them from 1 to 5 (1 being the lowest, 5 being the highest). For farmers, mitigation costs and co-benefits are two most important factors and hence these two criteria have greater weight than the others. The results of the evaluation are presented in Table 4.

Table 4. Prioritised mitigation options for rice production.

Option	Criteria					Total	Rank of priority
	Mitigation potential based on rice carbon footprint (x1)	*Harmony with policies (x1)*	*Mitigation cost (x2)*	*Technology availability (x1)*	*Co-benefits (x2)*		
A1	1	4	3	3	3	20	5
A2	5	5	1	3	5	25	2
A3	4	4	2	2	4	22	4
A4	5	4	5	3	3	28	1
A5	3	3	5	2	3	24	3

Based on the evaluation results, the study proposes that ICM receive the highest priority for GHG-emission reduction for rice production. The second priority options are alternate wetting and drying and the substitution of urea fertiliser by $(NH_4)_2SO_4$.

Conclusions

This study developed a methodological framework and conducted a pilot calculation of carbon footprints in the life cycle of rice for Phu Luong commune. The results are quite similar to those reported in earlier studies around the world, such as 2.9 kgCO_2e/kg of rice in Italy [13], 2.92 kg CO_2e/kg of rice in Thailand [14], and ranging from 1.5

to 2.5 kg CO_2e/kg of rice in China [15]. According to the results of the calculations, GHG emissions from operating agricultural machinery account for a large proportion of emissions; however, thus far, there has not been much research on mitigation potential as this concerns the use of agricultural machinery. Therefore, this research direction should be considered in future.

The authors declare that there is no conflict of interest regarding the publication of this article.

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