

The impacts of local farming system development trajectories on greenhouse gas emissions in the northern mountains of Vietnam

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Received: 26 January 2007 / Accepted: 29 June 2007 / Published online: 6 September 2007
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Abstract The northern mountain region of Vietnam (NMR) is dominated by swidden/fallow farming systems. The fallow land of these systems is populated by small trees and bushes. Since the 1960s the government of Vietnam has tried to limit or stop swiddening and replace it with permanent upland agricultural fields, paddy, fruit trees and animal husbandry. Discussion in the policy debate and literature focuses on the impacts these changes have on local people's livelihoods. There have been no attempts to evaluate the impact of these changes on greenhouse gas (GHG) emissions. This paper examines the realities of current farming system changes taking place at the hamlet level and other changes that could take place due to government land use policies and extension programs. The paper answers the following questions: How could farming system changes influence net GHGs? Which farming system changes in the NMR, the trajectories of changes that are currently observed

or those that would be followed if farmers adhere strictly to government policies and programs, will have a greater affect on the GHG contributions from agriculture in the region? Could 'clean development mechanism' (CDM) projects make a difference in the profitability of the pathways mentioned? Results show: (1) if farming systems in the NMR continue along currently observed change trajectories there will be increases in GHG emissions; (2) if the NMR farming systems change according to government policies and programs there will be a net sequestration of carbon in regrowing vegetation during the initial 20 years; (3) over the longer term, in areas where systems change to fit government policies, increased GHG emissions from other changes in the farming systems (e.g. increased paddy and increased pig raising in sties) will overtake the amounts of carbon sequestered in vegetation; (4) CMD projects only make a difference if (a) maximum biomass potential of regrowing fallow can be reached; (b) a favourable baseline is chosen; (c) timing and length of the accounting period is correct; and (d) farmers do not take compensatory action in response to government policies. Given these conditions it does not appear that currently envisioned clean development mechanisms would be beneficial to farmers in the NMR.

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Keywords Greenhouse gas emissions · Carbon sequestration · Farming system change · Vietnam

Introduction

Since the early 1990s there have been many regional and some global studies looking at changes in carbon pools in vegetation and soil, as well as net-emissions of CO₂ and non-CO₂ greenhouse gases (mainly CH₄ and N₂O) from natural and agricultural ecosystems. Smith et al. (2001) and

Smith (2004) investigate the effects that various changes in agricultural land use could have on the emissions of greenhouse gases (GHGs) for Europe in light of different agricultural policies that the European Union is considering. Similar studies have also been done for North America. In the case of the tropics, where the focus has been on deforestation, and sometimes on more subtle changes in forest structure and composition, the changes in forest lands and the attendant affects on GHGs have been discussed and debated (Skole and Tucker 1993; Foody and Curran 1994; Foody et al. 1996). Tropical agricultural production systems' roles in carbon storage and net-emissions of GHG were mainly looked at through the 1990s with respect to paddy cultivation and slash and burn agriculture's relationship to deforestation (Tinker et al. 1996; Skole 2000).

The focus began to change in the late 1990s and early 2000s with research on mitigating GHGs in the humid tropics focusing on slash-and-burn agriculture (Palm et al. 2000, 2004; Mutuo et al. 2005). These studies point out that other changes and potential changes to agricultural production systems in the tropics need to be described in more precise terms in order to assess their impacts on GHGs. In order to do this the effects of various soil treatment techniques, use of irrigation, use of burning, application of fertilizers, and the expansion or contraction of animal husbandry in the farming systems need to be quantified. The rate of regeneration of natural vegetation during fallow periods, which may be affected both by cultivation techniques and the use of fallow for grazing, also needs to be taken into account. In short, detailed analysis of agricultural development trends and alternative 'pathways' is required to understand current and predict future changes in carbon pools and net-emissions of GHGs from moist tropical agro-ecosystems.

In Vietnam, the focus of this paper, the research on GHG contributions from agriculture has been directed at an analysis of emissions from flooded paddy and the consequences of the expansion of this type of agriculture in the lowlands and deltas (Hydrometeorological Service of Vietnam 1999). There is no mention of contributions from shifting cultivation, also referred to as swidden/fallow, the main farming system in the uplands, nor any discussion of the effect that replacing swidden/fallow systems with permanent (yearly) upland fields will have on future GHG contributions from the agriculture sector. In Vietnam, as in many other countries where swidden/fallow is practiced, sloping land is classified as forest land and officially should not be cultivated. The result of this official viewpoint is that land used for swidden is not officially recognized and is usually considered as 'forest' land (Fox et al. 2000; Cartography Publishing House 2003; Leisz 2007). With respect to GHG contributions on a country level, this means that the contributions from the uplands are only discussed in terms of the forestry sector, mainly with regard to carbon and the

role mountainous areas play as carbon sinks (see for example the Economics of Greenhouse Gas Limitations: Country Study Series Vietnam. Hydrometeorological Service of Vietnam 1999). Given the reality that the largest land use system in many parts of Vietnam's mountainous regions is not 'forestry' but rather various types of shifting cultivation based farming systems (Leisz 2007), the other GHGs contributed from these areas need to be recognized and changes in these contributions need to be considered when discussing the overall GHG contribution of the country.

The 'Clean Development Mechanism' (CDM), part of the Kyoto Protocol, allows third world countries to 'sell' carbon storage/sequestration projects to 'annex 1' countries. It is worthwhile considering whether the relative economic profitability of various agricultural development pathways in the uplands of Southeast Asia may be affected by including carbon storage/emission reduction among the products and services delivered by the agricultural systems in question. Exact calculations of the potential value of carbon storage/sequestration projects are difficult to make, since both the rules regulating such projects and the market price of carbon sequestration are still unstable or even unknown. Nevertheless, scenario analyses may be carried out to gain insight as to whether 'carbon trading' may influence land use significantly. In this paper, we base such scenario analyses on agricultural system development pathways that are currently being followed in the northern mountain region (NMR) of Vietnam.

Carbon and nitrogen cycles of agro-ecosystems must be studied together, both at the micro-scale of process studies in soil and vegetation, and at the macro-scale, when discussing alternative agricultural pathways. An example is swidden/fallow, also called slash-and-burn and shifting cultivation, in the upland areas of northern Vietnam that relies on the build up of nutrient-pools in fallow vegetation. If replaced by permanent cultivation mineral fertilizers or manure are required and will cause increased N₂O and carbon emissions. In addition, the production of mineral fertilizers requires large energy inputs, giving rise to further CO₂-emissions. Besides these considerations, the role of animals in the system and the amount of GHG emissions from both intensive and extensive animal husbandry needs to be considered. If a system that previously included little animal raising switches to increased production of cattle, water buffalo and pigs, there will be a corresponding increase in CH₄ and N from the system; and if the animal husbandry practices also change, this will cause further changes to GHG contributions from the system.

The objectives of this paper are:

1. Identify the likely effects on GHG contributions of present and expected future farming system development pathways for Vietnam's mountainous areas; and

2. Initiate a discussion on the feasibility of CDM-projects and their possible desirable and undesirable effects on the environment and livelihoods.

Materials and methods

Farming system development pathways in the NMR

The study reviews the current farming systems and associated activities found in the NMR, government policies aimed at guiding the development or changing these systems, and knowledge gained from recent fieldwork to forecast the trajectories along which these systems are changing. Knowledge regarding the types and relative amounts of GHG emissions from each of the activities within the farming systems was used to indicate whether the change scenarios would increase or decrease GHG emissions. A case study methodology is used to illustrate how these change trajectories will quantitatively affect four study sites in the NMR.

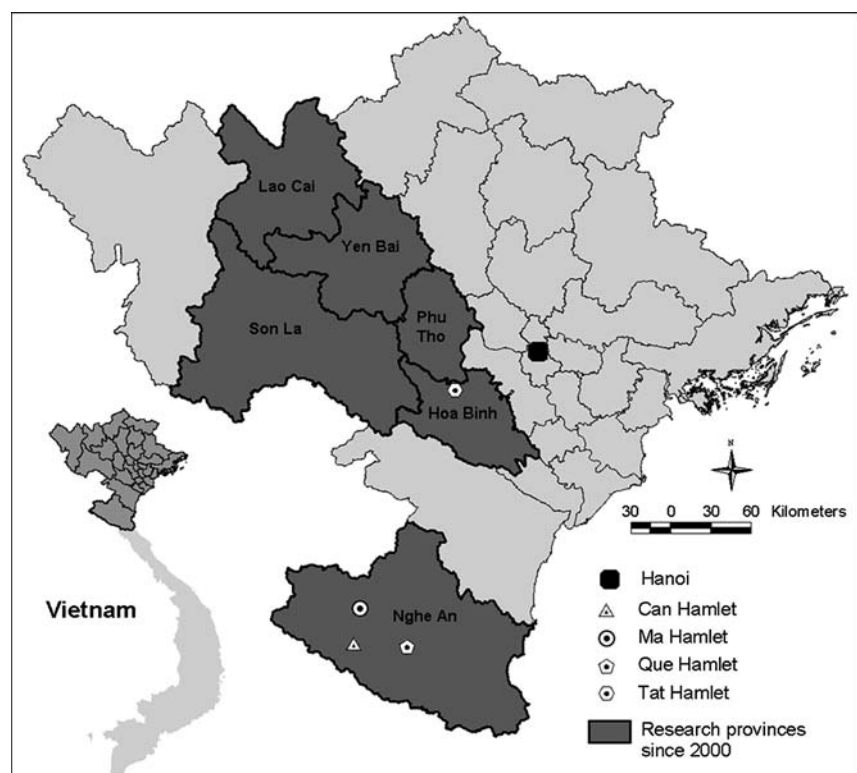
Current farming systems in the NMR and associated GHG contributions

Based on research done over the last six years in the provinces of Nghe An, Hoa Binh, Son La, Lao Cai, Phu Tho, and Yen Bai, of the NMR (Fig. 1), combined with

satellite image analysis, the activities found in the region's most common farming systems follow:

- Shifting, slash-and-burn, or swidden/fallow cultivation. These terms, often used interchangeably, refer to a system where one or a number of years of cultivation is followed by a period of fallow during which time the vegetation grows back. There are many different ways to categorize swidden/fallow systems. In the NMR two main types, following Schmidt-Vogt (1998), are present, secondary forest swidden systems, where a short cultivation period (1–3 years) is followed by a medium to long fallow period (4–10 years) and primary swidden systems, where a long cultivation period (3–5 years) is followed by a very long fallow period (20+ years). This paper uses the term swidden/fallow for both of these systems.
- Paddy systems (irrigated or seasonally inundated wet rice agriculture). These systems are found in the valley bottoms and on some terraced hillsides of the NMR.
- Composite swidden systems. A combination of swidden/fallow and paddy systems. These systems have been found in the NMR for hundreds of years and do not appear to be a response to limited paddy land, but rather are traditional and follow a rationale of risk-spreading, re-use of plant nutrients, flow of nutrients from swiddening to paddy fields by leaching/erosion, and better use of labour resources (Rambo 1998).

Fig. 1 Provinces visited and case study hamlets in the northern and north-central mountain regions of Vietnam



- Animal husbandry systems. The economic and subsistence importance of animal husbandry in most hamlets has traditionally been moderate. The main elements are cattle production, water buffalo rearing, pig raising (traditional free-ranging and, more recently, intensive pig raising in sties), and poultry production, mainly chickens and some ducks depending upon proximity to water. Animal husbandry is found as a component of all of the farming systems. In recent years the raising of cattle and pigs is beginning to dominate some of the systems.

Within each of these systems farmers incorporate some type of agroforestry and the extraction of forest products for domestic use and for sale. Extraction of timber and non-timber forest products currently plays a minor economic role in hamlets, though the subsistence role is often important. Timber extraction until recently was the responsibility of large para-statal companies and it is illegal for hamlets to cut and sell trees. In relation to carbon pools, illegal extraction of timber may prove to be important.

Recently some of the swidden/fallow areas have been transformed into farming systems dominated by permanent upland cultivation. This follows years of government policies aimed at sedentarizing the upland populations (Tran 2003). Wezel (2000) and Tachibana et al. (2001) both discuss how this is developing in different parts of the NMR and Leisz et al. (2005) illustrate that in one district the number of communes that have only permanent cultivation based systems has increased from 2 out of 38 in 1992, to 13 out of 38 in 2000. Whether this shift has an impact on GHG contributions is an open question. GHG contributions may increase from areas where cultivation is intensified and becomes permanent, while areas that are no longer periodically cultivated and have trees planted on them or forest regeneration takes place may act as net sinks (Table 1).

Government development and land use policies oriented to mountainous areas

Since independence in 1954 The Government of Vietnam has issued a number of laws and decrees aimed at promoting preferred development pathways in the mountains. The first of these policies (Tran 2003) was the “Sedentarization and Fixed Cultivation Program” implemented in the 1960s and 1970s. Other laws followed many of which had the goal of replacing cultivated sloping land (e.g. land used in swidden/fallow systems) with tree cover and reflect the government view that sloping land in mountainous areas is classified as, and considered forest land, not agriculture land (Tran 2003). Some of these are detailed in Table 2.

Specific agriculture practices have also been applied to and promoted for use in mountainous areas by policies and programs. The most prominent are:

- Irrigated and seasonally inundated rice cultivation. This activity is promoted through the VAC/RVAC programs (promoted in the NMR since the mid-to-late 1990s depending on the specific locality) and other credit programs that provide money for the building of terraces. The VAC program promotes the creation of paddy land, in-tandem with gardens (*vuon*), fishponds (*ao*) and livestock (*chuong*). The RVAC program includes the promotion of tree crops, e.g. fruit trees, tea trees, etc. (*rung*) on hillsides and also promotes the other VAC activities. Both of these programs were initially developed for the delta and midland areas and have been extended to the uplands.
- Animal husbandry. Billboards proclaiming “*Con heo vang*” (gold pigs) are seen in the countryside complementing the VAC/RVAC and rural credit programs funded by the government or by non-governmental organizations’ projects. Many of the projects promote the raising of pigs in sties (pens) to replace traditional free ranging pigs and the building of fish ponds. Credit programs are oriented to providing money for buying and raising cattle, though little extension work appears to be done in this area. Road building indirectly supports these activities providing better transportation networks to move animals to market.
- Permanent agriculture. Projects under the Ministry of Agriculture and Rural Development (MARD) promote crops grown on permanent upland fields. The most notable of these is the promotion of hybrid maize (Le and Rambo 2001; Wezel et al. 2000). This program (started in the late 1990s) provides inputs (hybrid seeds, fertilizer) and credit, as well as marketing channels, and seeks to replace the cultivation of swidden rice with the raising of hybrid maize for the market on permanently (year-to-year) cultivated fields. Other projects specific to provinces and districts are found that use similar mechanisms to promote permanent cultivation of crops for the market (see for example the project described by Castella and Quang 2002). Land allocation programs (Table 2) support this initiative through the permanent allocation of plots of land to farmers.

Methodology for calculating greenhouse gas contributions from farming systems

Assessment of emissions from livestock, paddy rice fields and fertilizers

In order to calculate the contribution of GHGs for each of the case study farming systems, the methods described in IPCC Guidelines for National Greenhouse Gas Inventories

Table 1 Present farming systems activities in the NMR and their role as a source of GHGs

Activity	GHG contribution
Swidden/fallow	No net contribution to CO ₂ (Tinker et al. 1996) assuming that cleared area regenerates to pre-cleared level of vegetation. CH ₄ will be released when burning humid fallow vegetation. No fertilizers are used in swidden/fallow, so N ₂ O emissions are small
Wet paddy rice (irrigated)	No net contribution to CO ₂ -CH ₄ is contributed, but the amount depends upon the irrigation practices and whether dry matter (e.g. manure) is applied to the paddy. N ₂ O is contributed if mineral fertilizer, animal manure, crop residues are used in the paddy
Wet paddy rice (rainfed—periodically inundated)	No net contribution to CO ₂ -CH ₄ is contributed, but the amount depends upon the depth of the standing water and amount of period when no standing water is found in the rice paddy area and whether dry matter (e.g. manure) is applied to the paddy. N ₂ O is contributed if mineral fertilizer, animal manure, crop residues are used in the paddy
Permanent upland agriculture fields	CH ₄ and N ₂ O will be released from burning and from manure and fertilizer application. C from burning of yearly stubble will be released
Free ranging cattle	CH ₄ is contributed from the animal; little to no CH ₄ from manure. Trace amounts of N ₂ O and NO _x from urine
Penned cattle (similar to drylot)	CH ₄ is contributed from the animal and from manure collecting in the pen. N ₂ O and NO _x are contributed from the concentrated faeces and urine in the pen
Free ranging water buffalo	CH ₄ is contributed from the animals; little to no CH ₄ from manure. Trace amounts of N ₂ O and NO _x from urine
Free ranging pigs	Little to no CH ₄ from manure. Trace amounts of N ₂ O and NO _x from urine
Penned pigs (similar to drylot)	CH ₄ is contributed from manure collecting in the pen. N ₂ O and NO _x are contributed from the concentrated faeces and urine in the pen
Free ranging chickens	Little to no CH ₄ or N ₂ O is contributed

Table 2 Government policies and programs in the uplands and their objectives since 1983

Year	Government policies/program	Objectives and implementing body
1983	Directives 29/7CP	Allocation of forest land not only to forest enterprises and co-operatives, but also to farm households
1986	Decision no. 1171/QD	Management regimes of production, protection, and special use forest
1988	Land reform	Allocation of agricultural land directly to land users
1990	Decision 72—HDNT	Socio-economic development program in the uplands
1991	Forest law	Law on forest protection and management
1992	327 program	Re-greening barren hills and making use of waste land
1992	1586/QDUB	The province policy on forest management renovation in state owned farms and forest enterprises
1994	Resolution no. 02/CP	Forestland allocation for forestry purposes
1995	Resolution no. 01/CP	Allocation of contract land for agriculture, forestry, and aquaculture
1998	661 program	Reforestation of 5 million ha during the period: 2000–2010
1999	Decision 245/TTg	State management of forest with recognition of the role of communes
1999	Circular letter 56/1999/TT/BNN-KL	Guidance reagrements for protecting and developing forests in native hamlet communities
2001	Direction 52/2001/CT/BNN-KL	To promote local groups and local people's participation in forest protection and development activities
2001	Determination 178/2001/QD TTg	Allow local people to collect NTFPs except for those noted on the protected species list
2004	Determination 04/2004/QD-BNN-LN	Regulating the exploitation of timber and other forest products

(1997, 2000) have been used. Details of the methods and parameters used are given in Appendix 1. Since little data from the area is available, standard values, fitting the farming systems and production methods best, have been

used. It is evident that large uncertainties exist, and the figures calculated should be considered only as indicative. An exception from the use of the IPCC methodology will be made as regards carbon storage in, emissions from, and

sequestration by, vegetation and soils. This is due to the availability of in situ information.

In situ measurements of changes in soil and vegetation carbon pools

The agricultural change scenarios, presented below, involve changes in land use/cover which will have great impacts on carbon pools in and GHG emissions from vegetation and soils. Since measurements/estimates of these pools have been carried out in the study area, these will be used for assessing the effect of the agricultural change trajectories on emissions, rather than default IPCC figures.

The vegetation carbon pool may be determined directly from a chronosequence of biomass in fallow vegetation and secondary forest. While such a chronosequence may be established for fallow/forest ages of up to 30 years, what happens beyond this period, including the development of secondary into primary forest, is not well known and may be very hard to establish since little information on logging activities is available. Carbon pools may be estimated by sampling the different forest/fallow vegetation age classes, carrying out measurements of diameter at breast height (DBH), and using an allometric equation to compute the dry weight. The carbon content may be assumed to be 50% of the dry weight. In the present case vegetation sampling was carried out in the village of Ban Luu Phong, see Christiansen (2006).

The soil carbon pool may be estimated by taking samples from the upper 0.5 m of the soil profile and measuring the amount of soil organic carbon (SOC) as a function of depth. Land use change is assumed to have little effect, at least at the time scales studied here, on SOC pools below the upper 0.5 m. Ideally, by measuring SOC under forest, fallow, cultivated fields, etc., it should be possible to establish the effects of land use on SOC pools.

Global warming effect

The estimated emissions of CO₂, CH₄ and N₂O can be added and compared by converting them into CO₂ equivalents by multiplying their mass with their 100-year 'global warming potentials' which describe their 'efficiency' as GHGs relative to CO₂. These are set to 21 for CH₄ and 310 for N₂O.

Results

General effects of changes in GHG contributions from farming system change trajectory scenarios

The laws, decrees, and programs described above reflect the government's desire to provoke the following changes

in the farming systems in the NMR: increase permanent agriculture on fixed fields; increase animal husbandry (mainly pigs, cattle and buffalo); increase paddy rice cultivation; expand fruit tree and other tree crop cultivation; and increase fish raising. From both government and market pressures, farming systems are changing at a system level and also on a 'within-system' level, e.g. individual agricultural activities within the systems are changing, or the emphasis placed on the different activities are changing, but the overall farming system remains the same.

Based on our fieldwork in the NMR we have noted the following main farming system change trajectories, some of these trajectories mirror the governments efforts, others vary from what the government promotes, either implicitly or explicitly.

1. Reductions in the area available for swidden/fallow, resulting in shortening of fallows;
2. Replacement of swidden/fallow with permanent and/or semi-permanent cultivation on upland fields, possibly market oriented agro-forestry;
3. Areal expansion of paddy production, and integration with swidden/fallow in "composite swiddening" systems;
4. Areal expansion of paddy rice production in combination with permanent or semi-permanent cultivation on neighbouring hillside fields;
5. Expansion of animal husbandry (free ranging cattle) (either as bush/forest cattle, or associated with conversion of fallow and secondary forest into grassland/bush);
6. Expansion of animal husbandry (penned cattle and penned pigs), no associated conversion of fallow and secondary forest into grassland/bush.

The projected effects on carbon pools and greenhouse gas emissions, associated with each of these pathways are outlined in Table 3.

Specific results from case studies illustrating the general trajectory results

In order to illustrate the above trajectories, the situations in four hamlets studied since 2001 are illustrated (Table 4). These hamlets are found in Nghe An and Hoa Binh provinces and the farming system change trajectories in the hamlets are representative of the farming system changes going on in the NMR.

Que hamlet is emblematic of a community that is transitioning from a strictly swidden/fallow farming system, with medium fallow lengths of 5–10 years, to a community that practices composite swiddening and is establishing permanent upland fields. As part of this transition, the farmers in Que are starting to raise, or are trying to

Table 3 Trajectory of farming system and system component changes in the NMR of Vietnam and the projected effect on GHG contributions

Initial farming system and components	Trajectory of changes in the farming system activities	GHG contributions (increase ↑, no change →, decrease ↓)		
		CO ₂	N ₂ O	CH ₄
Swidden/fallow dominated system				
Swidden/fallow cultivation	Decrease in fallow length from 5 to <5 years	↑	→	→
Animal husbandry				
Cattle	Increase in free ranging cattle in forest/fallow areas	→	→	↑
	Increase in penned cattle	→	↑	↑
Buffalo	Increase in free ranging buffalo	→	→	↑
Pigs	Same number of free ranging pigs;	→	→	→
	Increase in penned pigs	→	↑	↑
Chickens/ducks	Increase in chickens/ducks raised	→	→	→
Forest products				
NTFP	Increase in NTFP collection	→	→	→
Timber	Decrease in timber collection	↓	→	→
Wet paddy rice dominated system (both irrigated and rainfed)				
Paddy rice cultivation	Expansion of paddy rice area	→	→	↑
	Increase number of crops per year from 1 to 2	→	→	↑
	Increase in input use (chemical fertilizer)	→	↑	→
	Increase in input use (manure)	→	→	↑
Animal husbandry				
Cattle	Increase in free ranging cattle in forest/fallow areas	→	→	↑
	Increase in penned cattle	→	↑	↑
Buffalo	Increase in free ranging buffalo	→	→	↑
Pigs	Same number of free ranging pigs;	→	→	→
	Increase in penned pigs	→	↑	↑
Chickens/ducks	Increase in chickens/ducks raised	→	→	→
Forest products				
NTFP	Increase in NTFP collection	→	→	→
Timber	Decrease in timber collection	→	→	→
Composite swidden system				
Swidden/fallow cultivation	Decrease in fallow length from 5 to <5 years	↑	→	→
	No change in fallow length	→	→	→
Paddy rice cultivation	Expansion of wet paddy rice area;	→	→	↑
	Increase number of crops from 1 to 2	→	→	↑
	Increase in input use (chemical fertilizer)	→	↑	→
	Increase in input use (manure)	→	→	↑
Animal husbandry				
Cattle	Increase in free ranging cattle in forest/fallow areas	→	→	↑
	Increase in penned cattle	→	↑	↑
Buffalo	Increase in free ranging buffalo	→	→	↑
Pigs	Same number of free ranging pigs;	→	→	→
	Increase in penned pigs	→	↑	↑
Chickens/ducks	Increase in chickens/ducks raised	→	→	→
Forest products				
NTFP	Increase in NTFP collection	→	→	→
Timber	Decrease in timber collection	↓	→	→

Table 3 continued

Initial farming system and components	Trajectory of changes in the farming system activities	GHG contributions (increase ↑, no change →, decrease ↓)		
		CO ₂	N ₂ O	CH ₄
Other components (animal husbandry; NTFP, timber)	Trajectory same as found in swidden/fallow system	Effect same as above		
Swidden/fallow system to permanent agriculture system				
Swidden/fallow cultivation	Change to permanent upland fields no fallow time;	→	→	→
	Increase in input use (chemical fertilizer)	→	↑	→
	Increase in input use (manure)	→	→	↑
Animal husbandry				
Cattle	Increase in free ranging cattle in forest/fallow areas	→	→	↑
	Increase in penned cattle	→	↑	↑
Buffalo	Increase in free ranging buffalo	→	→	↑
Pigs	Same number of free ranging pigs;	→	→	→
	Increase in penned pigs	→	↑	↑
Chickens/ducks	Increase in chickens/ducks raised	→	→	→
Forest products				
NTFP	Increase in NTFP collection	→	→	→
Timber	Decrease in timber collection	↓	→	→

Table 4 Key features of each hamlet studied

Hamlet/province	Population	Topography	Access/isolation
Que Hamlet/Nghe An	409 (69 households)	Elevation 180 to 520 m. One long narrow valley, steep mountains over most of the hamlet area	Moderate access—30 km from market; on dirt road, passable for most of the year
Can Hamlet/Nghe An	835 (183 households)	Elevation 100 to 1,000 m. Valley area where hamlet is, rolling hills then steeper mountains moving away from valley towards the Pu Mat National Park	Accessible—11 km from market; year round access, located on an all year secondary road, 2 km from the national highway
Ma Hamlet/Nghe An	580 (138 households)	Elevation 100 to 940 m. No flat land, moderate to steep mountains, deep ravines running at right angle to the Ca River	Isolated—43 km from market; no road passable by vehicles; foot-path and river access to market
Tat Hamlet/Hoa Binh	476 (107 households)	Elevation 360 to 1,000 m. One long narrow valley, steep mountains over most of hamlet area	Accessible—17 km from market; on an all season road; daily bus to province capital

increase, the number of free-grazing cattle and water buffalo they raise. In recent years this has been difficult due to rice shortages that have necessitated the selling of cattle. The cattle and buffalo raising is oriented to serve the growing cattle market in the area. Que has been affected by land allocation policies and, since 2002 when enforced land allocation took place, the area available for swiddening has been limited to the south-eastern portion of the hamlet.

Can hamlet is an example of a community that has transitioned from a composite swidden community to one where the fallow lengths of upland fields have fallen to 2 years or less. This hamlet is firmly on the pathway to a

farming system that features permanent cultivation of upland fields; two crop a year paddy fields; and an increase in large animal husbandry that is pastured in defined fields. The upland areas are becoming grass dominated as the pasturing of cattle prevents the reestablishment of bush vegetation. Cattle and buffalo are transitioning from free-grazing to free-grazing during the day and penned at night. The transition in the farming system practices have been influenced by the enforced land allocation that took place in the late 1990s and by the increased attention of local authorities due to the hamlet's inclusion in the Pu Mat National Park buffer zone.

Ma hamlet is an example of a community where swidden/fallow systems have been practiced for as long as anyone can remember. Farmers report that they will continue to practice this form of agriculture and note that the main change they are making is in the increased investment in raising cattle for the market. The cattle are raised as free-ranging/grazing ‘forest’ cattle. Land allocation was attempted in the hamlet in 1998 but effectively rejected by the hamlet leaders. Extension agents almost never visit the hamlet or the surrounding hamlets within the commune due to its isolation.

Tat hamlet is an example of a community that has always practiced composite swidden cultivation and is currently in the process of modifying this system by increasing paddy area, changing the crop varieties grown in the swidden/fallow fields, and increasing the number of cattle raised within the hamlet. Cattle are mostly free-grazing, but some households have cattle that return to the housing compound at night and are penned beneath the house.

Pigs are also raised in each hamlet, with about one-half being raised in a traditional fashion, they are left to forage for themselves, and the other half are newly introduced varieties raised in small pens or sties. Table 5 details the observed farming system change trajectory of each hamlet under current conditions.

In order to estimate the future changes in GHG contributions, several assumptions are made for each farming system based on Table 3’s change trajectories. The changes to the activities that contribute GHGs and the assumptions made for each hamlet are summarized in Tables 1 and 2 in Appendix 2. A scenario representing the changes in the NMR hamlets’ farming systems desired by the government is outlined in Table 2 of Appendix 2. It is based on an interpretation of the government’s development, land allocation, forestry and agriculture policies for the uplands and outlines the changes to the farming systems of each case study hamlet that would take place if the government policies were strictly followed as well as the

assumptions involved. Table 6 overviews the situation regarding each hamlet’s activities that output GHGs under the presently observed farming system change trajectory and under an assumed trajectory if the government recommended farming system changes are made.

To illustrate the amount of GHGs that are contributed to the atmosphere at the time of the study, under the presently observed change trajectory scenario and under the full implementation of government policies scenario, calculations based on the IPCC guidelines are done. Tables 7 and 8 summarize the amount of GHGs (converted into CO₂ equivalents) that are contributed by changes from the ‘time of study’ scenario to the ‘presently observed change’ (O) scenario and the ‘full implementation of government policies’ (G) scenario. In the O scenario, only changes in emissions from increased livestock numbers and paddy fields are listed, while in the G scenario effects of changes in land use/cover are given as well. The emissions have been summed up over a 20-year period to allow comparison of effects of changes in carbon storage in vegetations and soils with annual emissions from livestock and paddy. The land use/cover conversion, associated with implementation of government policies, has a time horizon of several years, the effects on carbon storage in vegetation and soils will be measurable at time scales of decades, and in relation to CDM projects time scales of 20 years are also of the relevant magnitude.

Vegetation and soil carbon pools

Field work data shows that the live (above ground) vegetation carbon pool increases from close to zero in a harvested plot to around 50 ton/ha over a period of up to 30 years. Whether this accumulation takes place linearly or, more likely, following a logistic curve is not known, but if a linear increase is assumed, this involves an average carbon sequestration in the order of 1.7 ton/ha per year. These estimates, however, are based on the assumption that present illegal logging levels (2–3 ton timber/ha) are

Table 5 Farming systems of four case study hamlets

Hamlet	Historical farming system	Current farming system	Observed trajectory of farming system change
Que Hamlet	Swidden/fallow system	Swidden/fallow system with a few paddy areas	Composite swidden system expand paddy, decrease fallow length/permanent upland fields; increase large animal husbandry
Can Hamlet	Composite swidden system (1 crop/year in paddy)	Composite swidden system; some permanent upland fields	Paddy (2 crop/year) and permanent upland fields; increase large animal husbandry and pigs
Ma Hamlet	Swidden/fallow system	Swidden/fallow system	Swidden/fallow system; increase large animal husbandry
Tat Hamlet	Composite swidden system (1 crop/year in paddy)	Composite swidden system (2 crop/year in paddy; paddy area increasing)	Composite swidden system expand rice paddy area; decrease fallow length for upland fields, even moving to permanent fields; increase large animal husbandry and pigs

Table 6 Inputs to GHGs for each hamlet

Activity	Tat Hamlet	O	G	Que Hamlet	O	G	Can Hamlet	O	G	Ma Hamlet	O	G
Upland fields in rotation	75 ha	→	↓	43 ha	→	↓	80 ha	→	↓	159 ha	→	↓
Upland fields - permanent	0 ha	→	↑	0 ha	→	↑	0 ha	→	↑	0 ha	→	↑
Area of permanently re-growing bush/trees	0 ha	→	↑	0 ha	→	↑	0 ha	→	↑	0 ha	→	↑
Rice paddy	18 ha (2 crops)	↑	↑	4 ha (2 crops)	↑	↑	27.5 ha (2 crops)	↑	↑	0	→	→
Main Crops (upland)	Rice (45 ha); maize (30 ha)	R↓ M↑	R↓ M↑	Rice (43 ha); <1 ha maize	→	→	Rice (72.1 ha); maize (7.9 ha)	R↓ M↑	R↓ M↑	Rice (159 ha); <1 ha maize	→	→
Paddy area	Crop 1 multiple aeration; Crop 2 single aeration	→	→	Crop 1 multiple aeration; Crop 2 single aeration	→	→	Crop 1 multiple aeration; Crop 2 single aeration	→	→	-	→	→
Upland cultivation practice	Swidden (2 - 3 years crop; 3 - 5 fallow)	→	Permanent	Swidden (1 year crop; 3-5 years fallow)	→	Permanent	Swidden (1 year crop; 1-2 years fallow)	→	Permanent	Swidden (1 year crop; 5 to 10 years fallow)	→	Permanent
Crop residue upland field	Leave on field—eaten or decay	→	→	Leave on field—eaten or decay	→	→	Leave on field—eaten or decay	→	→	Leave on field—eaten or decay	→	→
Crop residue paddy fields	Burn	→	→	Burn	→	→	Burn	→	→	-	→	→
Fertiliser (N application) upland fields	None	→	→	None	→	→	None	→	→	None	→	→
Fertiliser (N application) paddy fields	48 kg/ha/crop	↑	↑	None	↑	↑	None	↑	↑	None	↑	↑
Manure application (upland fields)	None	→	↑	None	→	↑	None	→	↑	None	→	↑
Manure application (paddy fields)	4.2 ton/ha manure/compost (2.1 ton/crop)	↑	↑	None	→	↑	5 ton/ha compost (manure and organic waste—2.5 ton per crop)	↑	↑	-	→	→
Livestock	Cattle—335 Buffalo—168 Pigs—304	↑	↑	Cattle—149 Buffalo—117 Pigs—130	↑	↑	Cattle—146 Buffalo—171 Pigs—952	↑	↑	Cattle—474 Buffalo—179 Pigs—497	↑	↑

Table 6 continued

Activity	Tat Hamlet	O	G	Que Hamlet	O	G	Can Hamlet	O	G	Ma Hamlet	O	G
Manure Management	Cattle—free ranging Buffalo—free ranging Pigs—half free ranging; half penned (drylot)	C→ B→ P: free↓ P: pen↑	C, B and P: free↓ pen↑ P: free=0	Cattle—free ranging Buffalo—free ranging Pigs—half free ranging; half penned (drylot)	C→ B→ P free ↓ P pen↑	C, B and P: free↓ pen↑ P: free = 0	Cattle—free ranging (day); penned (night) Buffalo—free ranging (day); penned (night) Pigs—half free ranging; half penned (drylot)	C→ B→ P free↓ P pen↑	C, B and P: free↓ pen↑ P: free = 0	Cattle—free ranging Buffalo—free ranging Pigs—half free ranging; half penned (drylot)	C→ B→ P free↓ P pen↑	C, B and P: free↓ pen↑ P: free = 0
Livestock feed	All local feed (grass or fodder collected by household)	→	→	All local feed (grass or fodder collected by household)	→	→	All local feed (grass or fodder collected by household)	→	→	All local feed (grass or fodder collected by household)	→	→

Present values are given in the table; projected changes in GHG relevant parameters are indicated for two future scenarios: O observed farming system change trajectory (as outlined in Table 2 of annex 2) and G forecast changes if government policies are effectively implemented. ↑ indicates increased inputs relative to present, ↓ indicates decreased inputs relative to present, and → indicates unchanged inputs relative to present. Quantitative details found in annex 2

maintained. Christiansen (2006) concluded, that present levels of logging in fallows and secondary forests leads to considerably lower carbon sink potentials, than what is found in undisturbed forests of the same area (up to 250 ton/ha). It is therefore very likely, that a reduction in logging pressure could increase yearly accumulation potentials to a level of at least 3 ton/ha per year, and that this accumulation will continue over a period of more than 50 years.

The total carbon pool, CP_{tot}, associated with a given land use at village scale, may be determined as

$$CP_{tot} = \sum_n (A_n \times C_n),$$

where A_n is the area of fallow/secondary forest of age n, and C_n is the carbon pool per unit of area of a n year old fallow/secondary forest. This calculation needs only to be carried out for the land area affected by agricultural change. For each village and scenario we therefore need to establish A_n(n) for values of n between 0 and 30 years (or whatever time frame we work within). C_n(n) is assumed to be known, and in the above we have used a linear approximation (C_n = 1.7 × n ton/ha or C_n = 3.0 × n ton/ha, depending on whether illegal logging is taking place). We have defined the O scenarios to be identical to the baseline with respect to upland fields, so no change in carbon stocks takes place. The G scenario, on the other hand, is defined as having much smaller areas of upland fields, which are cultivated permanently or in short fallow rotation. The upland areas given up are assumed to develop into secondary forests. The resulting increases in carbon stocks are shown in Tables 7 and 8.

The assumptions made involve two problems: (a) the assumption of linearity causes shifting cultivation in uplands to have greater negative impacts on carbon stocks than a more realistic growth curve. The effect is estimated to be relatively small, however, when considering only a time period of up to 20 years. More realistic growth curves, not the least for fallows/secondary forest not affected by illegal logging, would be very useful. (b) The assumption of carbon stocks being only a function of the age of the fallow, rather than the full history of the plot, is unrealistic in a situation where the rotation system is changing: the accumulation of carbon in a plot may be expected to be slower the more intensively the plot has been cultivated in the past. Again, this effect is estimated to be small.

The soil organic carbon (SOC) pool in the upper 0.5 m (which is assumed to correspond to the soil layer directly affected by land use/cover change) is found to be between 3 and 6 kg/m² with an average of 5 kg/m² (Bruun, in preparation). The spatial variability, however, is so large that it hinders the estimation of the losses/gains associated

with land use change. Claims in the literature (Palm et al. 2000) of losses on the order of 25% of the ‘original’ carbon pool over a 50-year period, when moving from a situation of medium length fallow (approx. 5 years) to continuous cultivation, would involve an annual average loss of around 0.25 ton/ha per year. Similarly, a shortening of the fallow period from 5 to 3 years may involve a loss of 10% of SOC, corresponding to 5 ton/ha. If this loss is assumed to take place over a 50-year period, it would correspond to an average annual loss of 0.1 ton/ha per year. We consider these values to be somewhat speculative, and further research into the effects of land use change on SOC is required. The orders of magnitude involved are, however, so large that they potentially dominate the estimation of net emissions from agricultural change in the region, and they will strongly influence the overall conclusions, especially concerning the feasibility of CDM projects.

Tables 7 and 8 do not include entries on other sources of GHG emissions, such as changes in burning and production and use of mineral fertilizers. These are either of insignificant size or impossible to estimate on the basis of available data.

The result from examining these scenarios is that if the hamlets studied continue on their current farming system change trajectory an increase in net emissions over a 20-year period ($\rightarrow 2024$) would occur in all villages, ranging from 7 to 14.5 Gg CO₂ excluding soils, and from 7 to 15 Gg CO₂ including soils. The estimate of emissions including soils is very uncertain. Similarly it is suggested that if the government successfully implements its land allocation and VAC and RVAC programs in these hamlets, the present net emissions would be replaced by a net sequestration of between 0 and 45 Gg CO₂ excluding soils, 0–52 Gg CO₂ including soils, over the same 20-year period, generated primarily by increased soil and vegetation uptake in abandoned upland fields.

It should be noted that the “observed farming system change” trajectory ignores potential sequestrations resulting from “unforced” upland field management shifts. Since the

studied villages represent different stages in an ongoing process of land allocation policies, it could easily be argued that this static view is not entirely justified, and that a clearer separation between baseline management and projected future management would be more realistic. If upland management, therefore, was allowed to change in the “observed farming system change” trajectory, i.e. as a result of continued adaptation to present land policies (reduced area and/or reduced fallow times) or adoption of improved fallow management strategies, which are just beginning to be seen in Tat hamlet, the vegetation and SOC values would be similarly affected, changing the above conclusions.

Uncertainty and sensitivity of estimates

It is evident that many of the estimates of emissions are uncertain. Standard values of emission factors are used, even though local variations may be great. These uncertainties are most serious in cases where the estimated emissions are of a significant size. The overall GHG emissions and changes in carbon storage are believed to be particularly sensitive to uncertainties on the following points:

- Assumptions concerning the long-term accumulation of carbon in above- and below-ground biomass, beyond the level of typical fallow vegetation.
- Estimates of the carbon content of soils and assumptions concerning its response to changes in land use and cultivation techniques.
- CH₄ emission factors for livestock (and in particular cattle and buffalo). Standard IPCC factors have been used, not taking into account the feed used and other local factors.
- N₂O emissions factors for manure, depending strongly on assumptions concerning manure management techniques.
- CH₄ and CO emissions factors related to burning. Standard factors do not take the characteristics of the

Table 7 Total effect of land use changes on carbon emissions and sequestrations over a 20-year period relative to baseline values for the ‘observed farming system change’ trajectory

Hamlet	GHG emissions from livestock and manure	GHG emissions from paddy	GHG emissions from vegetation	GHG emissions from soils	Net effect (incl. soils)
Tat	-11.0	-0.4	0	-0.24	-11.4 (-11.64)
Can	-7.2	-0.4	0	-0.25	-7.6 (-7.85)
Que	-6.2	-1.0	0	-0.14	-7.2 (-7.34)
Ma	-14.6	0	0	-0.50	-14.6 (-15.1)

GHG emissions are calculated as net change from tables 1, 2 and 3 in Appendix 3 multiplied by 20 years. Emissions from vegetation caused by the shortening of fallow cycles are relatively small and not included. The emissions from SOC changes caused by shortening of fallows are given in brackets due to large uncertainties. Results are given in Gg CO₂ equivalents. Net emissions have a negative sign, sequestration positive

Table 8 Total effect of land use changes on carbon emissions and sequestrations over a 20-year period relative to baseline values for the ‘implementation of government policy’ trajectory

Hamlet	GHG emissions from livestock and manure	GHG emissions from paddy	GHG emissions from vegetation	GHG emissions from soils	Total (incl. soils)
Tat	-11.0	-1.4	16.0	1.77	3.6 (5.37)
Can	-7.2	-1.8	8.5	0.63	-0.5 (0.13)
Que	-6.2	-2.6	9.2	1.01	0.4 (1.41)
Ma	-14.6	0	59.5	7.50	44.9 (52.4)

Net emissions from vegetation are calculated as 20 years multiplied by the average annual change in carbon stocks multiplied by the area of land use changes assumed to take place over 20 years. Emissions associated with SOC changes, resulting from changes from swidden/fallow to permanent cultivation, from swidden/fallow to forest and from shortening of fallows are given in brackets, due to large uncertainties. Results are given in Gg CO₂ equivalents. Net emissions have a negative sign, sequestration positive

burn and the humidity of the fuel into account, and lead to estimates of insignificant magnitude. Humid fuel will cause a higher proportion of the carbon to be emitted as CH₄, giving rise to a much stronger GHG effect.

- Assumptions concerning fertilizer use in both paddy and semi-permanent upland fields.

The first two of these sources of uncertainty have the greatest potential impact, and in particular the observed spatial variability of SOC causes uncertainties in estimates of emissions caused by land use change.

Discussion

The farming systems changes and the related effects on carbon pools and GHG emissions in Vietnam’s NMR may be discussed from a number of different perspectives:

1. A carbon accounting and CDM perspective: do current, or foreseeable, agricultural development trends imply significant contributions, positive or negative, to atmospheric concentrations of GHGs? Do these contributions provide a basis for establishing CDM projects?
2. A broader environmental perspective: will conservation and climate change mitigation interests coincide in Vietnam’s NMR?
3. A national, economic perspective: will the development of a global market for carbon quota allow Vietnam to sell carbon storage, in the form of CDM-projects, and are the potential profits large enough to influence government policies on land use and land tenure?
4. A local livelihood perspective: will the option of CDM-projects be to the benefit or loss of local farmers? How will they affect food security?

The carbon accounting and CDM perspective

This paper has mainly addressed the first of these questions and, given the data available, only very preliminary

conclusions can be drawn in relation to it. The four cases studies presented here and the overall trajectory of farming system changes seen in the NMR suggest that the direction and size of GHG flows in the NMR will primarily be determined by the amount of carbon sequestered by the vegetation. The vegetation carbon pool clearly dominates calculations even given the rather conservative estimations taken here. Despite the potential net-sequestrations that appear to be possible by decreasing swiddening, this study shows how such changes come at the expense of significant “leakage” effects, since the replacements for swiddening activities (primarily paddy cultivation and animal husbandry) cause significant GHG emissions. As the accumulation of C in re-growing vegetation is fastest over the first 30-year period, net emissions will be negative seen over this period. Since this accumulation effectively stagnates beyond the first 30 years (at least without changed tree/forest management as suggested below), the other elements of the agricultural development trajectories, that cause increasing emissions, take over after this period, and eventually lead to positive net-emissions for the system as a whole. As shown earlier, one way to delay this is to assure that C accumulation, above- and below-ground, continues over a longer period, which would require ‘C maximizing’ tree/forest management, allowing the secondary forest to develop into ‘real rain-forest’.

These reflections lead us to suggest that the net-GHG effect of future agricultural development trajectories, and thus the potential for establishing ‘green’, sink CDM projects, depends on at least four key factors related to the management of the vegetation carbon pool:

- (a) The maximum biomass potential of re-growing fallows. This depends on logging activities. As suggested above, reducing or abandoning logging practices in the fallows could significantly increase total sequestration potential as well as yearly uptake. In the present scenarios the maximum biomass level

was kept to 50 ton C/ha over a period of 30 years. A simple calculation example in Ma hamlet suggests that even a modest increase in the yearly accumulation rate up to 3 ton/ha per year would double net sequestrations over the 30-year period and reach a level above 300 Gg CO₂. When considering CDM options in the NMR, therefore, policies, enforcements and incentives aimed at reducing logging below present levels could constitute an all-important parameter.

- (b) Choice of 'baseline'. What baseline or "business as usual" emission/sequestration scenarios are used for the area, and what is considered "additional" developments? In relation to this, the most important factors are how (i) existing (but in some hamlets not yet implemented) policies, especially concerning land allocation, and (ii) existing bans on logging, are dealt with. If full implementation of government policies, aimed at limiting swidden/fallow and eliminating illegal logging, are included in the baseline scenario, the potential for CDM projects is strongly reduced.
- (c) Timing and length of accounting periods. Sequestration gains are maximised if accounting periods coincide with the primary growth period of re-growing vegetation, but are lower or even negative for subsequent or longer periods (i.e. greater than 30 years). This indicates the relevance of suggesting that CDM projects produce 'temporary carbon credits', rather than permanent ones.
- (d) Leakage problems. If 'green' CDM projects were to be established in upland areas of the NMR, and if farmers were not fully compensated for their loss of income/subsistence due to limitations to upland shifting cultivation, they may be pushed to find other upland areas, e.g. in the Central Highlands, where they could settle and take up agriculture. This would imply that vegetation carbon pools would be reduced in other parts of Vietnam as a consequence of CDM-projects. This is what is normally termed 'carbon leakage'. The way to avoid leakage is to make 'carbon management' economically attractive to farmers. This may be achieved under three assumptions: firstly, there must be a sizeable potential for increased carbon storage, measured relative to a relevant baseline, as discussed above. Secondly, the opportunity costs of using upland areas for carbon storage must be sufficiently small and the price of CO₂-quota sufficiently high to make CDM projects profitable. Thirdly, CDM projects must be designed and organized in such a way that farmers, rather than government institutions at all levels, harvest the benefits.

The first of these assumptions have been discussed in extenso in this paper. The second depends, in a 30-year perspective, very much on the outcome of the ongoing negotiations of the second commitment period of the Kyoto Protocol. The third assumption, concerning organizational aspects of CDM, will be discussed below.

The broader environmental perspective

The second question is often assumed to have a positive answer: increasing carbon stocks generally coincide with increasing forest cover, which is a central environmental concern. However, the positive relationship between increasing forest cover and biodiversity is not always present and in the NMR, where population densities in the highlands are generally low, conservation interests may not be best served by increasing forest cover alone. The land cover mosaic, created by swidden/fallow, may actually support higher biological diversity than dense secondary forest (Schmidt-Vogt 1998; de Jong 1997), and if environmental protection gives priority to biodiversity conservation this implies that the positive relationship between building up carbon stocks and environmental protection breaks down.

The economic perspective

With respect to the third question, rich, industrialized countries ('Annex 1 countries' according to the Kyoto protocol) will be in the market to acquire emission quota by funding CDM project activities in non-annex 1 countries. The question raised here is whether such sink projects are likely to be attractive to the countries on the market to buy credits, to the Vietnamese government, and to local farmers. The interests of the national government and provincial authorities are closely linked to the above discussion on 'additionality' and choice of base-line scenarios. There seems to be agreement between present government land allocation policies (aimed at limiting swidden/fallow cultivation) and increased carbon storage that, on one side makes CDM projects an attractive option, yet on the other side creates problems with claiming that CDM projects limiting swiddening are really 'additional'.

From the case studies above, it appears that only under certain conditions will these trajectories lead to significant increases in carbon storage and reduction in emissions. However, viewed in isolation from other agricultural changes, an abandonment of swidden/fallow will increase carbon storage. The potential income from carbon credits obtainable from such a change depends on a number of

factors: (a) how much carbon can actually be stored, and over what time period, (b) the market price of carbon credits, and (c) the ‘transaction costs’ of such projects. If projects are implemented they need to be checked against a set of rules requiring proof of their additionality and sustainability. Both demands may be difficult to fulfill: considerable ‘carbon-leakage’ may occur, as discussed above, and local livelihoods and food security may be threatened by abandoning swidden/fallow cultivation, as argued below.

The option of benefiting from CDM may require that ‘carbon optimized’ development pathways are identified. Such pathways, as discussed above, may involve forest management with carbon storage as one among several objectives. If a slow but continuous increase in above- and below-ground carbon storage could be obtained by such management, expected increases in the price of carbon credits might make carbon storage a realistic ‘product’ or ‘service’ produced by upland farmers.

There are substantial challenges related to establishing ‘green’ CDM projects in Vietnam’s NMR. These are associated with (a) the establishment of an efficient monitoring system, documenting the increases in carbon stocks, (b) assuring that increased carbon stocks (which represent an economic value as timber) are protected against illegal logging, (c) reducing the risk that the fires used to clear fields for cultivation do not destroy carbon stocks, and (d) organization of community-based carbon management, assuring a fair distribution of incomes and tasks between farmers. Dealing with these challenges will create ‘transaction costs’, which may offset the economic gains of CDM projects. However, in Vietnam even remote villages are relatively well structured, which may form the basis for a CDM-related organization.

If the carbon credits sold to Annex 1 countries are permanent, farmers would be excluded from ever farming the abandoned swidden/fallow fields again since this would release the carbon stock. Given the population growth in Vietnam in general and in the uplands specifically, this may not be a viable solution. Rather, it might be worthwhile considering the option of selling only temporary credits in this type of ‘green’, sink CDM project. This would, however, imply a lower price.

The local livelihood perspective

The fourth question does not have a simple answer, since livelihood strategies vary widely, between regions and even between hamlets as documented by the case studies. Taking these case study hamlets as examples, it is obvious that the restrictions on swiddening, which would cause a considerable build-up of carbon stocks in vegetation and soils, would also threaten food-sufficiency and incomes.

This is already the case in Que hamlet, where the land allocation process has been effectively enforced and swidden/fallow areas have decreased from 120 ha in 1998 to 43 ha in 2003 (Jakobsen et al. 2006). The result is that the hamlet households have had to sell cattle in order to purchase rice. It is also clear that Que has the lowest contribution of GHGs from its farming system. The example from Que shows that while it may be tempting to enforce restrictions on swiddening to increase carbon stocks and increase forest cover to obtain the benefits noted above, these restrictions may severely threaten the farmers’ livelihoods and food-sufficiency.

Illegal logging is a very important factor determining the build-up of carbon stocks in fallow vegetation, secondary forest, and mature rainforest. If this logging could be substantially reduced, much larger carbon sequestration would result, which, in the case that a CDM project was in operation, would create income. Abandoning logging implies a serious income loss to the local population, yet in cases where the price of carbon credits is high enough; the sale of these credits may replace the loss of logging income. It is thus suggested that if income generated from selling carbon credits does benefit farmers/forest land managers, CDM projects could become an attractive element in local livelihood strategies. The world market prices on carbon credits are, however, still quite low.

Conclusion

The analysis shows that ongoing farming systems development trends in the uplands of Vietnam have significant effects on GHG emissions and carbon storage. Change in the vegetation and soil carbon pools are the largest factors in villages where substantial land use change takes place. If government policies aimed at reducing swidden/fallow cultivation and replacing it with paddy cultivation and animal husbandry were fully and continuously implemented, the result would be a considerable increase in carbon stocks. In particular, the data for Ma hamlet illustrates this. Both the increase in paddy cultivation and in animal husbandry would increase GHG (and particularly the CH₄ and N₂O) emissions, yet this is more than balanced by the CO₂ sequestration in the fallow vegetation developing into forest and in the soils lying undisturbed under these vegetation types.

The size of the negative net emission is controlled mainly by the effects of logging activities. Logging severely limits both the rate of tree/forest growth of the first 20 years and the maximum level of carbon stocks. This implies that if the carbon sequestration were to form the basis of CDM projects, it is of crucial importance that a ‘carbon maximizing’ forest management strategy that reduces logging activities

is implemented. This would require the active participation of the local population. This is probably only realistic if incomes from the sale of carbon credits compensate farmers for their losses from giving up illegal logging and swidden/fallow cultivation. Thus, prices of carbon credits must be high enough for this to be realistic.

The possibility of establishing CDM-projects that create local income is further conditioned by whether such projects fulfill the requirements with respect to a well-defined baseline and to 'additionality'. Both demands may create problems in the current case: the baseline scenario may (or may not) include the expected effects of the effective implementation of current Vietnamese government policies on land allocation. If it does, it would seriously limit the obtainable carbon credits, since current policies in themselves promote reduction of the area under swiddening, and will lead to increases in carbon stocks. If a more conservative 'business as before' scenario is used as a baseline, much higher carbon sequestration could be claimed. This, however, may be difficult to argue due to the fact that implementation is well underway. The same problem can be expressed in terms of 'additionality' of a CDM project: if high carbon sequestration would happen due to ongoing processes of reducing swiddening, it will be difficult to consider as 'additional' a CDM project that has the exact same result.

There are a number of additional problems associated with organizing CDM projects in remote upland areas, as those in question here. Whether the transaction costs associated with these problems will offset the potential benefits from CDM projects is not known.

It may also be argued that 'green' sink CDM projects of the sort described here should only produce temporary carbon credits, since national and local population growth may require that land given up to CDM projects is brought back into agriculture at some future time. There is likely to be a market for such temporary carbon credits, but the exact rules controlling the market as well as the prices are presently not known.

Finally, it needs to be emphasized that the improvement in carbon sequestration that is demonstrated above resulting under the 'full implementation of government policies' scenario is conditioned on the people's response to the implementation of the government policies. If the farming system changes promoted by the government do not provide adequate support for the people living in the area, then they will take compensatory actions that may decrease or eliminate the positive effect of the scenario on GHGs. These compensatory actions may be in the form of the inhabitants moving to another location where they can continue to practice their present farming system, a situation discussed in the section on CDM 'leakage problems'; or the farmers may seek compensation for accepting the

government policies by practicing illegal logging in areas that are not easily monitored; or the farmers may, after a time, restart their swidden/fallow system in areas that are officially relegated to tree/forest growth. If any of these compensatory actions take place after the government scenario has been in place for some years, the overall result could be a situation where the GHG contributions from the government scenario, modified by compensatory actions, equal or become greater than the contributions calculated for the presently observed change scenario. The key to gaining the decreased GHG contributions calculated for the full implementation of the government policy scenario is the provision of benefits to the local people so that they adhere to following the necessary policies and allow the scenario to stay in place over the time span needed for the carbon sequestration to take place.

Acknowledgments Research in Nghe An was funded by DANIDA under the University Support for Environmental Planning and Management Project. Research in Tat hamlet was funded by the Ford Foundation. Special thanks go to the researchers at the Center for Agricultural Research and Ecological Studies, Hanoi Agricultural University, in Hanoi, Vietnam, who helped carry out the research described in this paper. Also, the authors wish to thank Thilde Bruun for help with understanding and analyzing the soil data, Jens Jakobsen for insights into the situation in Que hamlet, and Nguyen Thanh Lam for help with organizing and carrying out the fieldwork.

Appendix 1: Methods for estimating GHG emissions

In the following, we briefly summarize the methods and parameters used in the estimation of the changes in GHG emissions caused by changes in agricultural practices in the four hamlets studied. The methods are based on the approach described in IPCC Guidelines for National Greenhouse Gas Inventories (1997, 2000).

1. Methane from enteric fermentation

The methane emissions from enteric fermentation depend mainly on animal type, production level, feed intake and feed quality. The IPCC methodology distinguishes methods with increasing detail. The simplest methodology, which is applied here, uses a fixed emission factor per animal. The emission factors that are used for the NMR of Vietnam are shown in Table 9.

Table 9 Enteric fermentation emission factors (kg CH₄ per head/year) (IPCC 1997)

Livestock*	Emission (kg CH ₄ head/year)
Cattle, non-dairy	44
Pigs	1

2. Methane from manure management

Methane is emitted during storage of animal manure, and the emissions depend on manure type, storage conditions and climate. The emissions increase with increasing temperature, and IPCC (1997) therefore consider three different climates depending on mean annual temperature: cool (temperature below 15°C), temperate (temperature from 15 to 25 °C) and warm (temperature above 25°C). The NMR of Vietnam has an average yearly temperature of 23.2°C, a temperate climate, heavily influenced by the fact that winter temperatures can average in the teens and come close to freezing at night during December, January and February.

The following types of manure management are considered:

(a) *Grazing* The manure from animals grazing on pastures or grasslands is allowed to lie as is. This applies to cattle and buffalo in the study area.

(b) *Drylot* Animals kept on unpaved feedlots where the manure is allowed to dry until periodically removed (dry climates). This is assumed to apply to pigs in the study area.

3. Nitrous oxide from manure management

Nitrous oxide will be emitted from faeces and urine excreted by animals, primarily during storage of the manure. The emissions are estimated using emission factors (kg

N₂O— per kg N excreted) that differ depending on the type of manure management. The same categories of manure management systems as applied for methane from manure management are used. No specific information on the amount of N excreted was available, so the values in Table 10 from IPCC (1997) for Asia were used.

4. Methane from rice production

The methane emissions from rice production strongly depend on the production system. The factors primarily affecting emissions include the water status of the rice system and the amount of plant residues applied. The emission factor is thus estimated as (IPCC 2000):

$$EF = EF_c SF_w SF_o$$

where EF is the resulting emission factor (kg CH₄/ha), EF_c is the seasonal integrated emission factor for continuously flooded fields without organic amendments (200 kg CH₄/ha), SF_w is a scaling factor to account for ecosystem and water management regime (Table 11), and SF_o is a scaling factor to account for the amount of organic amendments applied (Table 12).

5. GHG-emissions from burning

In agricultural burning, the CO₂ released should not be considered a net emission (IPCC 1997). The biomass burned is generally replaced by regrowth of the subsequent

Table 10 Default values for nitrogen excretion by livestock (kg N per head/year)

Animal type	N excretion (kg N head/year)
Dairy cattle	60
Non-dairy cattle	40
Sheep	12
Poultry	0.6
Pigs	16
Other animals	40

Table 12 Scaling factors (SF_o) for organic amendments (IPCC 2000)

Dry matter ^a applied (ton ha ⁻¹)	SF _o
0–1	1.0
1–2	1.5
2–4	1.8
4–8	2.5
8–15	3.5
>15	4.0

^a The organic amendments in rice straw, animal manure, green manure, compost and agricultural waste is specified in dry matter per ha

Table 11 Scaling factors (SF_w) for rice ecosystem and water management regimes (IPCC 2000)

Category	Water management regime	SF _w	
Upland	None	0	
Lowland	Irrigated	Continuous flooded—standing water throughout the rice growing season and may only be dry for harvest	1.0
		Intermittent flooded—single aeration (more than 3 days) during cropping season	0.5
		Intermittent flooded—more than one aeration period during the cropping season	0.2
	Rainfed	Flood prone—water may rise up to 50 cm during the cropping season	0.8
		Drought prone—drought periods occur during every cropping season	0.4

years, and an equivalent amount of CO₂ will be removed from the atmosphere during this regrowth. However, the burning will also release non-CO₂ greenhouse gases (CH₄ and N₂O). These emissions may be estimated following the IPCC methodology, where the emissions are proportional to the amount of carbon in the biomass burnt.

The methane emissions E_{CH_4} (kg CH₄/ha) are calculated as

$$E_{CH_4} = C R_{CH_4} 16/12$$

where C is the carbon released by burning (kg C/ha) and R_{CH_4} is the emission ratio, which is set to 0.004 for savannah burning and 0.005 for crop residue burning.

The nitrous oxide emissions E_{N_2O} (kg N₂O/a) are calculated as

$$E_{N_2O} = C R_{N_2O} R_{NC} 44/28$$

where R_{N_2O} is the emission ratio (0.007), and R_{NC} is the N/C ratio of the biomass burnt.

6. Nitrous oxide from fertilisers, manures and crop residues

All inputs of nitrogen to the cropping system will give rise to emissions of nitrous oxide. The emissions are estimated from the amount of nitrogen applied as input to the system multiplied with an emission factor, which varies depending on input type. The default emission factors are shown in Table 13.

The ammonia volatilisation is subtracted from mineral fertilisers and manures before applying the emission factor. An ammonia emission factor of 10% is used as default for fertilisers and 20% for manures.

The amount of crop residues and the N-fixation from crops with biological N fixation is estimated from the crop yields.

There are also nitrous oxide emissions from indirect sources, i.e. from ammonia volatilisation and nitrate leaching. These are also estimated using emission factors, and the amount of ammonia volatilisation and nitrate leaching may be estimated as a fraction of the nitrogen input.

Table 13 Default emission factors for N₂O emissions for N applied to soils (kg N₂O–N per 100 kg N) (IPCC 2000)

Type of nitrogen input	Emission factor (%)
Mineral N fertiliser	1.25
Animal manure	1.25
Crop residues	1.25
Nitrogen fixation	1.25

Table 14 Assumptions concerning future changes in agricultural land use, crops and methods for each hamlet, based on the observed farming system change trajectory

Activity	Tat Hamlet	Que Hamlet	Can Hamlet	Ma Hamlet
Upland fields	75 ha	43 ha	80 ha	159 ha
Assumption	All upland cultivated areas will remain approximately the same; fallow length may decrease			
Rice paddy	23 ha (2 crops) (+5 ha)	19 ha (2 crops) (+15 ha on flat alluvial area)	32.5 (2 crops) (+5 ha)	0
Assumption	Expansion of paddy area by terracing and building dams to store water for increased irrigation is encouraged by government policy and subsidized. This will happen in areas where it is possible to expand paddy. Tat and Can have some areas available. Que has 15 ha of alluvial flat land that can be expanded into if water is available			
Main Crops (upland)	Rice (30 ha); maize (45 ha)	Rice (43 ha); <1 ha maize	Rice (50 ha); maize (30 ha)	Rice (159 ha); <1 ha maize
Assumption	Maize production is encouraged by government programs. Where farmers have resources and are in contact with extension agents, maize production will be expanded. Can and Tat fit this profile			
Paddy area	Crop 1 multiple aeration; Crop 2 single aeration	Crop 1 multiple aeration; Crop 2 single aeration	Crop 1 multiple aeration; Crop 2 single aeration	–
Upland cultivation practice	Swidden (2–3 years crop; 3–5 fallow)	Swidden (1 year crop; 3–5 years fallow)	Swidden (1 year crop; 1–2 years fallow)	Swidden (1 year crop; 5–10 years fallow)
Crop residue upland field	Leave on field–eaten or decay	Leave on field–eaten or decay	Leave on field–eaten or decay	Leave on field–eaten or decay
Crop residue paddy fields	Burn	Burn	Burn	–

Table 14 continued

Activity	Tat Hamlet	Que Hamlet	Can Hamlet	Ma Hamlet
Fertiliser (N application) upland fields	None	None	None	None
Fertiliser (N application) paddy fields	100 kg/ha/crop	50 kg/ha/crop	100 kg/ha/crop	None
Assumption	Farmers try to use chemical fertilizers on their paddy fields, this will expand as resources are more available in Tat, Can, and Que. In Tat and Can they will likely use the recommended amount (between 90 and 120 kg/ha); in Que where resources are limited they will likely use less—estimate 0.5 of recommended (similar to the situation in Tat in 2003 after 4 years of extension work)			
Manure application (upland fields)	None	None	None	None
Manure application (paddy fields)	6 ton/ha manure/compost (3 ton/crop)	None	7 ton/ha compost (manure and organic waste—2.5 ton per crop)None	–
Livestock	Cattle 624 Buffalo 274 Pigs 333	Cattle 200 Buffalo 273 Pigs 153	Cattle 200 Buffalo 297 Pigs 1,162	Cattle 723 Buffalo 420 Pigs 707
Assumption	Ma hamlet is most oriented to large animal husbandry and expanded their herds the most—from 2000 to 2003, they had an average increase of 36 head of cattle/year, 35 head of buffalo/year and 30 pigs/year; Can hamlet has local rules prohibiting cattle raising, but encouraging buffalo raising for local use, they are most influenced by government extension efforts and in the past have aimed to increase pig raising in pens—because of the local rules it is forecast that the increase in cattle will be close to 0, buffalo will increase on a basis similar to Tat, where the use of buffalo is also similar, and pig raising will increase on a par with Ma where extension efforts from the government are credited with getting people to increase their pig raising in pens; Que hamlet has few resources for purchasing animals, they had to sell cattle in recent years to pay for rice (total number of cattle decreased by 53 from 2000 to 2003)—therefore the number of cattle is forecast to increase to close to the number in 2000, buffalo will continue to increase at a rate of 22 head/year (the average yearly increase between 2000 and 2003) to be used in the expanding rice paddy areas, and pigs will increase at the rate they have since 2000 (3 pigs/year); Tat hamlet is forecast to continue increasing cattle, buffalo and pigs at the rate that they increased between 1999 and 2004—48 cattle/year; 18 buffalo/year; and 4 pigs/year; reflecting the market demand in the lowland for cattle and to a lesser extent buffalo			
Manure management	Cattle—free ranging Buffalo—free ranging Pigs—onethird free ranging; twothird penned (dry/lot condition)	Cattle—free ranging Buffalo—free ranging Pigs—onethird free ranging; twothird penned (dry/lot condition)	Cattle—free ranging (day); penned (night) Buffalo—free ranging (day); penned (night) Pigs—onethird free ranging; twothird penned (dry/lot condition)	Cattle—free ranging Buffalo—free ranging Pigs—onethird free ranging; twothird penned (dry/lot condition)
Assumption	Almost all expansion of pig raising will be in line with government extension efforts to raise pigs in pens (manure is managed under dry/lot conditions); other animal husbandry practices will stay the same			
Livestock feed	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)
Assumption	All animal feed will continue to be locally collected and processed from local fodder			

Table 15 Forecast agricultural changes for each hamlet if government policies were effectively implemented

Activity	Tat Hamlet	Que Hamlet	Can Hamlet	Ma Hamlet
Upland fields	75 ha	43 ha	80 ha	ha
Assumption	Cropping will go from swidden/fallow system to permanent fields. This will result in the need for fertilizer/manure inputs for upland fields (see below)			
Area of regrowing bush/trees	300 ha	172 ha	160 ha	1,113 ha
Assumption	Upland fields will no longer be periodically cleared for swidden/fallow agriculture, so the area not made into permanent cropping area will be left to regenerate to mature forest (20 years of carbon credit potential). (†at based on 5 year rotation [onefifth in use fourfifth in fallow, so 4 × 75 ha is the amount of hectares that will move from fallow to forest]; Que based on 5 years rotation (4 × 42); Can based on 3 years rotation (2 × 80); Ma based on 8 years rotation (7 × 159)]			
Rice paddy	23 ha (2 crops) (+5 ha)	19 ha (2 crops) (+15 ha on flat alluvial area)	32.5 (2 crops) (+5 ha)	0
Assumption	Same assumption as in Table 12			
Main crops (upland)	Rice (30 ha); maize (45 ha)	Rice (43 ha); <1 ha maize	Rice (50 ha); maize (30 ha)	Rice (159 ha); <1 ha maize
Assumption	Same assumption as in Table 12			
Paddy area	Crop 1 multiple aeration; Crop 2 single aeration	Crop 1 multiple aeration; Crop 2 single aeration	Crop 1 multiple aeration; Crop 2 single aeration	–
Upland cultivation practice	Permanent	Permanent	Permanent	Permanent
Crop residue upland field	Leave on field—eaten or burn	Leave on field—eaten or burn	Leave on field—eaten or burn	Leave on field—eaten or burn
Assumption	Either residue on upland fields is eaten during dry season or it is burned before planting the next year (estimate half eaten; half burned).			
Crop residue paddy fields	Burn	Burn	Burn	–
Fertiliser (N application) upland fields	None	None	None	None
Fertiliser (N application) paddy fields	100 kg/ha/crop	100 kg/ha/crop	100 kg/ha/crop	None
Assumption	Hamlets where rice paddy is cultivated follow extension recommendations for fertilizer in paddy field (between 90 and 120 kg/ha).			
Manure application (upland fields)	5.5 tons/ha	5.5 tons/ha	5.5 tons/ha	5.5 tons/ha
Assumption	Recommendation for permanent fields is to spread between 5 and 6 tons/ha of manure on fields			
Manure application (paddy fields)	5.5 ton/ha/crop manure/compost (16.5 ton/ha/year)	5.5 ton/ha/crop manure/compost (16.5 ton/ha/year)	5.5 ton/ha/crop manure/compost (16.5 ton/ha/year)	–
Assumption	Recommendation for paddy fields is that between 5 tons/ha and 6 tons/ha be spread on paddy field per crop			
Livestock	Cattle—624 Buffalo—274 Pigs—333	Cattle—200 Buffalo—273 Pigs—153	Cattle—200 Buffalo—297 Pigs—1,162	Cattle—723 Buffalo—420 Pigs—707
Assumption	Same assumption as in Table 1			
Manure management	Cattle—free ranging (day); penned (night)	Cattle—free ranging (day); penned (night)	Cattle—free ranging (day); penned (night)	Cattle—free ranging (day); penned (night)
	Buffalo—free ranging (day); penned (night)	Buffalo—free ranging (day); penned (night)	Buffalo—free ranging (day); penned (night)	Buffalo—free ranging (day); penned (night)
	Pigs—penned (drylot)	Pigs—penned (drylot)	Pigs—penned (drylot)	Pigs—penned (drylot)
Assumption	Allocation of all forest and agriculture land will limit areas where animals can graze; it will be necessary to stable cattle and buffalo at night and pen raise all pigs as per the government extension efforts			

Table 15 continued

Activity	Tat Hamlet	Que Hamlet	Can Hamlet	Ma Hamlet
Livestock feed	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)	All local feed (grass or fodder collected by household)
Assumption	Same assumption as in Table 1			

7. CO₂ and nitrous oxide from fertiliser production

The average GHG emissions associated with the supply of mineral N fertiliser representative for the conditions in Central Europe were used due to lack of local representative data (Patyk and Reinhardt 1997). The emissions also include N₂O from fertiliser production. The emissions associated with production of 1 kg of fertiliser N is estimated at 2.85 kg CO₂, 7 g CH₄ and 15 g N₂O.

Appendix 2: Assumptions concerning agricultural pathways

Using the methodology outlined in Appendix 1, emissions for each scenario may be calculated, based on assumptions concerning the extent of changes. The exact assumptions made are outlined in Tables 14 and 15.

Appendix 3: Emissions from baseline, observed change trajectory, and government change trajectory farming systems

Emissions (in Gg CO₂ equivalents) from the baseline-, O- and G-scenarios, computed using the IPCC Guidelines (Tables 16, 17, 18). Emissions from vegetation burning and from production of mineral fertilizers are not included because they are insignificant. Emissions from use of mineral fertilizers have not been included because of great uncertainty concerning future fertilizer use.

Table 16 Emissions from livestock and paddy in the baseline scenario

	Tat	Que	Can	Ma
Total emissions in Gg CO ₂ -eq				
Livestock	0.51	0.28	0.35	0.66
Manure management	0.39	0.27	0.42	0.48
Paddy (CH ₄ from flooded area)	0.10	0.01	0.15	0
Total	1.00	0.56	0.92	1.14

Table 17 Emissions from scenario O

	Tat	Que	Can	Ma
Total emissions in Gg CO ₂ -eq				
Livestock	0.90	0.50	0.55	1.17
Manure management	0.55	0.36	0.52	0.70
Paddy (CH ₄ from flooded area)	0.12	0.06	0.17	0
Total	1.57	0.92	1.24	1.87

Table 18 Emissions from scenario G

	Tat	Que	Can	Ma
Total emissions in Gg CO ₂ -eq				
Livestock	0.90	0.50	0.55	1.17
Manure management	0.55	0.36	0.15	0.70
Paddy (CH ₄ from flooded area)	0.17	0.14	0.24	0
Total	1.62	1.00	0.94	1.87

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