USAID
FROM THE AMERICAN PEOPLE

PRODUCTIVE LANDSCAPES (PROLAND)

PRIORITIZING INVESTMENTS IN LAND-BASED CLIMATE MITIGATION IN VIETNAM

PHOTO CREDIT: TIM HOLLAND

DECEMBER 2019

This publication was produced for review by the United States Agency for International Development. It was prepared by Tetra Tech.

Prepared for the United States Agency for International Development (USAID) contract number AID-OAA-I-13-00058/AID-OAA-TO-14-00050, Productive Landscapes (ProLand), under the Restoring the Environment through Prosperity, Livelihoods, and Conserving Ecosystems (REPLACE) Indefinite Delivery Indefinite Quantity Contract.

Tetra Tech Contacts:

Mark Donahue, Chief of Party
Mark.Donahue@tetratech.com

Ed Harvey, Project Manager
Ed.Harvey@tetratech.com

Tetra Tech
159 Bank Street, Suite 300, Burlington, VT 05401
Tel: (802) 495-0282, Fax: (802) 658-4247
www.tetratechintdev.com

Photos courtesy of Tim Holland.

PRODUCTIVE LANDSCAPES (PROLAND)

Prioritizing Investments In Land-Based Climate Mitigation In Vietnam

JANUARY 2020

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

1M5R	One Must Do, Five Reductions Program
3R3G	Three Reductions, Three Gains Program
AFOLU	Agriculture, Forestry, and Other Land Use
AWD	Alternate Wetting and Drying
CAIT	Climate Access Indicators Tool
CCAFS	Climate Change for Agriculture and Food Security
CO_2e	Carbon Dioxide equivalent
ECM	Energy-Corrected Milk
EF	Emission Factor
FAO	Food and Agriculture Organization of the United Nations
FOLU	Forestry and Other Land Use
GDP	Gross Domestic Product
GFW	Global Forest Watch
GHG	Greenhouse Gas
ICRAF	World Agroforestry Centre
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
MAC	Marginal Abatement Cost
Mt	Million Tons (Metric)
MONRE	Ministry of Natural Resources and Environment
MRD	Mekong River Delta
$MtCO_2e$	Million Tons (Metric) of Carbon Dioxide Equivalent
N	Nitrogen
N_2O	Nitrous Oxide
NDC	Nationally Determined Contributions
NTFP	Non-Timber Forest Product
PES	Payments for Ecosystem Services
ProLand	Productive Landscapes Project

REDD+	Reducing Emissions from Deforestation and Forest Degradation
SL	Sustainable Landscapes
tCO_2e	Tons (Metric) of Carbon Dioxide Equivalent
TMR	Total Mixed Ration
UNFCCC	United Nations Framework Convention on Climate Change
USAID LEAF	United States Agency for International Development's Lowering Emissions in Asia's Forests
USAID	United States Agency for International Development
WRI	World Resources Institute
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

USAID Sustainable Landscapes (SL) programs promote the sustainable management of forests, agriculture, and other lands to sustain communities, protect ecosystems, and reduce GHG emissions. Prioritizing SL activities for emissions abatement must assess multiple components of any given opportunity, including the magnitude of the emissions abatement, probability of success, cost effectiveness, and presence of any associated benefits or harms. The magnitude of abatement is generally measured in terms of carbon dioxide equivalent (CO_2e) in order to compare the effects of different greenhouse gases. The net cost to land users is the largest factor in overall cost-effectiveness and is one of the most important indicators of the probability of success of a given activity; high costs to land users will render activities either impossible or undesirable to implement. Additionally, in an activity where land users do not have the option of opting in or opting out individually—for example, in the case of forest conservation or restoration where there may be opportunity costs resulting from changes in access to resources—high costs may indicate negative impacts on equity.

Cost is not the only indicator of the feasibility of a given opportunity. Institutional factors, local capacity, social factors, and cultural factors can all affect the probability of success. Some activities may be low cost from the point of view of a landholder but may nevertheless be impractical because of other barriers. Assessing the barriers and enabling factors that influence success of a given activity is highly contextual and not as easily quantified as total abatement potential or net cost; however, understanding those factors is essential for assessing the potential of an activity. Additionally, although emissions mitigation and enhanced sequestration are the primary metrics of success, there may be other co-benefits of the action in addition to any emissions benefits or cost savings. It may be possible to quantitatively assess mitigation, cost, and co-benefits of a particular abatement activity individually, but valuing different priorities of climate mitigation, cost, and co-benefits relative to each other as part of a prioritization exercise will depend on national and donor priorities.

A final element that is important to consider in the prioritization of SL programs is the extent of overlap or synergy both among sectors (investment in one sector would help implementation in another) and geographically (where a geographical region has high potential for multiple types of activity). Activities that may not be a high priority when viewed in isolation may in fact be good options when implemented in conjunction with a suite of other synergistic activities.

OPTIONS FOR SUSTAINABLE LANDSCAPES STRATEGIES IN VIETNAM

The first goal of this report is to identify SL options in Vietnam. For this we relied on two primary sources: an assessment of Vietnam's proposed actions as described in its intended nationally determined contributions (INDC) document (Escobar et al. 2019); and a pair of studies that provide a global overview of a comprehensive set of land-based climate mitigation options as well as national estimates for the potential scale of each of those options (Griscom et al., 2017; 2020).

To evaluate and compare various options, the magnitude of the potential mitigation and the cost effectiveness are two key indicators. The marginal abatement cost (MAC) curve is a common process for ordering the options by cost-effectiveness. The MAC is the full economic cost of the opportunity divided by the mitigation potential. For Agriculture, forestry, and other land use (AFOLU) opportunities, the full economic cost is primarily the net cost to the land users, accounting for the cost of investment, the net impacts on profitability, and the opportunity cost of any foregone activities. For Vietnam, a MAC analysis was completed based on the 41 AFOLU sector mitigation actions described in Vietnam's INDC; that set of options was the starting point for the analysis in this document.

In addition to the magnitude and cost assessment of the different mitigation options, this document also evaluates potential co-benefits, possible risks, and likely barriers to implementation of each set of potential strategy options. Co-benefits—benefits that are neither specifically cost related nor linked to emissions mitigation—are a factor to consider for SL programming, as they may help to align investments with existing programs or government priorities or may improve integration with other USAID projects. Many SL options have significant co-benefits, particularly to water quality, water availability, biodiversity, gender equality, and health. We summarize these briefly below in Table 1 and discuss them more substantively in Section 3 of this document.

Uptake of SL strategies may be limited by barriers related not to cost but to institutional inertia, vested interests, adherence to traditional or familiar practices, or lack of information and technical assistance. Institutional barriers may include the fact that many land-based climate interventions are cross-sectoral in nature and thus will sometimes fall outside the jurisdiction of any one ministry.

The scale of the actors involved also affects the likelihood of success of particular interventions and, by extension, an SL prioritization. In the case of Vietnam, the small-scale nature of many livestock operations makes activities requiring large up-front investment more difficult than they would be for larger farms. In the dairy sector, most families farm on one hectare of land. To justify investment in equipment, working with farms of ten or more hectares is more likely to be successful; however, this would require policy change. A large number of small holders also reduces the efficiency of activities that rely largely on extension and technical assistance as so many more actors are involved. This is a limitation for interventions such as improving livestock diets or AWD in rice—both of which do not take large up-front capital investments but that do have high demands for extension and technical assistance.

SELECTING SUITES OF COMPLEMENTARY ACTIVITIES

There are multiple areas of synergy among potential SL activities. Both the livestock and coffee sectors have geographic overlap with important areas of deforestation. As such, either could be part of a strategy where investments in agricultural extension—to improve livestock practices or expand agroforestry—were paired with increased enforcement efforts for forest conservation and investments in forest restoration. In contrast, interventions in rice, while having large mitigation potential in a crop that is central to the Vietnamese agricultural sector, have less potential for geographical synergies with activities in other sectors. Focusing on interventions with zero or low up-front investment costs for individual smallholders, particularly improved livestock diets and improved forage for cattle, could avoid the barrier posed by activities that require high upfront investment. At the same time, maintaining a limited geographic focus but with a suite of interventions in the livestock, agroforestry, forest restoration, and forest conservation sectors could help to lessen the challenges of promoting extension-intensive activities across large numbers of smallholders.

SL strategy options in Vietnam can be grouped into five broad categories: (1) conservation and restoration of upland forests and mangroves; (2) reforestation and improved natural forest management; (3) promotion of agroforestry; (4) improving cultivation practices for annual crops, particularly rice; and (5) encouraging climate-smart livestock practices. Each of these categories represents a suite of potential options. Choosing suites of activities that can be mutually re-enforcing and that may have geographic overlap can be an advantage for SL programming. In this document, we assess geographic focus, mitigation potential, and some of the likely benefits, risks, and barriers of each strategy option; we summarize these categories of options briefly in Table 1 below.

Table 1: Multi-criteria assessment of categories of SL strategies

Strategy	Total annual potential of INDCs in sector ($MtCO_2e$)	Cost per unit abatement $\$/tCO_2e$	Likely areas of geographic focus	Associated co-benefits	Potential risks	Barriers to implementation
Conservation and restoration of upland forests and mangroves	23.9	18.2	Central Highlands; North Central Coast; Northeast (mangroves); Northwest	Biodiversity conservation; watershed protection; NTFP potential; stabilization of water flows	Increased enforcement presence may lead to loss of access to NTFPs or wild game that communities may have used in the past.	Competition with high-value cash crops; competition with plantations; poor monitoring allowing some conversion to plantation to take place unreported.
Improved natural forest management and reforestation	5.7	6.0	Central Highlands; North Central Coast; Northeast	Improved soil retention; Potential stabilization of water flows (depending on species and context)	Previous investments in reforestation have frequently led to establishment of monocultures with limited biodiversity benefits and mixed effect on water flows. Has in some cases lead to increased inequality and negative impacts on poor households, particularly women.	Poor survivorship historically; high levels of past reforestation may mean that remaining areas are higher-cost or less beneficial.
Agroforestry promotion	6.2	-9.2	Central Highlands; Northwest	Improved soil retention and soil water-holding capacity; improved resilience of agriculture to climate change; increased income diversity and thus livelihood resilience. High potential to benefit smallholder farmers.	Slow economic returns to investment may provide risks to household income	Slow economic returns, especially in comparison to monoculture cash crops that are the primary competition to agroforestry systems. Potentially high demands for technical assistance
Annual crop sector	91.2	-7.3	Mekong River Delta; Red River Delta	Options proposed generally provide income improvements; improvements in water quality from reduced runoff and fertilizer over-use.	AWD in rice has the risk of increasing emissions, although this can be almost entirely mitigated by appropriate technical assistance; few if any risks to improved crop nutrient management or to improved management of crop residues	High demands for technical assistance; reticence of farmers consider high use of fertilizers as a form of insurance.

Strategy	Total annual potential of INDCs in sector ($MtCO_2e$)	Cost per unit abatement $/$tCO_2e$	Likely areas of geographic focus	Associated co-benefits	Potential risks	Barriers to implementation
Climate-smart livestock practices	11.6	-45.4	Throughout country, but particularly the two deltas and South Central Coast	Improved water quality; improved farmer incomes.	In the case of biogas digesters, risk of farmer investment taking a long time to pay off and posing a risk to household livelihood. Limited to no risks of improving practices in feed and grazing of livestock.	High technology demands and need for technical assistance; high labor demands, especially for rotational grazing.

1.0 INTRODUCTION

The purpose of the ProLand project is to provide assistance to USAID to catalyze change in land management systems so that people and institutions in developing countries can make informed, actionable, and effective development decisions. One of the tasks under the project is to provide tools and evidence in support of decision-making. As part of that task, a need was identified to develop a prioritization framework for USAID's sustainable landscapes programs that would assist USAID missions in selecting an optimal set of program opportunities for emissions mitigation and associated social and economic benefits.

A set of national case studies will provide support to decision-making for sustainable landscapes programing in the study countries and develop a broader framework for prioritization of sustainable landscape activities. This report on Vietnam is the first of those case studies. In addition to contributing to a broader learning process regarding activity prioritization, the specific goal of the report is to identify and prioritize greenhouse gas emissions mitigation and sequestration enhancement activities in the agriculture, forestry, and other land uses (AFOLU) sector in Vietnam.

1.1. METHODOLOGY

The three phases of our study were (1) to characterize emissions and sequestration in the AFOLU sector in Vietnam in order to understand which subsectors were most dominant in total contribution and in rate of change; (2) to identify a comprehensive suite of options for reducing those emissions; and (3) to prioritize among those actions and identify areas of synergy. For the first task, we assessed the overall emissions profile in the AFOLU sector using data from World Resources Institute, the Food and Agriculture Organization, and the Government of Vietnam. Where we identified discrepancies among data sources, we have noted those in the report and explained our decision for which source we decided to use.

In order to identify a suite of options to evaluate, we began with two overarching sources: one a pair of studies at a global scale (Griscom et al., 2017 and Griscom et al., 2020); and one a study focused on Vietnam (Escobar et al., 2019). Each of these sources identified AFOLU-sector mitigation and sequestration opportunities that provided the starting framework of our analysis. Following the identification of opportunities, we evaluated each one according to a consistent set of criteria as described below. For the purposes of this document, we have used five categories that together capture the options described in these three studies:

1. Conservation and restoration of upland forests and mangroves
2. Reforestation and improved natural forest management
3. Agroforestry promotion
4. Annual crop cultivation practices
5. Climate-smart livestock practices

1.2. PRIORITIZATION APPROACH

Our approach to prioritization was to evaluate a given activity with respect to four fundamental components:

1. Magnitude of potential emissions reduction or sequestration enhancement;

2. Likelihood of success;
3. Cost per unit of emissions reduction / sequestration;
4. Non-greenhouse gas (GHG) effects of the activity

All the activities proposed by the Government of Vietnam as a means of reaching its national GHG reduction commitments have already been assessed in terms of the magnitude of their potential emissions mitigation or sequestration; the expected costs to land users of each activity; and the cost per unit of mitigation or sequestration. We refer to these estimates throughout the report and also supplement them with alternate sources. For each identified activity, we present an assessment of any potential barriers to implementation that would affect the likelihood of success, as well as any additional benefits or harms possibly resulting from the activity that would need to be considered.

In addition to examining activities individually, we consider synergies among activities based on complementarity of activity type and in terms of geographic overlap. In the Conclusion, we discuss sets of activities where synergies or geographic proximity may be advantageous.

1.3. DOCUMENT STRUCTURE

The following section (Section 2) of the document contains a summary of AFOLU emissions in Vietnam and provides a high-level overview of different emissions abatement strategies identified globally and in the national INDC. In Section 3, we focus individually on groups of mitigation activities. For each of these groups we provide a general description of the activity and then describe its mitigation potential, cost estimates, barriers to implementation, and co-benefits. In Section 4, we provide an overview across sectors of geographic targeting and an overview of likely co-benefits resulting from each group of actions. Finally, Section 5 contains concluding points as well as a multi-criteria summary of the different groups of options.

1.4. NOTES FOR USERS

There is no single best way to prioritize Sustainable Landscapes investments (in Vietnam, or anywhere else). Prioritization exercises will differ depending on the specific goals of the decision-makers undertaking the exercise. Some questions that may help frame how best to approach prioritization are:

- Is the goal of the program to maximize climate mitigation for a given level of investment? Should the program also prioritize other goals, such as livelihood benefits or biodiversity conservation?
- Are there specific geographies that a program should target or avoid, for reasons of feasibility or for reasons of compatibility with other programs?
- Are there other existing or planned investments that an SL program should be designed to complement?

The goals of the present report are to familiarize the reader with possible SL interventions in Vietnam; to establish potential groups of complementary interventions that could be pursued as integrated suites; to evaluate each of those potential suites according to criteria that include cost, co-benefits, and practical feasibility; to identify areas of geographic focus; and to identify gaps and limitations in the existing data.

2.0 OVERVIEW OF EMISSIONS SECTORS AND MITIGATION OPPORTUNITIES

Vietnam is a rapidly developing country: its Gross Domestic Product (GDP) grew by 315 percent between 1991 and 2012, an impressive average of 7 percent per year. However, the country's total greenhouse gas (GHG) emissions grew by an estimated 937 percent—almost 12 percent per year—during this same period (USAID, 2016). The Government of Vietnam (GoV) pledged in its Intended Nationally Determined Contribution (INDC) to reduce its emissions by 8 percent unconditionally and by an additional 17 percent (25 percent total) conditional on donor support (GoV, 2015).

Emissions from the Agriculture, Forestry, and Other Land Use (AFOLU) sector play a large role in Vietnam's overall emissions profile and present important opportunities for emissions mitigation and enhanced sequestration. The agriculture sector represented 24.8 percent of net emissions in 2014, while the land use change and forestry sector was a net sink in the same year and sequestered GHGs equivalent to 7.3 percent of the country's net emissions (Figure 1).[1] According to a recent estimate, activities in the AFOLU sector have the potential to reduce Vietnam's net emissions by 213 $MtCO_2e$ (213 million metric tons) of carbon dioxide equivalent (CO_2e) relative to business as usual. This is equivalent to 84 percent of total national emissions, 63 $MtCO_2e$ of which could be achieved at a cost of less than $100 per Mg (per ton) (Griscom et al., 2017). Prioritizing emissions abatement opportunities is central to maximizing the activities' effectiveness at reducing net emissions in the AFOLU sector and achieving related social, economic, and environmental benefits.

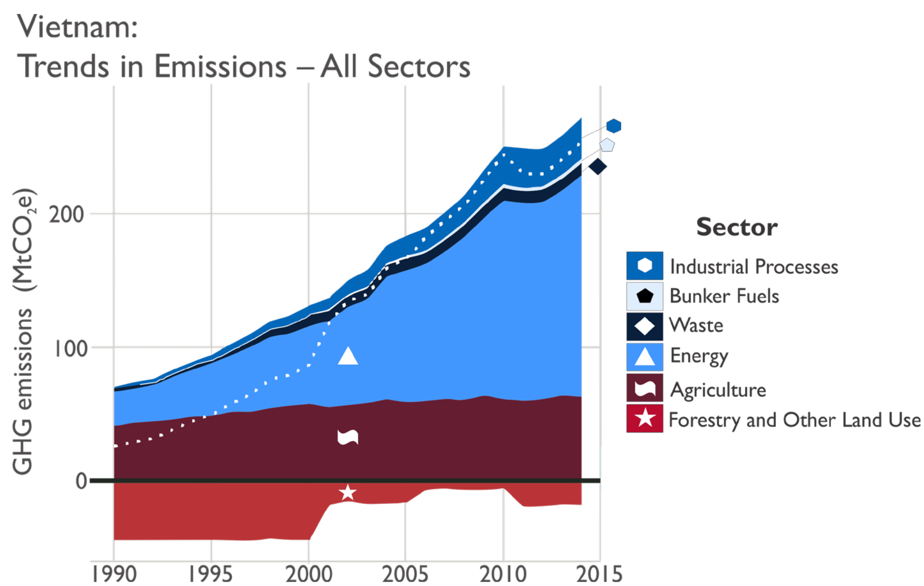

Figure 1. Greenhouse gas emissions in Vietnam by sector, 1990–2014 ($MtCO_2e$). Dotted line is the net emissions total after accounting for removals by the forestry and other land use (FOLU) subsector. Data from Climate Access Indicators Tool (CAIT), 2019.

[1] There are discrepancies between the Climate Access Indicators Tool (CAIT, 2019) global data product produced by World Resources Institute and the inventory presented in the GoV's Second National Communication to the United Nations Framework Convention on Climate Change (Ministry of Natural Resources and Environment, 2017). The GoV numbers are consistently higher: for example, GoV reports 89.4 million metric tons (Mt) of carbon dioxide equivalent (CO_2e) emissions in the agriculture sector; -34.2 $MtCO_2e$ in forestry and other land use (FOLU); and national net emissions of 259.3 $MtCO_2e$, whereas CAIT reports 62.5 $MtCO_2e$ in agriculture; -18.4 $MtCO_2e$ in FOLU; and net national emissions of 252.0 $MtCO_2e$. Neither source provides an explanation for this discrepancy. The USAID Factsheet for Vietnam (2016) identifies a similar discrepancy and uses the CAIT data. We have followed that approach and report the CAIT data here.

GHG emissions in Vietnam were 270.3 million metric tons (Mt) of carbon dioxide equivalent (CO_2e) in 2014, or 252.0 $MtCO_2e$ net including removals from land use and forestry (CAIT, 2019). Those emissions rose 59.7 percent in the decade from 2004 to 2014, or nearly 5 percent annually. Over the same period, Vietnam's share of global emissions rose slightly from 0.043 percent to 0.052 percent. The energy sector is the largest source of emissions in Vietnam, with 167 $MtCO_2e$ or 66.3 percent; that sector was also responsible for 79.5 percent of the net growth in emissions from 2004 to 2014 (Figure 1).

The agriculture sector is the second-largest source of emissions in Vietnam, producing 62.5 $MtCO_2e$, or 24.8 percent of the national total. In contrast to the rapid rate of increase in the energy sector, agricultural emissions in Vietnam are relatively steady when this sector is viewed as a whole, having only increased by 2.4 percent between 2004 and 2014 (0.2 percent per year). Within the agriculture sector, rice agriculture is responsible for 44.2 percent of agricultural emissions (27.6 $MtCO_2e$ in 2014); use of synthetic fertilizers (9.2 $MtCO_2e$; 14.7 percent) and enteric fermentation from livestock (9.9 $MtCO_2e$; 14.2 percent) are the second- and third-largest contributors. These three subsectors (rice agriculture, fertilizers, and enteric fermentation) together constitute 75 percent of Vietnam's agricultural emissions and 18.7 percent of its overall net emissions (Figure 2).

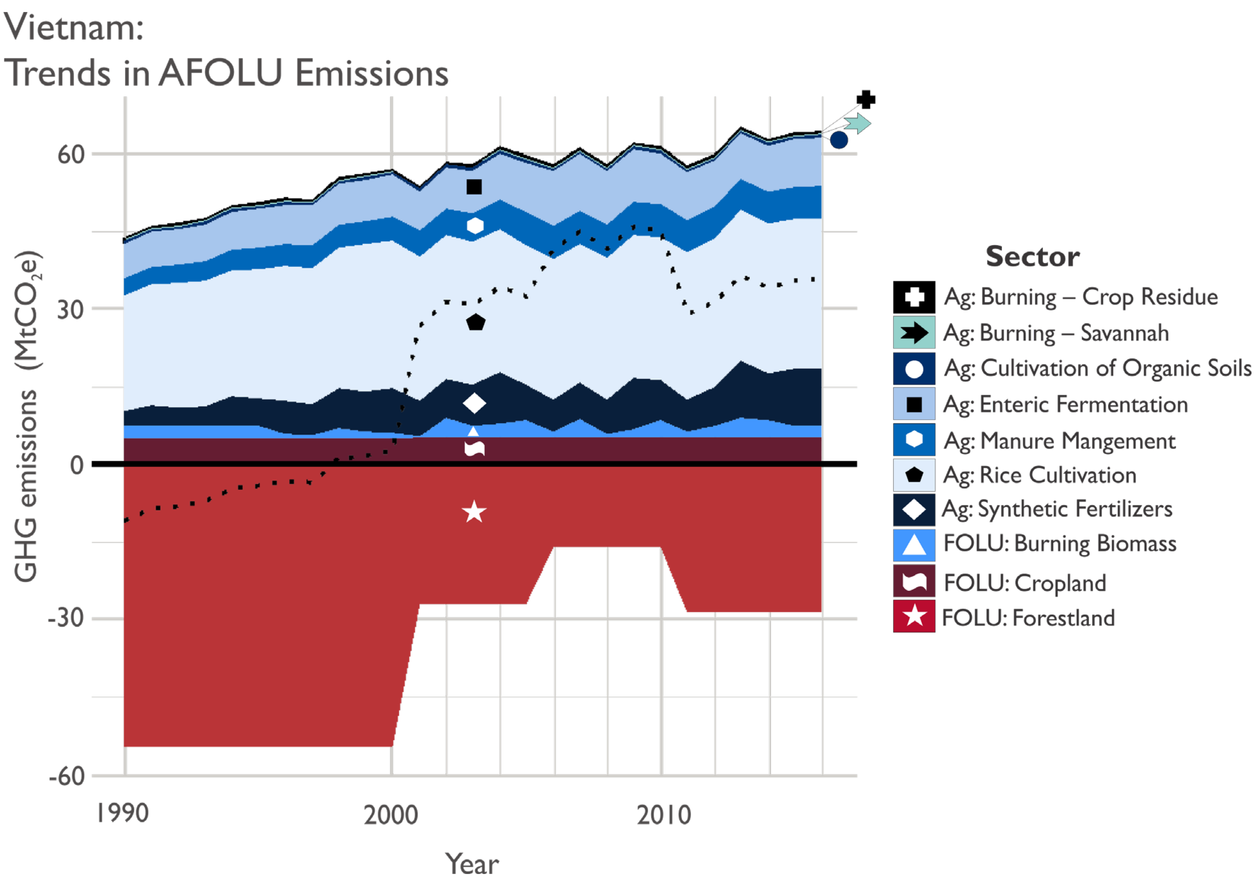

Figure 2. Emissions and removals in all AFOLU subsectors from 1990 to 2016 ($MtCO_2e$). Dotted line represents net emissions including sequestration on forestland and emissions from other subsectors. Subsectors prefaced in the legend with "Ag" and "FOLU" represent the constituents of the Agriculture and of the Forestry and Other Land Use (FOLU) sectors, respectively, as presented above in Figure 1.

Of the AFOLU subsectors, the use of synthetic fertilizers had the fastest-growing emissions in the decade from 2002–2007 to 2012–2017. Rice agriculture, the largest sector overall, had the second-largest increase in that period (Table 2).

Table 2. Emissions in the AFOLU subsectors. Ranking of total emissions and of rates of change is indicated by shading in the three right-most columns. Food and Agriculture Organization of the United Nations (FAO), 2019.

Subsector	Average subsector emissions by time period ($MtCO_2e$)			Rank of 2012–2017 emissions	Rank of absolute increase 2002–07 to 2012–2017	Rank of relative increase 2002–07 to 2012–2017
	2002–2007	2007–2012	2012–2017			
Ag: Rice Cultivation	27,469	27,569	28,981	1	2	5
Ag: Synthetic Fertilizers	7,666	7,539	10,016	2	1	1
Ag: Enteric Fermentation	9,065	10,134	9,037	3	9	10
Ag: Manure Management	5,856	6,338	6,193	4	3	4
FOLU: Cropland	5,121	5,115	5,116	5	8	9
FOLU: Burning Biomass	2,697	2,140	2,765	6	4	6
Ag: Cultivation of Organic Soils	546	545	546	7	6	7
Ag: Burning – Crop residues	410	427	443	8	5	3
Ag: Burning – Savanna	245	212	153	9	10	11
FOLU: Grassland	4	4	4	10	6	7
FOLU: Forest land	-24,933	-18,627	-28,600	11	11	2

Forestry and other land use (FOLU; in some cases, referred to by the equivalent term land use change and forestry or LUCF) is estimated to sequester more GHG than it emits in Vietnam, resulting in net emission from that sector of -28.6 $MtCO_2e$ (i.e., 28.6 $MtCO_2e$ of sequestration). This is primarily a result of the expansion of forest cover in Vietnam from its historic 1990 low of 27 percent to an estimated 48 percent in 2016 (FAO, 2019). Large-scale, nationally run programs such as Vietnam's 1998–2010 Five Million Hectare Reforestation Program (a $2.5 billion project funded jointly by the central government and international donors) have played a significant role in the total expansion of forest cover (national forest cover was 32 percent in 1998 when that program started, and 39.5 percent when it ended in 2010).

Reforestation efforts (and the expansion of commercial plantations, particularly rubber) have led to the net sequestration values seen in the national reporting for the FOLU sector. This net sequestration, however, masks continuing widespread loss and degradation of natural forests and the emissions associated with both of those processes. Monitoring by Global Forest Watch (GFW) combines remotely sensed measurements of forest cover change with estimates of ecosystem carbon density. This GFW data estimates that gross emissions from tree cover loss in Vietnam averaged 56 $MtCO_2e$ between 2001 and 2017 (emissions resulting from forest degradation would be additional to that value). This is comparable to the nation's total agricultural emissions.

2.1. OVERVIEW OF MITIGATION OPTIONS IN VIETNAM

Vietnam's INDC for climate mitigation commits to a net national emissions reduction of eight percent relative to business as usual by 2030. The INDC states that with sufficient donor support, the country could increase this contribution to 25 percent. An analysis of land-based climate mitigation pathways

(Griscom et al., 2017) suggests that those pathways (referred to as "natural climate solutions" in the study), when constrained by safeguards that protect food supply, fiber supply, and biodiversity, could supply that 8 percent reduction more than three times over. Additionally, 155 percent of the 8 percent target could be supplied at a cost of less than $100 per ton. That same analysis describes 20 pathways in all at the global scale and provides national-scale estimates of potential for ten of those pathways, which together represent more than 75 percent of the total global potential. We provide those options in full in Table A2 (Appendix A). According to the analysis of pathways for which national-scale data is available, the three largest categories of intervention in Vietnam (reforestation, avoided forest conversion, and improved rice cultivation) together supply 92 percent of the total mitigation potential and 87 percent of the cost-effective mitigation potential (Figure 3).

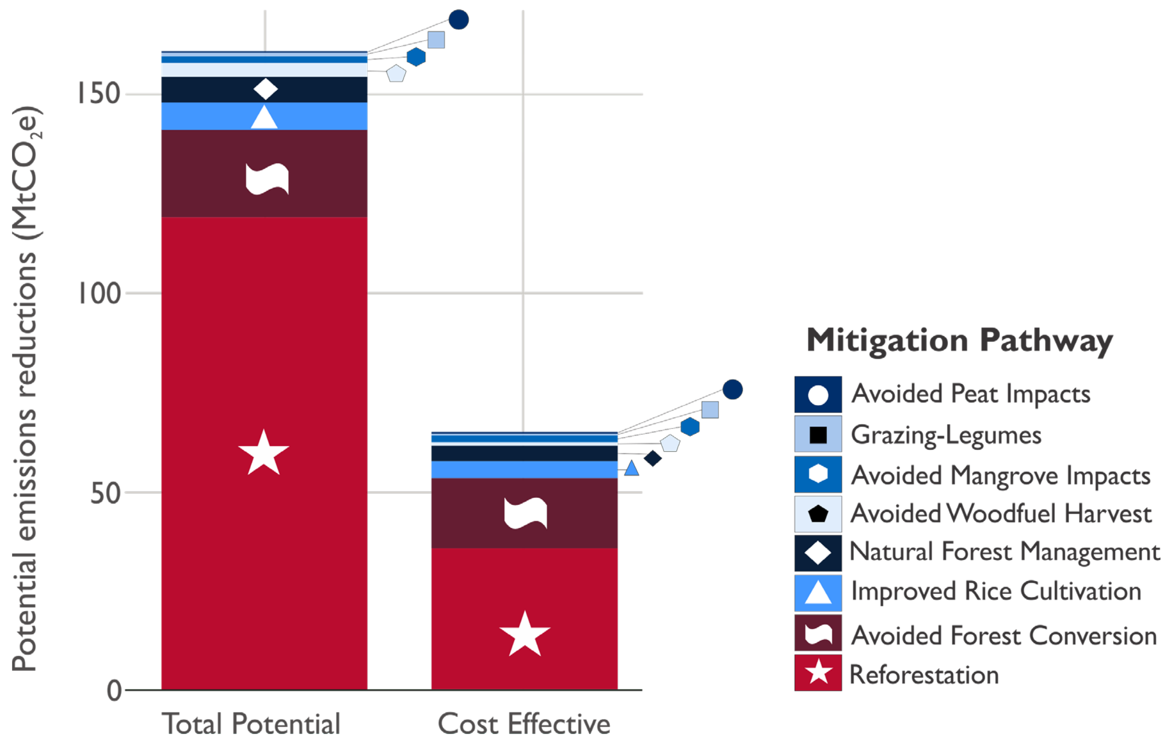

Figure 3: Potential for AFOLU-sector climate mitigation options in Vietnam (providing for safeguards for biodiversity and for food and fiber supply) as identified by Griscom et al. (2017). Stacked bars on the left represent the total potential for emissions reduction or sequestration, given safeguards, while bars on the right represent the potential that is cost effective at an assumed social cost of carbon of $100 in 2030.

An updated version of the Natural Climate Solutions analysis (Griscom et al., 2017) has been recently published (Griscom et al., 2020). It provides updated estimates on some pathways—notably, it is more conservative regarding reforestation and provides new country-level data on trees in agriculture as a pathway. It also includes national-scale data on additional pathways, meaning that 14 pathways are now covered. The two studies present slightly different information—a significant difference is that the updated study provides national estimates for cost-effective reforestation but does not provide them for the maximum potential of reforestation.

Generally, however, the results are consistent, the largest difference being that avoided forest conversion and reforestation trade places as the most and second-most important pathways between the two studies. In the updated version of the analysis, the five largest pathways, when constrained by safeguards, in descending order are: avoided forest conversion (43.7 MtCO2e annual cost-effective potential); reforestation (18.4 MtCO2e); improved natural forest management (11.8 MtCO2e);

improved rice cultivation (7.3 MtCO2e); and trees in agricultural lands (3.6 MtCO2e). Together, avoided forest conversion and reforestation provide two-thirds of the cost-effective potential of those pathways with national estimates available. Figure 4 displays the data for the 14 pathways available with the updated data.

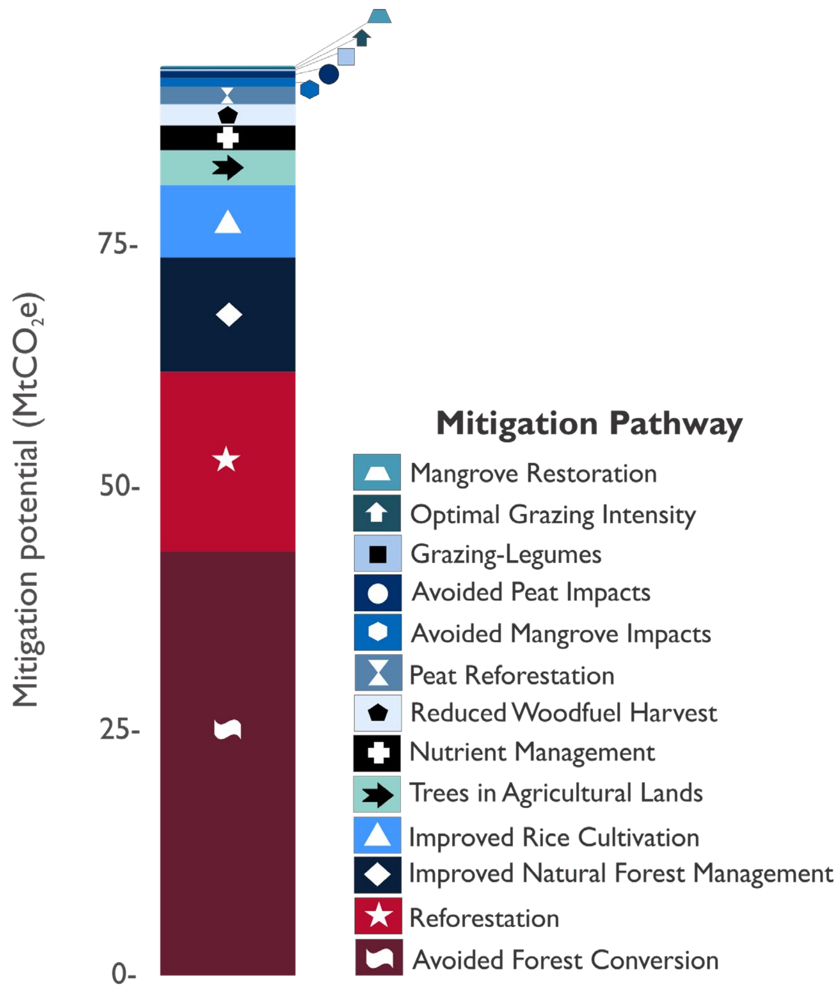

Figure 4: Cost-effective potential, providing for safeguards, of land-based GHG mitigation pathways in Vietnam, ranked by potential from bottom to top.

As discussed in Section 1.0, the GoV described in its INDC supporting documentation 41 actions or variations on actions that would result in land-based emissions reductions or enhancement of land-based sequestration. Table A1 (Appendix A) contains the full list of 41 mitigation actions, and Figure A1 contains the marginal abatement cost (MAC) curve as the GoV has presented it. Because these are options identified by a national planning process that is inevitably affected by political processes, we cannot necessarily assume that they represent the full range of biophysical potential. However, as we discuss further below, we find that the set of options identified in the INDC does in fact cover the most important sectors of potential as identified by the global studies of Griscom and colleagues (2017; 2020).

Escobar et al. (2019) assessed these proposed actions for their total mitigation potential and for cost per ton of removals or emissions reductions. That analysis found that the proposed actions would, together, result in reductions equivalent to 16.1 percent of total net national carbon emissions. This value drops to 15.6 percent and 14.8 percent, respectively, when only options that cost less than $100 and $50 per ton are included. These values—entirely from the AFOLU sector—are all significantly higher than the GoV's baseline commitment to an 8 percent reduction across all sectors.

This analysis reaffirmed the centrality of three categories also identified in the Griscom et al. analysis: forest conservation, forest restoration, and improved rice cultivation. Forest protection, forest restoration, and AWD—a prominent approach to reducing emissions from rice agriculture—were, in order, the three categories with the largest potential for emissions mitigation and removals enhancement. Together, they represented 80 percent of the total potential of options identified in the INDC (Table 3).

Table 3. Total mitigation potential and cost-effectiveness of mitigation actions proposed in Vietnam's INDC documentation. Cost estimates are from Carbonari et al. (2017). Minimum and maximum costs represent values for individual mitigation actions within each category presented here (each category had between 1 and 4 specific actions analyzed), sorted from highest total potential to lowest.

Category	Total 10-year Potential ($MtCO_2e$)	Total cost ($millions)	Average cost ($ / tCO_2e)	Minimum cost ($/$tCO_2e$)	Maximum cost ($/$tCO_2e$)
Forest protection	213.3	2,348.1	11.0	0.2	52.3
Forest restoration	68.8	2,473.6	36.0	1.4	145.4
Alternate wetting and drying (AWD) in irrigated rice	50.5	-1,047.2	-20.7	-24.6	-16.9
Manure management for fertilizer and biogas	29.6	-7.3	-0.2	-2.0	0.3
Establishing commercial plantations in bare land	14.1	-143.7	-10.2	-25.7	-0.9
Improved use of crop residues	8.7	438.3	50.2	12.2	187.1
Conversion of rice to aquaculture	6.5	-516.9	-79.0	-79.1	-79.1
Transitioning coffee to mixed-crop agroforestry	6.3	-60.4	-9.7	-529.4	15.1
Improved livestock diets	4.3	-512.8	-119.3	-130.6	-101.3
Low tillage agriculture	1.5	2.9	1.9	1.9	1.9
Nutrient management in annual crops	0.7	-14.5	-20.5	-41.2	-18.4
Rice converted to maize	0.6	240.6	388.1	388.3	388.3
Biochar	0.3	216.9	774.7	749.7	851.0

Table 3 illustrates the wide range in cost of different interventions. One limitation is that these do not represent project budget costs, but rather costs and benefits to landholders. Patterns of project cost may be quite different, and factors such as the total potential may become relatively more important than the unit cost per ton when considering opportunities from a donor perspective. It can be difficult to find data on project implementation costs and their relationship to concrete emissions reductions.

We have adapted those data to illustrate mitigation potential in each of 13 general categories, as shown below in Figures 5 and 6 (next page) and Table 3. The labels in these figures are linked to categories in Table A1 (Appendix A).

In Figure 1, the superior activities are to the right (larger potential magnitude) and to the bottom (lower cost per unit of abatement), considering the caveat mentioned above) of each chart. For Vietnam, the documentation of the country's INDC described 41 AFOLU sector mitigation activities. We have combined those 41 activities into 13 general categories, as shown below in Figure 5. All 41 activities are shown in Figure 6 and listed in Table A1.

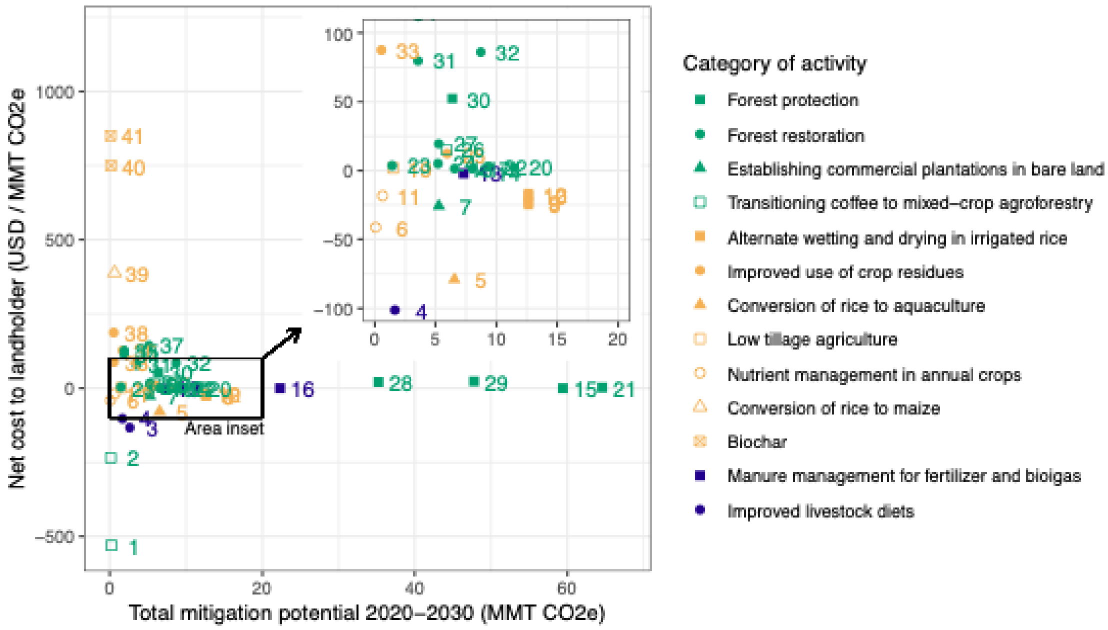

Figure 5. Total mitigation potential in million metric tons carbon dioxide equivalent ($MtCO_2e$) and net cost to landholder in USD / Mg of 41 land-based (AFOLU sector) mitigation/sequestration opportunities in Vietnam (Table A1 in Appendix A identifies activities by ID number). Colors are as follows: green = forest sector; yellow = agriculture; blue = livestock.

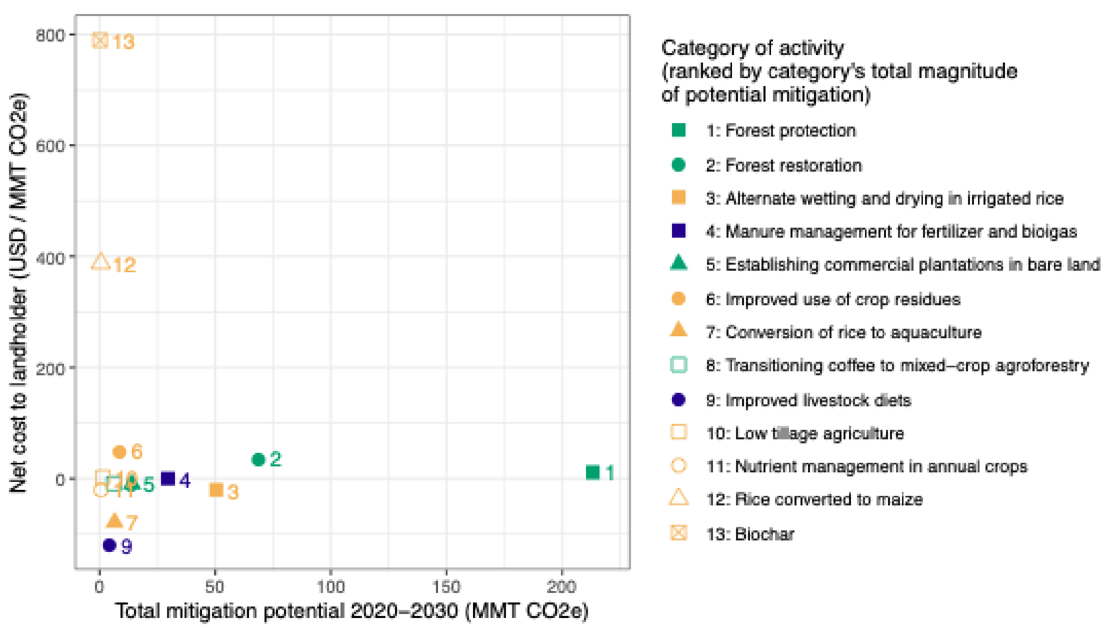

Figure 6. Mitigation potential and cost-effectiveness of actions in 13 categories of land-based (AFOLU sector) mitigation/sequestration opportunities in Vietnam. Legend on the right ranks the categories shown by the total magnitude of potential emissions abatement. Figure 6 presents the same data as Figure 5, but aggregates data by category.

The most attractive categories of opportunities are those to the right and in the lower part of each plot, representing those activities with the highest total potential and the greatest cost effectiveness. These include, in order, forest protection; forest restoration; alternate wetting and drying (AWD, an irrigation technique in rice agriculture; and manure management. The options below zero on the cost axis of the plot represent options with negative MACs, representing a savings to the land user. Several categories of intervention show net savings, including improving livestock diets, AWD, and establishing commercial plantations. Forest protection and forest restoration, the two largest categories by total potential, both show net costs of intervention that are relatively modest per unit of emissions reduction. Expanding the use of agroforestry practices in coffee presents relatively modest savings when evaluated as a category (Figure 5); when specific species options are evaluated (Figure 6); two agroforestry options are the two lowest-cost per unit of abatement. However, this is partly the result of the small overall level of sequestration in these two interventions (i.e., the small denominator).

An additional point to consider regarding the MAC estimates presented in Table 3 is the range of costs within categories. While some categories (e.g., AWD) are relatively consistent across different implementations (which represent different geographies), others (for example, agroforestry promotion) show large ranges in cost. In that particular example, intercropping coffee monocultures with fruit trees such as coffee and avocado can offer benefits to landholders that are very high when expressed per ton of CO_2 sequestered. These projects are inexpensive per unit of emission abatement, but we note their low overall potential: 220,000 tons nationally for the most cost-effective option. For that reason, those interventions may be attractive for small-scale projects but do not offer much scalability.

One important caveat with this data is that for options with a negative total cost (i.e., when the cost of the option is less than the cost of the business-as-usual case), the MAC will be misleading, because a smaller mitigation potential (i.e., the small denominator) will cause the MAC to be a larger negative number. Escobar et al. (2019) have displayed the mitigation potential of the options in their MAC curve by the width of each bar. In this analysis, we present the information differently, by transforming the Escobar et al. (2019) data and plotting it to show the intersection of mitigation potential and cost-effectiveness. Options further to the right have greater mitigation potential and options lower on the plot have greater cost-effectiveness. In this plot, the misleading results from negative cost-effectiveness due to very small mitigation potential become more obvious relative to the MAC curve.

3.0 POTENTIAL EMISSIONS ABATEMENT STRATEGIES

Land-based climate mitigation options that are practical in Vietnam, and identified in the national INDC, can be clustered into five general categories (as introduced above):

1. Conservation and restoration of upland forests and mangroves
2. Reforestation and improved natural forest management
3. Agroforestry promotion
4. Annual crop cultivation practices
5. Climate-smart livestock practices

For each of these categories and for some of the constituent options within each of the categories, we have analyzed information on total mitigation potential, additional information on potential costs, likely co-benefits of the strategies, and any potential barriers to implementation. We discuss these in the sections below.

3.1. CONSERVATION AND RESTORATION OF UPLAND FORESTS AND MANGROVES

Although Vietnam has an increasing total forest area, the extent of natural forest continues to decrease rapidly. Estimates in 2012 were that only 80,000ha of primary natural forest remains in the country, with most of that found in the Central Highlands and the southeast (Thuy et al., 2012). This rapid loss is a critical threat to the nation's biodiversity, and on local scales is frequently a threat to the stability of water flows and to soil retention. Additionally, areas of natural forest in Vietnam tend to be located in parts of the country with a high incidence of poverty (Muller et al., 2006), meaning that programs addressing forest conservation may also be well positioned to improve livelihoods and alleviate poverty.

3.1.1. MITIGATION POTENTIAL

The natural primary forests being lost in Vietnam are also the forests with the highest carbon density in the country. Global Forest Watch (2019) estimates that emissions from forest cover loss in Vietnam averaged 16 MtCO_2e annually between 2001 and 2017. Although net emissions from the forest sector may be negative because of the large levels of forest regrowth nationwide over the same period, emissions from forest loss nonetheless offer a large opportunity: they are estimated to be on a similar scale as the emissions from the entire agricultural sector.

3.1.2. COST ESTIMATES

Avoiding forest conversion can be more expensive per unit of emissions/removals than is reforestation. An analysis of 57 REDD+ projects (Graham et al., 2016) implemented, or in the process of implementation, in mainland Southeast Asia found that reforestation was the least expensive activity implemented by these projects with a cost of $33 per ton CO_2e. Improved enforcement of protected areas was the next most cost-effective at $49 per ton, while promoting reduced-impact logging was more expensive still at $94 per ton. Avoiding forest conversion by purchasing land that would otherwise be converted to timber plantation or oil palm plantation had a cost, respectively, of $130 or $275 per ton.

The analysis by Escobar et al. (2019) found significantly lower prices per ton of emissions abatement: different categories of forest conservation ranged from $0.2 per ton to $52.3 per ton, with most being closer to the lower end of that range. This difference may be due in part to the fact that Escobar et al. are presenting costs to land users, whereas Graham et al. are presenting project costs.

Costs of forest restoration vary greatly. Restoration itself can be divided into passive and active. Passive restoration consists of avoiding the disturbance: for example, preventing grazing in an area. Generally, passive restoration can be quite low cost. A case study from Latin America found that the economic benefits from four ecosystem services—timber, NTFPs, tourism, and carbon—that increased as a result of the restoration more than compensated for lost access due to grazing (Bullock et al., 2011). A similar study in the Colombian Andes found that a carbon price of $1.99 per ton CO_2e would have been sufficient to compensate pastoralists for lost access to forested areas (Chazdon and Guariguata, 2016).

Active restoration, however, can be far more expensive. One estimate from Brazil was $5,000 per hectare of forest restored. Even if those were relatively high productivity forests, they would likely add about one ton of biomass carbon per year, which would be equivalent to about 3.67 tons of CO_2 (Chazdon et al., 2016).

3.1.3. BARRIERS TO IMPLEMENTATION

The primary underlying driver of forest loss, and thus the largest factor preventing forest conservation, is competition with high-value agricultural commodities. In cases where forests are being lost to high-value crops such as coffee, sugar cane, or paddy rice, it can be very difficult to provide sufficient incentives to slow the agricultural expansion (Holland and McNally, 2010).

Enforcing forest conservation is extremely difficult even in those cases where surrounding communities have relatively bought into the idea of its value. Poaching is a constant threat in natural areas. With regard to agricultural expansion into forested areas, national-level regulations relating to conservation are often undermined at local jurisdictional levels as a result of corruption or a lack of alignment of institutional priorities.

There are examples of ecologically appropriate regeneration that would certainly have better outcomes for biodiversity in Vietnam and might have more equally distributed economic impacts than previous reforestation efforts (McElwee, 2009). International data suggests that this restoration, while feasible and ecologically effective, is significantly more expensive than plantation establishment and has more dispersed economic impacts, and therefore may be harder to adopt.

Vietnam's Ministry of Natural Resources and Environment (MONRE) is officially responsible for the nationally appropriate mitigation actions; however, policy related to agriculture and forestry (the two primary components of land-based GHG mitigation) are under the jurisdiction of the Ministry of Agriculture and Rural Development (MARD). Although cross-ministry collaboration certainly takes place, and MARD has been closely involved in many climate-linked initiatives (notably Reducing Emissions from Deforestation and Forest Degradation [REDD+]), the fragmentation of authority and expertise can be a challenge for implementation of forest conservation.

3.1.4. CO-BENEFITS

Natural forests have a wide range of co-benefits, including biodiversity conservation, protection of watersheds, and potential for NTFP harvest. NTFP harvest is particularly important for poor households, and maintaining access to forests has been shown in Vietnam to reduce inequality (Nguyen and Tran, 2018).

Forest restoration and reforestation exist on a continuum; however, in general, forest restoration refers to improving an existing degraded ecosystem, whereas reforestation refers to planting a new forest in an area where forest cover had, at one point, been entirely lost.

Restoring natural forests can be an effective approach to regain ecosystem services from a degraded ecosystem and to bring a forest back to a pre-disturbance state. Techniques are site specific. Good information exists on techniques globally (e.g., Chazdon and Guariguata, 2016); however, there is little data on forest restoration in Vietnam. Activities proposed by the GoV and described by Escobar et al. (2019), some of which they call forest restoration, generally refer to reforestation, discussed in the following section.

In many cases, forest restoration can effectively restore many of the ecosystem services provided by the preexisting undisturbed ecosystem. The co-benefits of forest restoration, when done well, are essentially the same as the benefits from natural forests: biodiversity, protection of watersheds, and increased NTFP harvests.

3.2. REFORESTATION AND IMPROVED NATURAL FOREST MANAGEMENT

Vietnam has a long and extensive history of reforestation, as described in Section 2.0. Much of the country's reforestation has established commercial monocultures of exotic species such as eucalyptus and acacia (McElwee, 2009) with a resulting significant change in species composition in the country and a reduction in biodiversity. Tree cover in Vietnam is now back to the same level it was in the mid-twentieth century, although the characteristics of the forests are much changed.

3.2.1. MITIGATION POTENTIAL

Despite the large-scale reforestation that has taken place in recent decades in Vietnam, there still exists large potential for further expansion. According to Griscom et al. (2017), reforestation remains the largest potential land-based intervention for emissions abatement in the country and represents more than half of the total potential abatement in the AFOLU sector.

3.2.2. COST ESTIMATES

The Vietnam Forest Sector Development Project, funded by the World Bank, provides a useful estimate of reforestation costs. A project focusing on the reforestation of bare hillsides, it operated in six provinces of Vietnam from 2004–2015 (World Bank, 2018). It disbursed $90.2m, and resulted in the planting of 76,571ha of land in commercial *Acacia sp.*[2] Using project estimates of yield and FAO values for carbon density, this suggests about 9.65 $MtCO_2e$ of maximum potential sequestration. That equates to about $9.35 of project investment per ton of sequestration—in fact, less than the estimates based on marginal abatement cost. This difference may be due to the lack of competing land use in the project context (in that the reforestation took place on otherwise bare land).

3.2.3. BARRIERS TO IMPLEMENTATION

Plantations in Vietnam have had poor survivorship, often linked to species choice. In some cases, this is a result of misalignment between species preference and ecological conditions that extension or other outreach could potentially overcome. Previous experience indicates that farmer preferences have generally been for reforestation with exotic monocultures at the expense of natural regeneration of the

[2] Using a value of 1.05 tons CO_2e per meter cubed of plantation biomass 9.65 million tons of CO_2e sequestered as a result of project activities.

more diverse, albeit degraded, natural ecosystem (McElwee, 2009). This practice has potentially had negative effects on biodiversity and water flows.

Large-scale reforestation programs have been taking place for years in Vietnam and have reforested millions of hectares. For this reason, the country certainly has the capacity for these kinds of projects. However, previous reforestation efforts are likely to have already targeted areas with lower costs and/or areas that were associated with more significant co-benefits. As such, investments going forward might generally be of a higher cost.

In many cases, plantation development has also led to reduced access to land for NTFP harvest, which has generally had a disproportionate negative impact on women and poor households (McElwee, 2009).

3.2.4. CO-BENEFITS

Plantations have significantly fewer noneconomic co-benefits than do restored forests or primary natural forests. They generally provide higher incomes for landholders, but there is evidence that the large plantation establishment programs may actually have served to increase inequality by allowing relatively few people to capture most of the benefits.

Depending on the species and the condition, plantations can have positive impacts on soil retention. They can have either positive or negative impacts on water flows (Little et al. 2009).

3.3. PROMOTING AGROFORESTRY

Agroforestry refers to the integration of trees into farms and other agricultural lands (Duguma et al., 2017). The presence of trees increases carbon storage on agricultural landscapes to a level that is roughly half as much as is lost when an equivalent area of tropical forest is deforested, and roughly three times as much as would an equivalent area of pasture or cropland, although this varies greatly depending on species and planting practices. Agroforestry also provides other benefits, such as improved soil retention, improved soil fertility when nitrogen-fixing species are used, improved habitat, enhancing biodiversity, and products such as fuelwood or fodder.

In the livestock sector, including fodder trees in dairy and beef production systems is a way to reduce fluctuations in forage availability, increase crude protein intake, and boost animal productivity. Farmers can use tree foliage to supplement forage from pastures or from a cut-and-carry system. Leguminous trees often have highly digestible foliage with very high protein content. Tree fodder is also often available during dry periods when ground forage is not growing well. Small- and large-scale livestock operations throughout Latin America and in parts of Africa use these types of silvo-pastoral systems.

The agroforestry-related actions described by the government of Vietnam focus exclusively on integrating trees into coffee production landscapes. Species used for intercropping with coffee generally include fruit trees or fodder trees such as *Cassia siamea* or *Leucaena leucocephala*, two species used for both shade and animal forage. However, the potential for agroforestry in Vietnam is broader than coffee. Tea plantations can be planted alongside low-density acacia, while cashew trees are frequently intercropped with annual crops such as maize or rice.

3.3.1. MITIGATION POTENTIAL

Agricultural land in Vietnam averages 30.3 tons of aboveground biomass carbon per hectare (Zomer et al., 2016). This is significantly higher than would be seen in a monoculture of an annual crop such as maize, but lower than levels measured in intensive agroforestry systems that averaged 57 tons per hectare in a global survey (Sanchez, 2000). Other estimates of aboveground carbon potential of agroforestry in Asia include home gardens in Kerala, India averaging 16 to 36 tons per hectare (Kumar

2011) and community bamboo forests ranging from 21.7 to 76.6 tons per hectare (Nath and Das 2012). Agroforestry can also improve soil carbon retention relative to agriculture without trees. In a coffee production system in Indonesia where some forest remnants were maintained after clearing, soil carbon stocks stayed at 45 percent to 79 percent of the level that they would maintained in primary forest prior to clearing (van Noordwijk et al., 2002).

The expansion of agroforestry within coffee plantations in Vietnam is estimated to have a potential of 6.5 $MtCO_2e$ sequestration over ten years from 2020 to 2030 (Escobar et al., 2019). This is just over one percent of Vietnam's 2014 total agricultural emissions. However, other estimates put the potential for sequestration from agroforestry significantly higher than this. A study published by the World Agroforestry Centre (ICRAF) estimated that agroforestry at its maximum potential in Vietnam could sequester 92 million tons of carbon over ten years, equivalent to 338 $MtCO_2e$ or 33.8 $MtCO_2e$ per year—more than half of agricultural emissions (Mulia et al., 2018). The large gap between these estimates likely results from the fact that the ICRAF study used an approach focusing on the potential extent of agroforestry production based on physical characteristics of the land. As a result, it likely represents a long-term ceiling for agroforestry rather than a plausible estimate for actions that could be implemented within years or a decade.

This type of agroforestry for livestock production has several potential pathways to reduce net GHG emissions. First, the carbon accumulation in the growing trees sequesters CO_2 from the atmosphere. Second, the higher digestibility of the tree forage has the potential to reduce enteric methane emissions from the dairy or beef cattle. Lastly, if the tree forage is displacing other forage grown with N applications, it is possible that N_2O emissions could be reduced.

We have not found estimates of the mitigation potential for this activity for Vietnam or Southeast Asia. However, in Latin America it has been shown that this activity can reduce up to 26.6 $MtCO_2e$ per hectare per year (Cuartas et al., 2014).

One of the advantages of agroforestry as a strategy is its prevalence (Duguma et al., 2017). Although not all farmers in Vietnam will use agroforestry practices, their use is sufficiently prevalent across a range of agricultural production systems that many farmers will have some familiarity with them.

3.3.2. COST ESTIMATES

Escobar et al. (2019) estimate that agroforestry can usually generate cost savings for farmers as they obtain additional products such as fruit or forage and, in some cases, may see improvements in soil fertility. However, the estimates of benefit per unit of emissions abatement are probably overstated because the total scale of mitigation potential (as reported in Escobar et al.) is relatively small.

Specific costs for agroforestry in livestock systems in Vietnam have not been published. However, there will be some initial costs to establish the trees in the farming system. These include the cost for purchasing the trees to be planted, as well labor costs to get them planted and established. According to research in other regions, the tree forage will increase animal productivity and can improve farm profits, which is a negative cost (Cuartas et al., 2014).

3.3.3. BARRIERS TO IMPLEMENTATION

Widespread adoption of this application of agroforestry will take a long time. It requires effective education and outreach, including demonstration. Agroforestry will also have competition from high-value cash crops that provide few co-benefits but that provide good economic returns (Holland and McNally 2010). Farmers are likely to be slow to adopt this system, due to the different management required for using tree fodder. Tree saplings need to be widely available for farmers who choose to plant them, and it may be valuable for policy to create subsidized tree saplings for this purpose.

In at least one case, land use categorization intersected with jurisdictional fragmentation and created a potential barrier for implementation of agroforestry. In that example, the accounting of its mitigation potential of agroforestry was divided between the agriculture and forestry sectors, with the apparent result that the scale of its potential contribution was watered down (Mulia et al., 2018). This risks agroforestry being assigned a lower priority for climate mitigation by individual ministries than it would be assigned if viewed holistically.

3.3.4. CO-BENEFITS

Agroforestry improves soil fertility and can improve agricultural resilience to climate change by reducing soil surface temperatures and by diversifying farmers' holdings. Additionally, tree species can improve soil stability and soil fertility. This system has the potential to increase wildlife habitat on farms.

3.4. ANNUAL CROP CULTIVATION PRACTICES

Vietnam is a country of 31 million hectares of land with over 12 million devoted to agriculture. Per capita food availability has moved into the top tier of middle-income countries (World Bank, 2016). Rice yields are second among emerging Asian nations, but fertilizer application rates are heavy and there is growing land and water degradation (World Bank, 2016). Vietnam ranks in the top five nations globally in the export of rice, shrimp, coffee, cashews, and pepper. Although efficiency of input use is the agricultural sector is low (World Bank, 2016), this may present win-win opportunities for farming and climate change mitigation.

The value produced by Vietnam's agriculture sector grew by an impressive 3.7 percent per year from 2000 to 2012, the third-fastest rate of growth of all Asian nations. The regions of Vietnam with greatest growth during this period are the Central Highlands (8.7 percent), followed by the Southeast (4.6 percent), the Northwest (4.5 percent) and the Northeast (4.4 percent). The Red River Delta, one of Vietnam's two "rice bowls," has seen sluggish growth in agriculture (1.2 percent) due to urbanization and recent problems in coastal aquaculture. The Central Highlands have seen their share of the value of national agriculture almost double, from 6 to 11 percent, during this period. The Mekong Delta continues to account for one-third of Vietnam's agricultural output; together with the Southeast and the Central Highlands, this is over 60 percent (World Bank, 2016). As economies develop, the percentage of the population directly involved in agriculture generally shrinks. In Vietnam, agriculture remains a crucially important sector, with 60 percent of the population involved (International Food Policy Research Institute [IFPRI] press release).

The primary subsectors of Vietnam's agriculture are crops (56.2 percent), aquaculture (16.3 percent), and livestock (16.1 percent). Since 2000, the relative dominance of the crop subsector has diminished, while livestock has steadily increased and aquaculture has more than tripled (World Bank, 2016). Other important crops grown in Vietnam include sugarcane, cassava, maize, sweet potatoes, coffee, tea, fruits, and nuts. Agriculture remains highly labor-intensive, although mechanization is rapidly increasing.

CAIT (2019) estimates that Vietnam's agricultural sector is responsible for 62.5 $MtCO_2e$, or 24.8 percent, of the country's total net GHG emissions, which makes the sector a prime target for cost-effective mitigation actions. As part of Vietnam's Nationally Determined Commitments to the Paris Agreement, the unconditional mitigation goal for agriculture is 6.4 $MtCO_2e$. The conditional mitigation goal (i.e., dependent on external funding sources) for the agriculture sector is 39.8 $MtCO_2e$.

Rice is an extremely important crop globally; no other food supplies more calories to the world's population. However, rice cultivation is also estimated to produce 11 percent of global anthropogenic methane emissions (Runkle et al., 2019) and is responsible for close to 2.5 percent of total global warming potential (Kritee et al., 2018). Rice production in Vietnam covers an estimated 7.5 million hectares, or close to 60 percent, of the nation's agricultural land. The two major rice-growing regions of Vietnam are the Mekong River Delta (MRD) and the Red River Delta. The MRD region produces 50 percent of the nation's rice and over 95 percent of the rice for export (GoV, 2017). Since 1995, rice yields have increased from 3.7 to 5.8 tons per hectare (Stuart et al., 2018). Recent farm financial survey results from 180 farmers in three Vietnamese provinces indicate that on average, conventional rice farmers earn US$1,680/ha in revenue. The major cost items include fertilizer, labor, and pest management. The average total costs were $687/ha and the average profit was $993/ha (GoV, 2017).

1. The FAO (2019) estimated that paddy rice was emitting 28.8 $MtCO_2e$ in 2016, which was 18 percent of the total national emissions. This rate of emissions is expected to decline in coming decades, as the land area producing rice is projected to decline to 7.0 million hectares. Regardless of the decline, important opportunities for mitigation from the rice sector will remain a high priority for Vietnam. Paddy rice production generally involves continuously flooded fields. These provide ideal conditions for methanogens (bacteria that produce methane gas), due to the breakdown of organic matter in the water, which creates a hypoxic environment. The Intergovernmental Panel on Climate Change (IPCC) has a baseline emission factor (EF) for methane from continuously flooded rice of 1.3 kg/ha/day.

Much of the agricultural land in Vietnam's river delta areas lies up to 2 meters below current sea level (World Bank, 2016). Using the period of 1980 to 1999 as a baseline, MONRE estimates that sea level rise could be as much as 17cm by 2030; 30cm by 2050; and 75 to 100cm by 2100 (World Bank, 2016, attributed to MONRE estimate). The projected increase in sea level rise and resulting intrusion of salinity threaten to constrain future rice-production areas in Vietnam. The anticipated acceleration of the rate of sea level rise due to climate change creates greater potential constraints on rice production over time and underscores the importance of GHG mitigation action now. Due to projected land constraints, intensification in the rice subsector may become increasingly important for food security and highlights the need to reduce the carbon-intensity of rice production.

The Vietnam INDC proposed four types of actions related to reducing GHG emissions from the rice sector, which will be discussed below. They are as follows:

1. Alternate wedding and drying
2. Crop nutrient management
3. Improved management of crop residues
4. Conversion of rice to shrimp aquaculture

3.4.1. ALTERNATE WETTING AND DRYING IN RICE

Alternate wetting and drying (AWD), developed by the International Rice Research Institute (IRRI), is being introduced across Asia. A flood management practice used to maximize rainfall capture and reduce irrigation pumping, AWD introduces periods of time during the growing season when the water level in the flooded rice field is allowed to recede to or below the soil surface. The timing, frequency, and extent of the dry periods will depend on many factors, such as the stage of growth, as well as on weather and field conditions.

Mid-season drainage, a simple form of AWD with one seven-day aeration (dry period) just at the end of the vegetative growth stage, has been widely practiced in China and Japan for the past several decades (Sander et al., 2015). There has been a substantial amount of research on AWD across Asia. The countries with the most experience in AWD seem to be Vietnam, Philippines, Bangladesh, China, and Thailand (Sander, 2019, personal communication).

Current efforts seem to focus on scaling AWD through education, outreach, and technical assistance, as well as on policy change and supply-chain initiatives.

MITIGATION POTENTIAL

The dry period allows the soil to regain an aerobic condition, which reduces methanogenesis and methane emissions that result from anaerobic decomposition of plant material on flooded rice paddies. According to IRRI, reduction in GHG emissions, mostly methane, from paddy rice will range from 30 to 70 percent (IRRI, 2019). The scaling factor for AWD using multiple aeration is 0.52, representing an average reduction of 48 percent from the baseline EF of 1.3 kg/ha/day (Tirol-Padre, 2018).

Paddy rice also emits nitrous oxide (N_2O). One recent study claims that under certain conditions, AWD can increase N_2O emissions enough to negate reductions in methane. Kritee et al. (2018) estimated that under certain soil and water management conditions, N_2O flux could be 30 to 45 times higher due to AWD. They advocate for wider understanding of the conditions that can cause this result before decisions are made to address the climate impacts from rice using AWD. However, Sander (2019, personal communication) says that almost all studies on the climate impacts of rice have included measurements of N_2O and no other studies have shown that N_2O increases will negate methane reductions. In a recent paper, Sander et al. (2015) said:

> The available data, however, suggest that the incremental N_2O emission through AWD is insignificant as long as the N fertilization remains within a reasonable range. Thus, the combination of AWD with efficient fertilization techniques, such as Site-Specific Nutrient Management, is the best way to avoid excessive N levels in the soil and thus, negative trade-off s in terms of mitigation potentials.

To help ensure that all efforts are achieving their proposed mitigation results, a clear understanding of this potential trade-off seems prudent. This is especially the case in Vietnam, where fertilizer inputs are frequently higher than appropriate. As such, any intervention promoting AWD should be coupled with technical assistance targeting appropriate application levels of fertilizers.

Vietnam's INDC estimates that it can meet 14 percent (0.9 $MtCO_2e$) of its unconditional mitigation goal of 6.4 $MtCO_2e$ using AWD in conjunction with sustainable rice intensification. It also estimates that with foreign investment the country can meet 17.6 percent (7.0 $MtCO_2e$) of the unconditional commitment. In a recent report, the Climate Change for Agriculture and Food Security (CCAFS) initiative states that AWD could achieve an estimated reduction of 10.9 $MtCO_2e$ in the MRD alone (Tran et al., 2019).

COST ESTIMATES

The literature seems quite clear that AWD benefits the farmer financially, making this intervention a win-win. From recently published survey results (Tran et al., 2019) of Vietnamese rice farmers in An Giang, Kein Giang, and Soc Trang provinces in the MRD, we have averaged the results across the provinces, expressed the results in US$, and analyzed the cost impacts of AWD by line item (Table 4). It is important to note that the specific impacts of AWD on costs were not consistent across the three provinces. For example, AWD reduced labor costs in two provinces by 18 to 35 percent, but increased labor costs by 35 percent in Soc Trang province. Similarly, fertilizer costs were significantly reduced in two provinces, but increased by 9 percent in An Giang province. For all three provinces, total costs were reduced and revenue was increased with AWD, resulting in significantly improved profitability.

Table 4. Costs and revenue from conventional and AWD in An Giang, Kein Giang, and Soc Trang provinces in Vietnam's MRD

	VND per hectare			USD per hectare			Cost difference
	AWD	Conv.	Diff.	AWD	Conv.	Diff.	
Sample size (farms)	120	60		120	60		%
Total cost	14,980.83	15,982.61	-1,001.78	644.18	687.25	-43.08	-6.27%
Land preparation	1,744.57	1,436.19	308.37	75.02	61.76	13.26	21.47%
Seed	1,484.83	1,795.18	-310.35	63.85	77.19	-13.35	**-17.29%**
Fertilizer application	3,858.43	3,980.85	-122.42	165.91	171.18	-5.26	-3.08%
Weed management	356.67	358.99	-2.31	15.34	15.44	-0.10	-0.64%
Pest and disease management	2,145.53	2,492.09	-346.56	92.26	107.16	-14.90	**-13.91%**
Rodent management	91.67	94.31	-2.64	3.94	4.06	-0.11	-2.80%
Snail management	404.45	399.30	5.16	17.39	17.17	0.22	1.29%
Harvesting	1,922.01	2,094.28	-172.27	82.65	90.05	-7.41	-8.23%
Irrigation water	269.70	710.34	-240.64	20.20	30.54	-10.35	**-33.88%**
Labor	2,502.97	2,621.09	-118.12	107.63	112.71	-5.08	-4.51%
Total revenue	42,510.79	39,072.77	3,438.02	1,827.96	1,680.13	147.83	8.80%
Profit	29,529.96	23,090.16	4,439.80	1,183.79	992.88	190.91	19.23%

Under AWD, the greatest percentage decrease in costs were for irrigation water (34 percent), seed (17 percent), and pest and disease control (14 percent). In absolute terms, the greatest savings were for pest and disease control ($14.90/ha), seed ($13.35/ha), and irrigation water ($10.35/ha). Most of the AWD literature focuses on the water costs, which can be reduced up to 25 percent or 500 liters per kg of rice produced. The savings on water is due to lower pumping cost or irrigation fees because less water is used and less is lost to runoff and evaporation. The savings for seed costs seems to be a result of planting seeds into dry ground instead of planting vegetative cuttings into flooded fields. The saving for pest and disease control results from the effect of intermittent dry periods on breaking disease and pest cycles in the field.

The average overall reduction in costs across the three provinces was 6.27 percent, or US$43.08, per hectare. The average increase in revenue was 8.8 percent, due in part to yield increase, which is often in the range of 5 percent (Sander, 2019; personal communication). The other factor is that with AWD, farmers can often harvest a bit earlier than for conventional rice. Because the market price for rice tends to drop during and after harvest, when a glut is available, early harvesting sometime results in a higher price (Sander 2019; personal communication). Overall, the survey of 180 farms shows an average increase in profitability of US$191/ha, or 19.23 percent.

A recent analysis by Escobar et al. (2019) estimates that AWD could reduce 25.27 MtCO_2e from rice production in the MRD for a cost of US$23.70/Mt$CO_2$e, which represents a win-win scenario. The cost of mitigation with AWD in the Red River Delta is estimated to be US$17.60/ Mt$CO_2$e. The cost estimates by Escobar et al. focus only on the on-farm costs. The reason Vietnam's technical report on its INDCs shows a cost of US$91/ Mt$CO_2$e could be the inclusion of institutional and infrastructure costs, but the report does not make the cost calculations clear.

BARRIERS TO IMPLEMENTATION

Access to reliable irrigation water throughout the growing season is essential for successful use of AWD. Lack of reliable access to water when needed to re-wet the fields could impact yields, and represents an important potential barrier to AWD implementation. Because AWD is a different way to produce rice, achieving widespread implementation requires coordinated outreach and technical assistance to farmers. AWD already takes high priority in several of Vietnam's policies, such as the green growth strategy, the restructured project of crop production development, and the restructured rice production project (Tran et al. 2019).

Because of the extensive network of dikes that are required to manage irrigation in rice cultivation, significant vested interests already exist in the sector. The interests that govern this large preexisting infrastructure may favor the status quo and as such may affect the potential for success of AWD.

CO-BENEFITS

Because of all the attention AWD receives, IRRI has recently published a report specifically focused on the co-benefits of this production system (Allen and Sander, 2019). These benefits include:

- Improved soil health and soil structure from the aeration;
- Improved human health from reduced mosquito and water borne diseases, as well reduced availability of arsenic and mercury to the plants;
- Reduced nitrogen and phosphorus runoff by 30 percent and up to 89 percent reduction in pesticide runoff; and
- Reduced need to burn straw, causing improvements in air quality.

3.4.2. CROP NUTRIENT MANAGEMENT

N_2O has about 300 times the global warming potential of CO2. The presence of excess nitrogen (N) is enhances N_2O emissions from cropland. The factors that most greatly affect N_2O emissions and nitrate loss to ground and surface water are fertilizer application rate, timing, method, and placement. Applying science-based recommendations for nutrient management can greatly reduce N_2O and nitrate losses. Appropriate application rate is the most important of these factors for reducing N losses. Nutrient management can also increase farm profitability.

Although fertilizer application rates to rice doubled from 70 to 140 kg per hectare from 1990 to 2004, they seem to have leveled off as a result of nationwide programs such as "Three Reductions, Three Gains" (3R3G) and "One Must Do, Five Reductions" (1M5R), which aimed, in part, to reduce fertilizer application rates (Stuart et al., 2018). An estimated 10 million tons of fertilizer are used per year in Vietnam, with two-thirds of that applied to rice (World Bank, 2016). The World Bank (2016) estimates that the average application rate on paddy rice is 180 kg per hectare, which is 30 to 200 percent more than in other countries in Southeast Asia. In many countries, a rational choice for farmers is to apply fertilizer at rates above the agronomic (and economic) optimum as a perceived insurance policy against reduced yields. This is especially true where fertilizer prices are relatively low or subsidized.

Increasing nutrient use efficiency is paramount for balancing food security and environmental quality. The agronomic optimum for fertilizer application in rice is around 120 kg N per hectare, while the economic optimum N rate (i.e., the rate that results in the greatest profit) will depend on the price received for rice and the price paid for N fertilizer. Rates above the economic optimum will cost the farmer more on average, but farmers often view extra fertilizer as an insurance policy to maximize yields. Ju et al. (2009) estimate that Chinese farmers could reduce N application rates by 30 to 60 percent without reducing yields. Escobar et al. (2019) identified the substitution of ammonium sulfate for urea in fertilizer application to maize and sugarcane as a way to reduce N_2O emissions from cropland. Ways to get better nutrient use efficiency include periodic soil testing; better accounting of nutrients in manure and other organic fertilizers; plant breeding and genetic modifications; decision support tools; and slow-release fertilizers (Dickie et al., 2014).

Nutrient management on agriculture land is implemented across the globe to various degrees. It is an obvious area in which to try to increase efficiency of production and mitigate the environmental effects of agricultural production.

MITIGATION POTENTIAL

Griscom et al. (2017) have estimated that cropland nutrient management has by far the greatest mitigation potential for low-cost (i.e., <$100 per ton) reductions globally among agricultural and grassland opportunities. Dickie et al. (2014) note that estimated global mitigation potential from reducing N_2O flux from soils is 325 million tons of CO_2e.

Specific estimates of the mitigation potential of cropland nutrient management for Vietnam are few. Escobar et al. (2019) estimate that substituting ammonium sulfate for urea in maize could reduce 0.64 $MtCO_2e$, but just 0.07 $MtCO_2e$ for sugarcane. There is not a mitigation estimate for reducing application rates; this is an important area for further research.

COST ESTIMATES

Escobar et al. (2019) estimate that nationally, farmers could save almost $12 million by replacing urea with ammonium sulfate. Additionally, reducing application rates will almost always result in a cost-savings for the farmers. The financial savings may be small, but the benefits to climate change and to water quality can be quite large. Specific research on the impact of nutrient management in Vietnam is necessary to understand the mitigation potential and costs.

BARRIERS TO IMPLEMENTATION

Widespread adoption of nutrient management on cropland will require coordinated and effective education and outreach campaigns, including demonstrations and incentivizing on-farm trials. Some farmers will refuse to reduce application rates. Getting to scale with widespread nutrient management will be slow.

CO-BENEFITS

The primary co-benefit of nutrient management is the protection of ground and surface water.

3.4.3. IMPROVED MANAGEMENT OF CROP RESIDUES

Rice straw is a by-product of rice-grain harvesting. An average of 6 to 8 tons of straw are produced per hectare per year in Asia (IRRI website https://www.irri.org/rice-straw-management). Organic amendments to rice paddies tend to increase methane emissions and the rate of emissions per unit of organic amendment. This increase in emissions is greatest for straw amendments to the field and is much lower for adding compost (Yan et al., 2005). Removing rice straw from the paddies after harvest is becoming more common with the rapidly increasing number of balers in Vietnam. IRRI estimates that the number of balers in the MRD has increased from fewer than ten in 2013 to more than 5,000 in 2018 (IRRI BMZ project). However, it is estimated that 60 to 70 percent of rice straw is still burned in the field, which contributes to air quality problems, including GHG emissions.

There are several possible uses for harvested rice straw, including composting and using as a soil amendment, bioenergy production, and producing fiber-based materials, such as plates, cups, baskets, and packing materials. Dried straw can also be used for cultivating rice straw mushrooms, which grow well in Vietnam.

Rice straw harvesting is a relatively new opportunity, but the leadership of IRRI and other organizations are looking into it across the rice-producing regions of Asia.

MITIGATION POTENTIAL

Tran et al. (2019) have estimated that rice straw management in the MRD could mitigate 5.97 $MtCO_2e$. They state a goal of an additional 250,000 hectares for rice straw removal by 2030. Depending on the ramp up of acreage, this goal would result in a reduction of at least 2 MT per hectare per year.

COST ESTIMATES

The estimated on-farm costs of achieving the 5.97 $MtCO_2e$ reduction are US$72.71 million. These costs include machinery, labor, and fuel. The cost-effectiveness of rice straw removal is estimated to be US$12.20 per $MtCO_2e$.

If more uses for rice straw are generated and demand increases, the price paid for rice straw will increase, which will improve the profitability of harvesting it as a crop. As the profitability increases, the cost of producing C offsets with rice straw harvesting will decrease.

BARRIERS TO IMPLEMENTATION

To get to scale on rice straw removal, actions need to be taken to increase both the demand for rice straw as an input into other products and the supply of rice straw by facilitating the availability and use of baling equipment. To increase the demand, investments should be considered to expand markets for products made from rice straw, such as biodegradable plates and cups, as well as baskets and packing materials.

Facilitating more straw balers in the rice-growing regions of Vietnam would be an important step toward greater removal of rice straw. Because the balers are very expensive alternative ownership models must be examined. For example, looking into cooperative ownership structures or facilitating small business development of custom baling operations. It may be the case the companies using the rice straw as an input would benefit from financing the purchase of more balers.

CO-BENEFITS

As a biodegradable material for use in the creation of disposable products, rice straw harvesting has the potential to reduce pollution associated with the production and disposal of plastics. This opportunity could also help to reduce solid waste.

3.4.4. RICE-TO-SHRIMP CONVERSION

DESCRIPTION

Escobar et al. (2019) list the mitigation potential of converting rice land to shrimp to be 6.54 $MtCO_2e$ and a cost saving per $MtCO_2e$ of $-79. Although the numbers are attractive from a climate change perspective, we have not included a full analysis of this option due to the significant environmental threats that shrimp farming poses. The primary threat is nutrient and disease pollution to water from intensive shrimp farming, although there may also be a concern that incentivizing shrimp aquaculture generally could lead to the increased destruction of mangroves frequently associated with shrimp production.

Although numerous farmers have learned how to make much more money by farming shrimp instead of rice, there are larger economic risks due to the possibility of losing harvests to disease. It is possible that on rice lands where soils have become saline due to saltwater intrusion, shrimp farming could help to offset the pressure on mangroves and could, if managed properly, reduce impacts on water quality. This is an area for further investigation.

3.5. CLIMATE-SMART LIVESTOCK PRACTICES

The livestock sector grew at an average rate of 4.7 percent per year from 2000 to 2013, but the growth rate has been volatile due to both disease outbreaks and fluctuating feed price and availability (World Bank, 2016, p. 24). Projections by the World Bank are that the livestock sector will continue to grow quickly, as the diets of increasing numbers of Vietnamese include larger amounts of animal products (World Bank, 2016). The growth in Vietnam's meat demand continues to increase faster than meat production, and several factors are likely to prevent production from keeping pace with demand. First, land tenure rules in Vietnam are such that the majority of production occurs on very small farms. Second, dependence on imported feed makes production more expensive. Third, the geography of the country makes transportation of inputs and product expensive.

Swine production, which is 74 percent of the meat consumed in the country, dominates Vietnam's livestock sector. Poultry is second, followed by dairy and beef. The dairy sector is becoming increasingly important: demand for milk and dairy products increased from 1 to 16 kg of milk equivalent per person per year between 1986 and 2011 (Nguyen et al., 2018). Between 2002 and 2010, milk production increased more than five-fold with close to 20,000 small family dairy farms operational as of 2010 as a result of an active national dairy development plan, which is credited with creating 50,000 jobs in family farming. Dairy production still falls far short of domestic demand, and large amounts of powdered milk are still imported. Reconstituted milk from imported milk powder comprised about 80 percent of milk consumption in 2010. As a result, the GoV created a plan in 2008–2009 to boost domestic dairy production by facilitating the creation of large commercial dairy farms (Nguyen et al., 2018).

Currently, there are a handful of mega-dairy farms in Vietnam, but the majority of dairy farms are extremely small, with an average herd size of six cows (Deutertre et al., 2015). Cows are kept in stalls and fed using a cut-and-carry system of elephant grass and maize. The typical land holding is one hectare, of which 70 percent would grow elephant grass. The maize is often grown as an inter-seasonal crop with rice in the Red River Delta. Vietnam is also home to the TH Dairy farm, which is the largest dairy farm in Asia, milking 22,000 cows.

Dairy farming is one of the most profitable agricultural enterprises in northern Vietnam (Deutertre et al., 2015). Coming out of the 2014 "Restructuration plan of the livestock sector towards enhancing added value and sustainable development," there is a push to move from 20,000 six-cow family farms toward 2,000 farms of 20 or more cows each that can produce 2.5 times the amount of milk. In addition, several mega-farms will round out the domestic milk production. The mega-farms produce an average of 20L of milk/cow/day. There is large variation in the feeding and milk production of the smallholder farms, but they average near 11L of milk/cow/day (Deutertre, personal communication).

The mega-farms have been developed on former state farms. For smallholders, there is no market for land, so increasing land holdings for some farms to increase their size will be difficult without new policy action. Creating policy takes time and represents a barrier to implementation for some mitigation options.

3.5.1. BIOGAS FROM SWINE MANURE

There has been a dramatic increase in energy consumption in Vietnam since 2000. Demand for natural gas is increasing by about 20 percent per year, and Vietnam's reliance on imported fossil fuels is predicted to increase.

For over 15 years, Dutch international development organization SNV and others have been promoting small-scale biogas digesters to collect methane from pig waste. Manure is stored in sealed tanks, and the methane is captured and used for household cooking.

Larger-scale operations in the U.S. and Europe are capturing and using biogas from swine operations. Small-scale swine operations in less-developed nations, including Vietnam, are also starting to use it more widely. According to SNV, more than 250,000 of these small-scale digesters, not all for swine waste, have been constructed in Vietnam.

MITIGATION POTENTIAL

Escobar et al. (2019) estimate that biogas capture from swine operations has the potential to mitigate 22.32 million tons of CO_2e from 2020 to 2030, which is one of the largest potential reductions in their analysis.

An individual sow will produce an average of 642 kg of manure from farrow to finish (Chastain et al., 1998). Piglet manure releases more than twice the methane (443L per kg manure) of most other livestock, including mature sows (177L per kg manure). Over its production cycle, each pig will produce an average of 156,507L of methane (calculated using numbers from Chastain et al., 1998 and Cu et al., 2015).

COST ESTIMATES

The small digesters suitable for a household operating a small pig operation cost between $500 and $1000. Each of the small digesters can reduce between 4 and 8 MtCO_2e per year, with a useful life of around 20 years. If a unit ran for ten years and produced 4 MtCO_2e per year, it would produce reductions at a cost of $25 per Mt$CO_2$e. If it ran for 20 years and produced 8 MT per year, the cost would be $6.25 per MT.

SNV estimates the value of the biogas used in the household at approximately $120 per year on average (Ismail, 2018). With this value factored in, the range of net costs (i.e., savings in this case) would range from -$50 to -$175 per MtCO_2e.

The results of research by Escobar et al. (2019) estimate the cost of this intervention to be $0.30 per Mt$CO_2$e. Unfortunately, their calculations are not shown, but the costs of funding the programming, including education and outreach, as well as distribution of the digesters, may be large enough to result in this opportunity having total costs of near $0 per Mt$CO_2$e.

BARRIERS TO IMPLEMENTATION

To get this technology to scale, investment is required to purchase 10,000 or more digesters. Training and technical assistance are required to get farmers using and managing the digesters correctly.

CO-BENEFITS

As gas cookstoves displace wood cookstoves, which are known to cause respiratory problems throughout the less-developed world, the most important co-benefit is human health.

3.5.2. ADDRESSING EMISSIONS FROM ENTERIC FERMENTATION: DAIRY TOTAL MIXED RATION

From 6 to 12 percent of the energy consumed by cows leaves their bodies as methane. Increasing the quality and digestibility of the feed consumed by dairy cows will increase the feed conversion ratio (i.e., food consumed to milk produced), boost milk production, and reduce enteric methane emissions toward the lower end of the range. There is large variability in enteric methane emissions, but feed intake and ration digestibility are two important factors. Feeding management can reduce enteric methane emissions by 2.5 to 15 percent per unit of energy-corrected milk (ECM) (Knapp et al., 2014).

Goopy et al. (2018) devised a way to use on-farm data to develop more precise estimates of enteric methane emission factors for dairy in Kenya. A similar approach could be used in Vietnam. They analyzed feed samples to measure digestibility and feed intake by the cows to develop emission factors, which were up to 40 percent lower than IPCC Tier 1 EFs.

A total mixed ration (TMR) for dairy cows consists of mixing the forage with the grains and minerals before feeding. TMR helps boost production by preventing the rumen from becoming overly acidic, which can occur when the cow eats large amounts of grain at one time without forage.

Because of the large variability related to feeding management and enteric methane emissions, this mitigation opportunity should incorporate accurate baseline and project information on the complete feed intake and the analysis of each feed.

The feeding of TMR is typical in modern dairy production in more developed countries. It has been shown to increase production, and the science connecting increased feed digestibility to reduce enteric methane emissions is solid.

MITIGATION POTENTIAL

Although Escobar et al. (2019) do not provide calculations for the reduction potential, they estimate that 2.63 $MtCO_2e$ can be reduced by increasing the number of dairy cows being fed TMR by 135,000 from 2020 to 2030. Unfortunately, these numbers imply a reduction of 1.77 $MtCO_2e$ per cow per year, which would be at least a 30 percent reduction. Reductions of this percentage from feeding management alone are not consistent with emissions value in the scientific literature.

If we assume that cows in Vietnam produce more methane (say, 150 kg methane per year) than most cows in the U.S. or Europe (120 kg) due to lower feed efficiency, and we assume a generous reduction of 15 percent from this intervention, there would be an average reduction of 0.76 $MtCO_2e$ per cow per year. If we further assume that the goal of 135,000 additional cows is reached in 2020 (which is probably not the assumption in Escobar et al.) and maintained through 2030, then 1.14 $MtCO_2e$ would be reduced.

COST ESTIMATES

Because of increased milk production and resulting profits, Escobar et al. (2019) have estimated that dairy TMR will increase profitability in the dairy farm sector by $344 million over 11 years. This translates into a savings of $231 per cow per year. This sizeable savings for dairy farms represents a negative cost for the dairy TMR intervention.

Escobar et al. (2019) do not mention infrastructure costs; presumably, TMR mixing wagons will be required on larger farms. The TMR could be mixed and fed by hand on smaller farms.

BARRIERS TO IMPLEMENTATION

To reach scale, this mitigation opportunity requires 10,000 or more dairy farmers to adopt the use of TMR feeding. Many factors affect adoption rates, and they are not easy to predict. At the very least, effective agricultural extension will be required to educate farmers and demonstrate the benefits. If improved production and profitability can be shown, adoption is more likely. The GoV is actively trying to increase productivity in the dairy sector, which bodes well for this intervention.

The use of TMR is not generally a complementary strategy with pasture-based dairy production, in which the focus is reducing costs by maximizing the percent of nutrient intake from grazed pasture forage. The "Market and Agricultural Linking Chains in Asia" (Malica) initiative has envisioned a dairy development scenario in which Vietnam has 39 mega-farms and over 12,000 small and large family farms (Nguyen et al., 2018). Focusing the increase in TMR feeding on the larger family farms may be more effective than focusing on the small family farms, due to efficiency in outreach and the potential economies of scale that may allow for purchase of TMR feeding equipment.

CO-BENEFITS

There are no significant noneconomic co-benefits of TMR feeding for dairy.

3.5.3. REDUCING NET EMISSIONS FROM ENTERIC METHANE, SOIL CARBON, AND NITROUS OXIDE: ROTATIONAL GRAZING FOR DAIRY

Rotational grazing is an alternative forage production strategy that can be used to reduce livestock production costs. It is a system in which the animals graze one section (paddock) of a larger pasture for a short period of time, often 12 or 24 hours for dairy cows. The animals are rotated through the paddocks, allowing previously grazed paddocks to regrow to an optimal level for nutrient yield before regrazing. French agronomist Andre Voisin first described the scientific principle underlying rotational grazing in the late 1950s (Voisin, 1959).

The principle behind rotational grazing is to remove the selectivity from the animals' grazing behavior by providing them with uniform high-quality pasture forage in a paddock that is small enough that animals will consume all of the forage before any regrowth occurs. The negative effects of selective grazing in non-rotational systems over time are that often more nutritious plants are killed from overgrazing while less desirable plants are allowed to reproduce; eventually, the pasture is dominated by less desirable species and forage quality greatly decreases.

Knapp et al. (2014) indicate that reductions of 15 to 30 percent of enteric methane from dairy cows per unit of ECM could be achieved with combinations of genetic and management approaches. These include reducing animal stress and increasing the lifetime productivity of cows. The latter requires either increasing milk output per cow per year and/or increasing the number of lactations for which each cow remains in the herd, to spread out the nonproductive emissions during the cow's first two to three years of life. Rotational grazing has been shown to result in healthier cows, lower culling rates, and more lactations (Knapp et al. 2014). Relative to the current low average productivity of dairy cows in Vietnam, rotational grazing has the potential to greatly increase lifetime productivity of cows.

Although rotational grazing, like dairy production in general, is often more common in temperate climates, it is being successfully used in tropical areas around the world, including parts of Africa, Central and South America, and the Caribbean. Rotational grazing is the backbone of livestock production in many nations, such as Ireland and the U.K., and has been especially predominant in New Zealand, where dairy farmers produce milk profitably though they receive a relatively low price for their output.

MITIGATION POTENTIAL

There are three important mechanisms through which rotational grazing can reduce net GHG emissions. First, rotational grazing increases soil carbon. The pasture creates an increasingly dense sward of grasses, sedges, and legumes that provide a permanent vegetative cover. Regrowth and periodic grazing create a cycle of development and pulsing of root reserves, which becomes soil organic carbon. Second, rotational grazing, when managed correctly, provides the cows with a highly digestible feed source. Higher digestibility reduces the amount of enteric methane production. It also results in greater feed efficiency and higher milk production and profits. Third, with the animals living on the pasture, which will have increased biological activity and nutrient cycling, manure is dispersed and much more readily absorbed into the soil profile. The greatly reduced collection and storage of manure will reduce both methane and N_2O emissions. New research shows that N_2O flux from urine deposits of grazing cattle is reduced an average of 42 percent when deposited on pastures with adequate vegetation in rainy, tropical regions, relative to degraded pastures (Chirinda et al., 2019). Griscom et al. (2017) have identified three grazing management scenarios as having significant mitigation potential globally. Although their analysis is very coarse, they estimate that optimal-intensity grazing has the potential to reduce 0.21 $MtCO_2e$, while grazing legumes has a potential of 0.63 $MtCO_2e$.

Although specific estimates of the mitigation potential of rotational grazing in Vietnam or Southeast Asia are scarce, the scientific literature is clear that improving dairy cow productivity will reduce net GHG emissions per unit of milk (O'Brien et al., 2014). Rotz (2018) has shown that net GHG emissions per cow is 29 percent lower on dairy farms using well-managed grazing versus a high-producing confinement feeding operation. The technical potential of rotational grazing to reduce net GHG emissions from dairy production in Vietnam could be very large, particularly because rotational grazing should be able to increase milk production per cow from levels currently realized in Vietnam. Lorenz et al. (2019) conclude that rotational grazing can reduce net GHG emissions even with lower milk production per cow. Dairy farms in Vietnam that achieve equal or greater milk per cow using rotational grazing will have a much smaller carbon footprint.

The greatest reduction potential will arise on farms that are feeding a more mature forage with lower digestibility and starting to manage pastures to provide cows with less mature, more digestible grazed forage. This will reduce enteric methane production, increase feed efficiency, and boost milk production. The carbon-intensity of milk production could be dramatically reduced by increasing production per cow while decreasing net GHG emissions.

COST ESTIMATES

The use of rotational grazing, if done according to its best-practice scientific principles, has the ability to increase milk production per cow and per hectare, as well as to greatly reduce the costs of production. The primary savings would be for labor, purchased feed, and machinery and equipment costs. Investment would be required for electric fencing, including wire, posts, and charger. Solar fence chargers are relatively affordable and highly effective in tropical regions. Perimeter fencing requires permanent posts and high-tensile galvanized steel wire (one strand). Even less expensive are the step-in posts and rope-like poly-wire that can be moved with the cows to create temporary internal paddocks.

BARRIERS TO IIMPLEMENTATION

Rotational grazing is a very different way to farm relative to a cut-and-carry forage system with confinement feeding. It would take a significant amount of demonstration and technical assistance to help farmers understand the system and use it effectively. This process would likely require a sizeable investment by the GoV, the donor community, and the private sector. The time frame required to get to scale with rotational grazing is likely to be at least five to eight years.

Another important barrier to implementation is the land tenure system in Vietnam. For farms of one hectare and six cows, the investment in fencing and technical assistance may not be worthwhile. It would be more cost-effective for farms of 20 to 30 cows or more. However, these farms would need the use of additional land for grazing. This will require some policy change. It is possible that the mega-farms may be interested in using rotational grazing for some of their cows. According to Deutertre (personal communication), the mega-farms need to sell the government on a vision of how they can be "sustainable" farms, and grazing may help them in this regard.

CO-BENEFITS

Rotational grazing for dairy has many co-benefits. In terms of water quality, the dense sward of aboveground vegetation helps to hold soil in place. This reduces sediment and nutrient loss to surface waters.

The same high sward density also offers flood protection that results from higher soil organic matter content, allowing for increased water infiltration and water-holding capacity in the soil. This can help to mitigate downstream flooding during high-rainfall periods.

For biodiversity, the polyculture of grass and legume species is often able to provide habitat for a wider array of species, both aboveground and below.

Rotational grazing has the ability to enhance animal health and food safety. Cows out on pasture are generally healthier than stall-confined cows and require less-frequent antibiotic treatment. Udders are usually cleaner, which can help reduce the incidence of mastitis and lower bacteria and somatic cell counts in the milk.

4.0 PRIORITIZING FOR GEOGRAPHIES AND CO-BENEFITS

4.1. GEOGRAPHIC PRIORITIZATION

The five broad SL strategies discussed above focus on different sectors of the economy or the environment and as such will tend to focus on different locations within the country. To the extent that these geographical areas overlap, it may allow for integrated programming that plans multiple types of SL investment in the same geographic area. This may be the case, for example, with forest conservation and agroforestry in perennial crops, as these tend to cluster in similar areas. Activities in the rice sector, however, cluster largely in the Red and Mekong River deltas and their surrounding areas, and they generally have little overlap with areas that are important for forest conservation or agroforestry.

Emissions from forest loss—the sector with the largest total potential for land-based emissions abatement per Griscom et al. 2020—are concentrated in a small fraction of Vietnam's 58 provinces. Half of the country's emissions from deforestation originate in the ten provinces shown in Table 5; more than a quarter of those emissions come from only four provinces in central Vietnam: Nghe An, Quang Nam, Quang Ngai, and Kon Tum. In many provinces in northern and southern Vietnam, emissions from deforestation are stable or decreasing. However, emissions linked to deforestation increased in all the provinces of central Vietnam except Da Nang (Global Forest Watch 2019).

Table 5. Emissions from deforestation in the 10 "most-emitting" provinces, 2013–2017

Province	Emissions from Deforestation ($MtCO_2e$) – annual average $MtCO_2e$ (Rank)		Increase in annual average; 2003–2007 to 2013–2017 (Rank)	Rate of increase (2003–2007 to 2013–2017)
	2003–2007	2013–2017		
Nghe An	1.46 (5)	8.21 (1)	6.75 (1)	462%
Quang Nam	1.4 (8)	7.48 (2)	6.08 (2)	434%
Quang Ngai	1.37 (9)	5.15 (3)	3.78 (3)	275%
Kon Tum	1.61 (4)	4.12 (4)	2.51 (6)	155%
Quang Ninh	0.89 (13)	3.99 (5)	3.1 (4)	347%
Gia Lai	1.64 (3)	3.84 (6)	2.2 (12)	134%
Quang Tri	0.96 (12)	3.28 (7)	2.32 (11)	242%
Ba Ria-Vung	0.78 (15)	3.24 (8)	2.46 (7)	316%
Thanh Hoa	0.63 (20)	3.07 (9)	2.44 (9)	390%
Quang Binh	0.39 (25)	3.00 (10)	2.61 (5)	676%

Figure 7 shows the spatial patterning of five key statistics for understanding spatial prioritization of SL options. Emissions from deforestation is a good proxy for the potential of both avoided forest conversion and reforestation; plantation extent is an indicator of potential for improved forest management; area of rice paddy is an indicator of potential for investments in the rice sector; area of coffee plantation is a rough proxy for potential to invest in agroforestry in perennial crops; and number of cattle per unit area is a proxy for likely geographies for livestock-sector investment. Additionally, Figure 7 shows the human development index (HDI) as calculated at provincial level as an indicator of geographies where poverty alleviation and income improvements may be a priority.

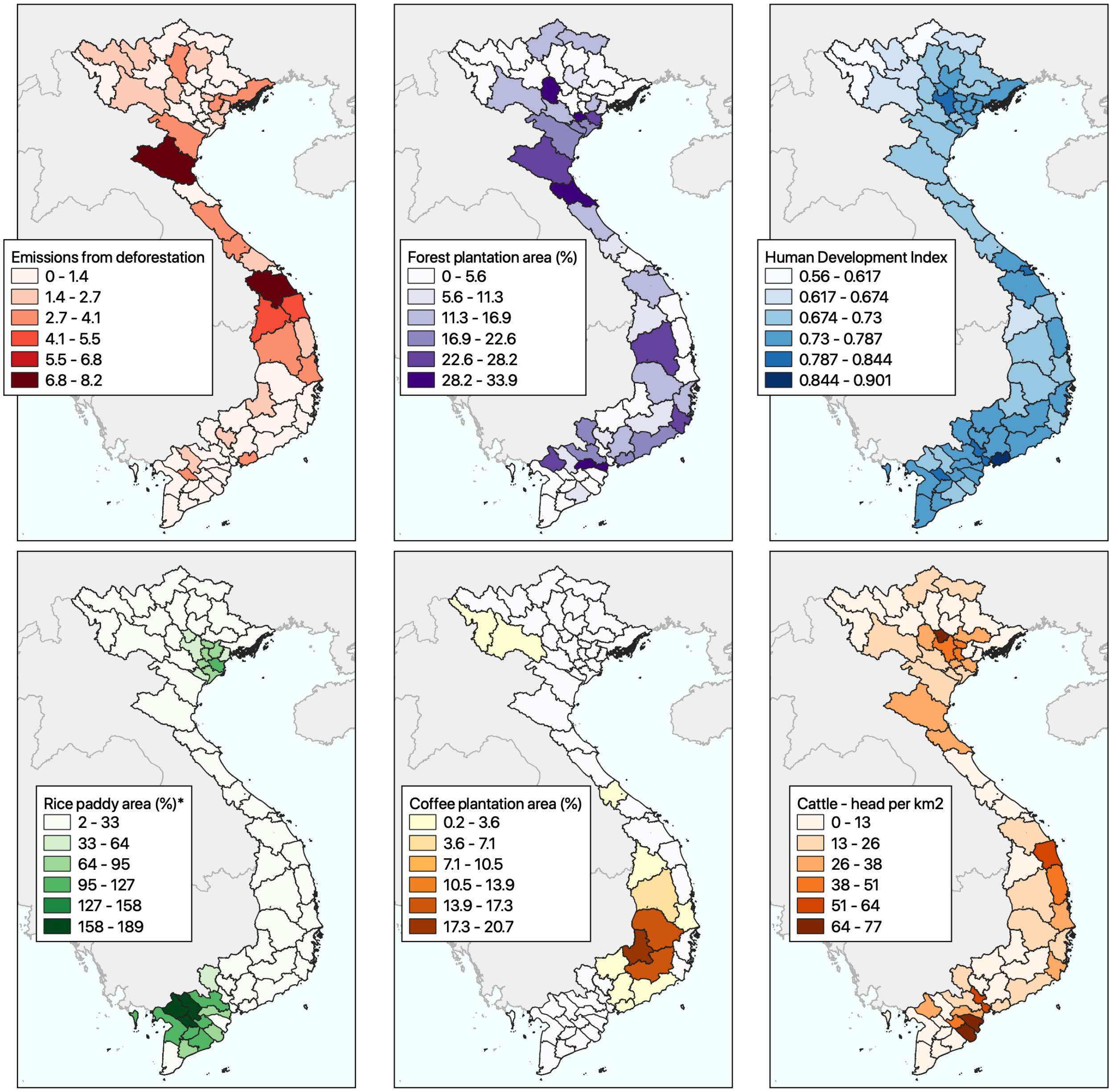

Figure 7: Spatial patterning of sectors and indicators that may be relevant to SL planning. Reading L-R from top left, (1) average annual emissions from deforestation 2013-2017, $MtCO_2e$ (Global Forest Watch); (2) area in forest plantations as percent of provincial area (MONRE 2017); (3) Human Development Index (HDI) 2012 (UNDP 2016); (4) Area of rice paddy planted annually as percentage of provincial area (*)—note this can be greater than 100 percent because of multiple plantings (FAO 2019); (5) area of coffee plantations as percentage of provincial area (FAO 2019); (6) Cattle density in head of cattle per km^2 (FAO 2019).

There are some areas of geographic overlap. Deforestation is seen in multiple hotspots, particularly the North Central Coast, the northern part of the Central Highlands, and to a lesser degree in the Northwest. In the Central Highlands, this may allow opportunities for integration of forest conservation programs with promotion of agroforestry in coffee production systems as these overlap to some degree. An example of that integration already exists: in Lam Dong, a province in the Central Highlands with a large amount of coffee production and moderate rates of forest loss, the USAID-supported

Lowering Emissions in Asia's Forests (USAID LEAF) project[3] has already made investments in forest conservation that also encourage sustainable land management, including agroforestry promotion.

Overlap exists in other regions as well: in the South Central Coast, there is some overlap between areas of deforestation and areas of cattle production, so here there may be opportunities for integrated programming of forest conservation and climate-smart livestock practices. Livestock production is also prevalent in parts of the Red and Mekong River deltas, which could provide opportunities for integration between rice-focused investments and livestock-focused ones.

One exercise in prioritization is to look at areas where prominent potential types of intervention overlap geographically. Table 6 below illustrates one way of doing this by comparing the ten provinces with the highest total areas of loss of natural forests between 2003 and 2013 with the ranks of those same provinces in terms of coffee production, livestock raising, and rice cultivation. Loss of natural forests can be seen as an indicator of areas with high potential for forest conservation and forest restoration activities. Area of coffee, numbers of livestock, and area under rice cultivation can be used as proxies for the scale of opportunity for SL activities in, respectively, the expansion of agroforestry in coffee, improved livestock diets and manure management, and improved practices in rice agriculture.

This ranking exercise makes it clear that there are generally strong areas of overlap between coffee production and areas of forest loss, with the four Central Highland provinces that are the nation's largest coffee producers—together producing 86 percent of the national output—all being in the top six provinces out of 63 in terms of total area of natural forest lost from 2003 to 2013. Although agroforestry in coffee has a relatively low overall potential for emissions mitigation, the potential that does exist is very cost-effective and thus may represent an opportunity to generate alternative livelihoods that may in turn support forest conservation efforts in the same areas. There is also some overlap between provinces of high forest loss and high livestock production, potentially in the provinces of Gia Lai, Dak Lak, and Phu Yen.

Table 6. Ranking of Vietnam's 63 provinces in terms of the loss of natural forests (a proxy for both forest conservation potential and forest restoration); remaining area of natural forests; coffee production; cattle raising; and rice cultivation. Provinces shown are either top ten by forest loss area, top ten by remaining forest area, or both.

Region	Province	Loss of natural forests by area (rank 2003–2013)	Natural forests (rank by 2013 area)	Coffee production (rank by area)	Livestock (rank by head of cattle)	Rice cultivation (rank by area of paddy)
Central Highlands	Dak Nong	1	21	3	54	60
Southeast	Binh Thuan	2	17	12	10	21
Central Highlands	Gia Lai	3	2	4	2	30
Southeast	Binh Phuoc	4	35	6	43	61
Central Highlands	Lam Dong	5	6	2	27	54
Central Highlands	Dak Lak	6	5	1	8	24
Northeast	Quang Ninh	7	26		53	46
Northwest	Hoa Binh	8	28		31	49
Northeast	Thai Nguyen	9	32		36	31
South Central Coast	Phu Yen	10	30	13	7	37
Central Highlands	Kon Tum	12	4	7	30	58
South Central Coast	Quang Nam	39	8		12	25
Northwest	Dien Bien	41	10	11	34	41

[3] https://www.leafasia.org/library/infographic-improving-forest-management-lam-dong

Region	Province	Loss of natural forests by area (rank 2003–2013)	Natural forests (rank by 2013 area)	Coffee production (rank by area)	Livestock (rank by head of cattle)	Rice cultivation (rank by area of paddy)
North Central Coast	Quang Binh	44	7		22	38
North Central Coast	Thanh Hoa	50	9		5	6
North Central Coast	Nghe An	54	1		1	12
Northwest	Son La	55	3	8	6	40

It may also be the case that investments are intended to prioritize goals other than emissions abatement but may nonetheless attempt to reduce emissions as a secondary benefit. As an example, if poverty alleviation is a priority, the HDI indicates that the Northwest and Northeast could be areas of focus. In those areas, SL-related opportunities could be found in avoided forest conversion, improved forest management, and to a lesser extent in the coffee and livestock sectors.

4.2. CO-BENEFITS

The noneconomic co-benefits of activities are another factor to consider in prioritizing SL programming, especially in cases where the identification of co-benefits can help to align projects with existing government priorities or where it enables integration with other USAID programs. Many of the activities identified for Vietnam have significant co-benefits for water quality, water availability, biodiversity, gender equality, and health (Table 7).

Activities in the forest sector, particularly forest conservation, forest restoration, reforestation of degraded or bare lands, and expansion of agroforestry practices in agricultural lands have similar patterns of co-benefits; however, there are some important differences. Forest conservation, forest restoration, and agroforestry all have significant positive benefits for biodiversity, particularly in the case of forest conservation. Additionally, these three categories of activities all have positive effects on the potential for collection of non-timber forest products (NTFPs) such as medicinal plants and fruits.

Improved access to NTFPs generally also has positive impacts on social and gender equality, in particular because poorer households tend to rely on them relatively more, and their collection is frequently undertaken by women within a household. In addition, establishing plantations in degraded areas also has the potential for positive biodiversity impacts; however, experience with reforestation in Vietnam to date has tended to show an overreliance on commercial monocrops with low biodiversity values. Commercial monocrops tend to provide fewer opportunities for NTFP harvest. In the case of most forest-based activities, there are significant benefits to soil stability and moderation of water flows. Here, again, commercial plantations can be outliers in terms of the benefits they generate. While plantations provide many of the same benefits in terms of erosion control and slope stability as natural forests, some of the species used most frequently in Vietnam—notably acacia species and eucalypts—can have very high water demands and can, in some cases, reduce stream flows.

Changes in rice cultivation practices—including AWD irrigation practices, better management of straw, and more efficient fertilizer use—generate multiple co-benefits, including improved soil health; improved human health from reduced mosquito- and water-borne diseases; lower levels of heavy metal uptake into the rice; improved air quality from less straw burning; and reduced nutrient runoff into waterways.

In the livestock sector, improved manure management can also improve water quality and human health when biodigesters are used as part of a strategy to replace wood cookstoves with gas stoves. This latter point also serves to address one element of gender inequality, as the negative health impacts of wood cookstoves fall disproportionately on women and girls. Rotational grazing has significant co-benefits, including improvements in water quality, increased flood protection, and improved biodiversity.

Table 7. Summary of co-benefits by strategy group in Vietnam INDC (groupings described in Table A2)

Category	Co-benefits	Total 10-year Potential ($MtCO_2e$)
Forest protection	Biodiversity; water availability; NTFP harvest	213.3
Forest restoration	Biodiversity; water availability; NTFP harvest	68.8
Alternate wetting and drying in irrigated rice	Improved soil health; Reduction in water-based disease vectors	50.5
Manure management for fertilizer and biogas	Water quality; Health from reduced wood smoke	29.6
Establishing commercial plantations in bare land	Limited co-benefits; small benefit to biodiversity; impact on water availability can be either positive or negative	14.1
Improved use of crop residues	Reduce solid waste; reduced air pollution from burning	8.7
Conversion of rice to aquaculture	Limited to none	6.5
Transitioning coffee to mixed-crop agroforestry	Improved soil stability; improved soil fertility in some cases; some biodiversity benefits.	6.3
Improved livestock diets	Grazing management has animal health and food safety benefits; working conditions and air quality for humans	4.3
Low-tillage agriculture	Surface water quality protection from soil loss; reduced siltation of dams; reduced air pollution from machinery use	1.5
Nutrient management in annual crops	Protection of ground and surface water quality	0.7
Rice converted to maize	Limited to none	0.6
Biochar	Improved water quality from reduced fertilizer use and loss; reduced air pollution from less fertilizer production	0.3

5.0 SUMMARY AND CONCLUSION

There are many synergies among potential SL options; investments that target suites of related activities will generally be the most effective and efficient. In some cases, an integrated approach may be essential to the success of the individual components; for example, in the case of alternate wetting and drying where technical support on nutrient management may be required to avoid potential negative outcomes of AWD, or in the case of forest conservation, where investments in agroforestry can provide livelihood improvements that may in turn support conservation goals.

In some cases, integration of strategies will take place across sectors of intervention—as in the potential case of agroforestry and forest conservation mentioned above, or possibly in cases where investments in different sectors would overlap geographically (Figure 7). Interventions in rice, while having large mitigation potential in a sector that is of great importance in the Vietnamese economy, seem to have much less potential for synergies with activities in other sectors. However, the complexity of rice production as a system means that effective investment in climate mitigation would of necessity require an integrated approach within the sector.

Deciding among SL strategies in large part depends upon priorities of the program, whether its goal is solely to maximize climate benefit per unit of investment or instead it seeks to also improve other outcomes such as biodiversity, water quality, social equality, or livelihoods. Additionally, geography may affect the choice of strategies if there are regions that a program has reason to target because of existing activities or other priorities. We conclude this document by providing a summary (Table 8) that provides information on total potential; likely cost per unit of abatement; geographic targeting; and the benefits and risks of, and potential barriers to, each potential intervention.

Table 8: Multi-criteria assessment of categories of SL strategies

Strategy	Total annual potential of INDCs in sector ($MtCO_2e$)	Cost per unit abatement $/$tCO_2e$	Likely areas of geographic focus	Associated co-benefits	Potential Risks	Barriers to implementation
Conservation and restoration of upland forests and mangroves	23.9	18.2	Central Highlands; North Central Coast; Northeast (mangroves); Northwest	Biodiversity conservation; watershed protection; NTFP potential; stabilization of water flows	Increased enforcement presence may lead to loss of access to NTFPs or wild game that communities may have used in the past.	Competition with high-value cash crops; competition with plantations; poor monitoring allowing some conversion to plantation to take place unreported.
Improved natural forest management and reforestation	5.7	6.0	Central Highlands; North Central Coast; Northeast	Improved soil retention; Potential stabilization of water flows (depending on species and context)	Previous investments in reforestation have frequently led to establishment of monocultures with limited biodiversity benefits and mixed effect on water flows. Has in some cases lead to increased inequality and negative impacts on poor households, particularly women.	Poor survivorship historically; high levels of past reforestation may mean that remaining areas are higher-cost or less beneficial.
Agroforestry promotion	6.2	-9.2	Central Highlands; Northwest	Improved soil retention and soil water-holding capacity; improved resilience of agriculture to climate change; increased income diversity and thus livelihood resilience. High potential to benefit smallholder farmers.	Slow economic returns to investment may provide risks to household income	Slow economic returns, especially in comparison to monoculture cash crops that are the primary competition to agroforestry systems. Potentially high demands for technical assistance
Annual crop sector	91.2	-7.3	Mekong River Delta; Red River Delta	Options proposed generally provide income improvements; improvements in water quality from reduced runoff and fertilizer over-use.	AWD in rice has the risk of increasing emissions, although this can be almost entirely mitigated by appropriate technical assistance; few if any risks to improved crop nutrient management or to improved management of crop residues	High demands for technical assistance; reticence of farmers consider high use of fertilizers as a form of insurance.

Strategy	Total annual potential of INDCs in sector ($MtCO_2e$)	Cost per unit abatement $/t$CO_2$e	Likely areas of geographic focus	Associated co-benefits	Potential Risks	Barriers to implementation
Climate-smart livestock practices	11.6	-45.4	Throughout country, but particularly the two deltas and South Central Coast	Improved water quality; improved farmer incomes.	In the case of biogas digestors, risk of farmer investment taking a long time to pay off and posing a risk to household livelihood. Limited to no risks of improving practices in feed and grazing of livestock.	High technology demands and need for technical assistance; high labor demands, especially for rotational grazing.

REFERENCES

Allen, J. M. & Sander, B. O. (2019). The diverse benefits of alternate wetting and drying (AWD). Los Baños, Philippines: International Rice Research Institute. Retrieved from http://www.ccafs.cgiar.org

Chastain, J. P., Camberato, J. J., Albrecht, J. E., & Adams, J. (1998). Swine Manure Production and Nutrient Content. Clemson University Agriculture Extension Manuals.

Chazdon, R. L. & Guariguata, M. R. (2016). Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. *Biotropica*, *48*(6), 716–730. doi:10.1111/btp.12381

Chazdon, R. L., Broadbent, E. N., Rozendaal, D. M. A., Bongers, F., Zambrano, A. M. A., Aide, T. M., . . . Poorter, L. (2016). Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. *Science Advances, 2*(5), e1501639. doi:10.1126/sciadv.1501639

Climate Access Indicators Tool (CAIT). (2019). Climate Data Explorer. World Resources Institute. Accessed May 2019 at https://cait.wri.org

Cu, T. T., Nguyen, T. X., Triolo, J. M., Pedersen, L., Le, V. D., Le, P. D. & Sommer, S. G. (2014). Biogas production from Vietnamese animal manure, plant residues and organic waste: influence of biomass composition on methane yield. *Asian-Australas Journal of Animal Science, 28*(2): 280–289. doi:10.5713/ajas.14.0312

Cuartas, C. A., Naranjo, J. F., Tarazona, A. M., Murgueitio, E., Chara, J. D., Ku, J., . . . Barahona, R. (2014). Contribution of intensive silvopastoral systems to animal performance and to adaptation and mitigation of climate change. *Revista Colombiana de Ciencias Pecuarias*. 27, 76–94.

Dickie, A., Streck, C., Roe, S., Zurek, M., Haupt, F. & Dolginow, A. (2014). *Strategies for mitigating climate change in agriculture: Abridged report.* Climate Focus and California Environmental Associates, prepared with the support of the Climate and Land Use Alliance. Report and supplementary materials available at www.agriculturalmitigation.org

Duguma, L. A., Nzyoka, J., Minang, P. A. & Bernard, F. (2017). *How agroforestry propels achievement of nationally determined contributions.* (ICRAF Policy Brief no. 34). World Agroforestry Centre, Nairobi, Kenya.

Duteurtre, G. (May 2019). CIRAD. Personal communication.

Duteurtre, G., Cesaro, J. D., Nguyen, M. H., Pham, D. K., & Nguyen, N. L. (2015). *TH dairy company (Vietnam): Is such a large-scale investment sustainable?* (Revalter working paper). Hanoi, 17 pp.

Escobar Carbonari, D., Grosjean, G., Läderach, P., Nghia, T. D., Sander, B. O., McKinley, J., . . . Tapasco, J. (2019). Reviewing Vietnam's nationally determined contribution: A new perspective using the marginal cost of abatement. *Frontiers in Sustainable Food Systems*, *3*, Article14. doi:10.3389/fsufs.2019.00014

Fageria, N. K. & Baligar, V. C. (2001). Lowland rice response to nitrogen fertilization. *Communications in Soil Science and Plant Analysis*, *32*(9), 1405–1429.

Food and Agriculture Organization (FAO). (2019). FAOSTAT Database: Agricultural Emissions. http://www.fao.org/faostat/en/#data. Accessed May 2019. Food and Agriculture Organization, Rome.

Global Forest Watch. (2019). Country Dashboard: Vietnam. https://www.globalforestwatch.org/ Accessed November 2019.

Goopy, J. P., Onyango, A. A., Dickhoefer, U. & Butterbach-Bahl, K. (2018). A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa – Results for Nyando, Western Kenya. *Agricultural Systems*, 161, 72–80.

Government of Vietnam. (2015). Intended Nationally Determined Contribution of Viet Nam. Hanoi, Vietnam.

Government of Vietnam. (2017). Resolution No 120/NQ-CP on 17 November 2017 on sustainable development of the MRD region to adapt to climate change. Government of Vietnam. Hanoi, Vietnam.

Graham, V., Susan, G., Laurance, I., Grech, A., McGregor, A., & Venter, O. (2016). A comparative assessment of the financial costs and carbon benefits of REDD+ strategies in Southeast Asia. *Environmental Research Letters 11*(11).

Griscom, B., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W.H., Shochf, D., Siikamäki, J.V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R.T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M.R., Herrero, M., Kiesecker, J., Landis, E., Laestadius, L., Leavitt, S.M., Minnemeyer, S., Polasky, S., Potapov, P., Putz, F.E., Sanderman, J., Silvius, M., Wollenberg, E., and Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences of the United Nations (PNAS), 114*, 11645-11650.

Griscom, B., Busch, J., Cook-Patton, S.C., Ellis, P.W., Funk, J., Leavitt, S.M., Lomax, G, Turner, W., Chapman, M., Engelmann, J., Gurwick, N.P., Landis, E., Lawrence, D., Malhi, Y., Murray, L.S., Navarrete, D, Roe, S., Scull, S., Smith, P., Streck, C., Walker, W.S., and Worthington, T. (2020). National mitigation potential from natural climate solutions in the tropics. *Philosophical Transactions of the Royal Society of London B*. DOI: 10.1098/rstb.2019.0126

Holland, T. & McNally, R. (2010). REDD Working Papers: REDD and sustainable development – perspective from Viet Nam. IIED https://pubs.iied.org/G02773/

International Rice Research Institute (IRR). (2019). GHG mitigation in rice: alternate wetting and drying. Available at https://ghgmitigation.irri.org/mitigation-technologies/alternate-wetting-and-drying.

Ismail, M. (2018). Pig waste powers Vietnam. *The Asean Post*. https://theaseanpost.com/article/pig-waste-powers-vietnam (September)

Ju, X., Xing, G., Chen, X., Zhang, S., Zhang, L., Liu, X., . . . Zhang, F. (2009). Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proceedings of the National Academy of Sciences of the United Nations (PNAS)*, *106*(9), 3041–3046. doi:10.1073/pnas.0813417106

Knapp, J. R., Laur, G. L., Vadas, P. A., Weiss, W. P. & Tricarico, J. M. (2014). Invited review: enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions. *Journal of Dairy Science*, *97*, 3231–3261.

Kumar, B. M. (2011) Species richness and aboveground carbon stocks in the homegardens of central Kerala, India. *Agriculture, Ecosystems & Environment, 140*, 430–440.

Little, C., Lara, A., McPhee, J., Urrutia, R. Revealing the impact of forest exotic plantations on water yield in large scale watersheds in south-central Chile. *Journal of Hydrology*, *374*(1–2), 162–170.

Lorenz, H., Reinsch, T., Hess, S. & Taube, F. (2019). Is low-input dairy farming more climate friendly? A meta-analysis of the carbon footprints of different production systems. *Journal of Cleaner Production*, *211*, 161–170.

McElwee, (2009). Reforesting "bare hills" in Vietnam: Social and environmental consequences of the 5 million hectare reforestation program. *Ambio*, *38*(6), 325–33.

Ministry of Natural Resources and Environment of the Government of Vietnam (MONRE). (2017). The second biennial updated report of Viet Nam to the UNFCCC. Ministry of Natural Resources and Environment, Government of Vietnam, Hanoi, Vietnam.

Mulia, R., Nguyen, M.P., Pham, T.V., Dinh, T.H. Potential mitigation contribution from agroforestry to Viet Nam's NDC. World Agroforestry Centre (ICRAF) Viet Nam. Hanoi, Vietnam.

Müller, D., Epprecht, M. & Sunderlin, D.W. (2006). *Where are the poor and where are the trees? Targeting of poverty reduction and forest conservation in Vietnam* (Working Paper No. 34). CIFOR, Bogor, Indonesia.

Nath, A. J. & Das, A. K. (2012). Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India. *Tropical Ecology 53*, 287–293.

Ngonidzashe, C., Loaiza, S., Arenas, L., Ruiz, V., Faverín, C., Alvarez, C., . . . Cardenas, C. (2019). Adequate vegetative cover decreases nitrous oxide emissions from cattle urine deposited in grazed pastures under rainy season conditions. *Scientific Reports*, *9*, Article 908.

Nguyen & Tran (2018). Forestland and rural household livelihoods in the North Central Provinces, Vietnam. *Land Use Policy*, *79*, 10–19.

Nguyen, M. H., Cesaro, J-D., Duteurtre, G., & Dorin, B. (2018). *Livestock farms' upscaling unlimited? Building scenarios for Vietnam's dairy sector by 2030*. (Policy brief). https://www.malica.org/

O'Brien, D., Capper, J. L., Garnsworthy, P. C., Grainger, C., & Shalloo, L. (2014). A case study of the carbon footprint of milk from high-performing confinement and grass-based dairy farms. *Journal of Dairy Science, 97*, 1835–1851. doi:10.3168/jds.2013-7174

Rachmat, M., Nguyen, M. P., Pham, T. V., & Dinh, T. H. (2018). *Potential mitigation contribution from agroforestry to Viet Nam's NDC.* World Agroforestry Centre (ICRAF). Viet Nam, Southeast Asia Program, Hanoi, Viet Nam.

Rotz, C. A. (2018). Modeling greenhouse gas emissions from dairy farms. *Journal of Dairy Science*, *101*(7), 6675–6690.

Runkle, B., Suvočarev, K., Reba, M. L., Reavis, C. W., Smith, S. F., Chiu, Y-L, & Fong, B. (2019). Methane emission reductions from the alternate wetting and drying of rice fields detected using the eddy covariance method. *Environmental Science Technology*, *53*(2), 671–681. doi:10.1021/acs.est.8b0553

Sanchez, P. (2000). Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystems and Environment, 82*, 371–383.

Sander, B. O., (2019). Personal communication

Sander, B. O., Wassmann R., & Siopongco J. D. L. C. (2015). Mitigating greenhouse gas emissions from rice production through water-saving techniques: Potential, adoption and empirical evidence. In C. T. Hoanh, V. Smakhtin, & T. Johnston (Eds.), *Climate Change and Agricultural Water Management in Developing Countries* (pp. 193–207). Oxford: CABI.

Symon, M. N., Samejima, H., Katsura, K., Kikuta, M., Gweyi-Onyango, J. P., Kimani, J. M., . . . Makihara, D. (2018). Grainyield responses of lowland rice varieties to increased amount of nitrogen fertilizer under tropical highland conditions in central Kenya, *Plant Production Science*, *21*(2), 59–70. doi:10.1080/1343943X.2018.1436000

Thuy, P. T., Moeliono, M., Nguyen, T. H., Nguyen, H. T., & Vu, T. H. (2012). *The context of REDD+ in Vietnam Drivers, agents and institutions* (Occasional Paper 75). Center for International Forestry Research (CIFOR).

Tirol-Padre, A., Minamikawa, K., Tokida, T., Wassmann, R. & Yagi, K. (2018). Site-specific feasibility of alternate wetting and drying as a greenhouse gas mitigation option in irrigated rice fields in Southeast Asia: A synthesis. *Soil Science and Plant Nutrition, 64*(1), 2–13. doi:10.1080/00380768.2017.1409602

Tran, V. T., Mai, V. T., Nguyen, T. D. T., Le, H. A., Richards, M. B., Sebastian, L., . . . Sander, B. O. (2019). *An investment plan for low-emission rice production in the Mekong River Delta region in support of Vietnam's Nationally Determined Contribution to the Paris Agreement* (CCAFS Working Paper no. 263). Wageningen, Netherlands: CGIAR Research Program on Climate Change, *Agriculture and Food Security (CCAFS)*. Available online at: www.ccafs.cgiar.org

United Nations Development Programme (UNDP). (2016). *Development that works for all: Viet Nam human development report 2015 on inclusive growth*. Hanoi: Social Sciences Publishing House.

United States Agency for International Development (USAID). (2016). Greenhouse Gas Emissions Factsheet: Vietnam.

van Noordwijk, M., Rahayu, S., Hairiah, K., Wulan, Y. C., Farida, A., & Verbist, B. (2002). Carbon stock assessment for a forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): From allometric equations to land use change analysis. *Science in China (Series C), 45* Supp., 75–86.

Voisin, A. (1959). *Grass productivity* (First Ed.). New York: Philosophical Library, Inc.

West, P. C., Gibbs, H. K., Monfreda, C., Wagner, J., Barford, C. C., Carpenter, S. R. & Foley, J. A. (2010). Trading carbon for food: Global comparison of carbon stocks vs. crop yields on agricultural land. *Proceedings of the National Academy of Sciences*, *107*(46), 19645–19648.

World Bank. (2018). Project Performance Assessment Report for the Vietnam Forest Sector Development Project (P066051 (IDA) and P074414 (GEF)). Independent Evaluation Group, World Bank. Washington, DC.

Zomer, R. J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., . . . Wang, M. (2016). Global tree cover and biomass carbon on agricultural land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*, *6*, 29987. doi:10.1038/srep29987

APPENDIX A

Table A1. AFOLU-sector emissions abatement opportunities proposed for Vietnam in documentation supporting national INDC. Goals, descriptions, mitigation potential, and costs per ton all directly from Escobar et al. 2019.

Category of action (as used in Figures 5 and 6)	Mitigation action	Goal	Description	10-year mitigation potential	USD / ton CO_2e	Cost effectiveness rank (also Fig 1a label)
Forest protection	Rain forest protection 2	10% of the commitments of forest protection	Prevent degradation of rainforest by to commercial forestry (acacia) prevents the release of emissions.	64.59	2.6	21
Forest protection	Rain forest protection 1	10% of the commitments of forest protection	Prevent degradation of rainforest by to commercial forestry (acacia) prevents the release of emissions.	59.41	0.2	15
Forest protection	Mangrove protection	100% of commitments of coastal forest protection	Prevent the change of mangroves into aquaculture prevent emissions of GHG.	47.75	23.1	29
Forest protection	Forest protection 1	10% of the commitments of forest protection	Prevent degradation of tropical and subtropical forest due to agricultural crops (cassava and maize) prevents the release of emissions.	35.22	20.9	28
Manure management for fertilizer and biogas	Biogas from pigs	20% increment in the users of this technology	Biogas decrease GHG coming from waste in pigs farm compare to conventional waste management.	22.32	0.3	16
Alternate wetting and drying in irrigated rice	AWD Mekong 1	25% of the commitments of water management in rice	Reduced methane production due to less water use in AWD rice compared with conventional rice.	12.63	-24.6	8
Alternate wetting and drying in irrigated rice	AWD mekong 2	25% of the commitments of water management in rice	Reduced methane production due to less water use in AWD rice compared with conventional rice.	12.63	-22.9	9
Alternate wetting and drying in irrigated rice	AWD red river 1	25% of the commitments of water management in rice	Reduced methane production due to less water use in AWD rice compared with conventional rice.	12.63	-18.5	10
Alternate wetting and drying in irrigated rice	AWD red river 2	25% of the commitments of water management in rice	Reduced methane production due to less water use in AWD rice compared with conventional rice.	12.63	-16.9	12
Forest restoration	Rain forest	25% of commitments of	Restore rainforest in bare land increase the	11.48	2.3	20

Category of action (as used in Figures 5 and 6)	Mitigation action	Goal	Description	10-year mitigation potential	USD / ton CO_2e	Cost effectivenes s rank (also Fig 1a label)
	restoration 1	the bare and unused land that will be transformed	amount of carbon sequestration per area			
Forest restoration	Forest restoration 1	25% of commitments of the bare and unused land that will be transformed	Restore tropical and subtropical forest in bare land increase the amount of carbon sequestration per area.	9.39	2.9	22
Establishing commercial plantations in bare land	Acacia in bare land	50% of the commitments of plantation of large wood production.	Acacia planted in bare land increases the carbon stocks in the area.	8.81	-0.9	14
Forest restoration	Forest restoration 3	12.5% of the commitments in forest regeneration	Restore tropical and subtropical forest in agricultural crops (cassava and maize) increase the amount of carbon sequestration per area.	8.73	86.2	32
Forest restoration	Rain forest restoration 2	25% of commitments of the bare and unused land that will be transformed	Restore rainforest in bare land increase the amount of carbon sequestration per area	8.03	1.4	17
Manure management for fertilizer and biogas	Compost from pigs	Double the number of current users of the technology	Composting decrease GHG coming from conventional waste management in pigs farm	7.31	-2	13
Forest restoration	Forest restoration 2	40% of the commitments of natural forest regeneration.	Restore tropical and subtropical forest from a degraded state increase the amount of carbon sequestration per area.	6.57	1.8	18
Conversion of rice to aquaculture	Rice into shrimp	50% of the projections of rice area reduction.	Replace rice by aquaculture reduce methane emission.	6.54	-79.1	5
Forest protection	Bamboo protection 1	5% of the commitments of forest protection	Transformation of bamboo forest into crops (maize and cassava) prevented to avoid emission from deforestation	6.37	52.3	30
Improved use of crop residues	Rice straw	25% of commitments of integrated crop management	Reduce the straw incorporation can decrease methane emissions compare to conventional straw management	5.97	12.2	25
Transitioning coffee to mixed-crop agroforestry	Coffee and cassia	40% of the goal of changing 30% of current coffee in agroforestry	Agroforestry in coffee increase the amount of carbon sequestration per area compare to monoculture coffee	5.9	15.1	26

Category of action (as used in Figures 5 and 6)	Mitigation action	Goal	Description	10-year mitigation potential	USD / ton CO_2e	Cost effectiveness rank (also Fig 1a label)
Forest restoration	Rain forest restoration 3	25% of commitments of the bare and unused land that will be transformed	Restore rainforest in bare land increase the amount of carbon sequestration per area	5.28	19.9	27
Establishing commercial plantations in bare land	Rubber in bare land	50% of the commitments in plantation of large wood production.	Rubber planted in bare land increase the amount of carbon sequestration per area.	5.27	-25.7	7
Forest restoration	Bamboo restoration 1	25% of commitments of the bare and unused land that will be transformed	Restore bamboo forest in bare land to increase the amount of carbon sequestered per unit area.	5.22	5.1	24
Forest restoration	Bamboo restoration 3	12.5% of the commitments in forest regeneration	Restore bamboo forest in current maize and cassava fields increase the amount of carbon sequestration per area, and decrease agriculture emissions	5.17	145.4	37
Forest restoration	Rain forest restoration 4	25% of commitments of the bare and unused land that will be transformed	Restore rainforest in bare land increase the amount of carbon sequestration per area	3.59	80	31
Improved livestock diets	Dairy TMR	Increase the percentage of user of this technology from 53 to 70%	Better diets in dairy cattle contributes to decrease enteric fermentation	2.63	-130.6	3
Forest restoration	Mangrove restoration 1	50% of commitments of coastal forest restoration.	Recover mangrove in sandy in current aquaculture increase the amount of carbon sequestration per area.	1.93	114.6	34
Forest restoration	Mangrove restoration 2	50% of commitments of coastal forest restoration.	Recover mangrove in sandy in current aquaculture increase the amount of carbon sequestration per area.	1.93	127.5	35
Improved use of crop residues	Maize compost	5% of the commitments of urea substitution.	Applying compost in maize fields increase carbon sequestration compare to conventional soil management	1.69	129.8	36
Improved livestock diets	Beef diet supplement	10% increment in the users of this technology	Supplement beef cattle decrease enteric fermentation compare to no supplemented diets	1.67	-101.3	4
Low tillage agriculture	Low tillage (S & P)	5% of commitments of integrated crop management	Low tillage in agricultural can reduce emissions and help to increase carbon sequestration compare to conventional tilling	1.52	1.9	19

Category of action (as used in Figures 5 and 6)	Mitigation action	Goal	Description	10-year mitigation potential	USD / ton CO_2e	Cost effectiveness rank (also Fig 1a label)
Forest restoration	Bamboo restoration 2	20% of the commitments of natural and production forest regeneration	Recover bamboo forest from degraded states to increase the amount of carbon sequestration per unit area.	1.46	3.8	23
Nutrient management in annual crops	Maize AS	5% of the commitments of urea substitution	Replacement of urea by ammonium sulfate in maize fields decrease nitrous oxide emissions	0.64	-18.4	11
Rice converted to maize	Rice for maize	50% of the projections of rice area reduction	Replace rice by maize reduce methane emission.	0.62	388.3	39
Improved use of crop residues	Maize residues	25% of commitments of integrated crop management	Not burning residues in maize decrease emissions.	0.55	88.1	33
Improved use of crop residues	Sugarcane compost	5% of the commitments of urea substitution.	Applying compost in sugarcane fields to increase carbon sequestration compared with conventional soil management	0.52	187.1	38
Transitioning coffee to mixed-crop agroforestry	Coffee and avocado	30% of the goal of changing 30% of current coffee in agroforestry	Agroforestry in coffee increase the amount of carbon sequestration per area compare to monoculture coffee	0.22	-529.4	1
Biochar	Biochar maize	50% of the commitments in biochar.	Applied biochar offsets N2 O emissions	0.17	749.7	40
Transitioning coffee to mixed-crop agroforestry	Coffee and durian	30% of the goal of changing 30% of current coffee in agroforestry	Agroforestry in coffee increase the amount of carbon sequestration per area compare to monoculture coffee	0.13	-234.7	2
Biochar	Biochar rice	50% of the commitments in biochar.	Applied biochar offsets N2 O emissions	0.11	851	41
Nutrient management in annual crops	Sugarcane AS	5% of the commitments of urea substitution	Replace urea with ammonium sulfate in sugarcane fields to decrease nitrous oxide emissions	0.07	-41.2	6

Figure A1. Marginal abatement curve from Escobar et al. 2019 (Figure 2 in that paper). In this graph, actions are indicated by rectangles that are ordered from the lowest cost per unit of abatement on the left side to the highest cost on the right side. The width of each rectangle represents the total abatement potential of that action so that as you read the graph from left to right, the actions add up to the total potential abatement possible under a given cost per unit.

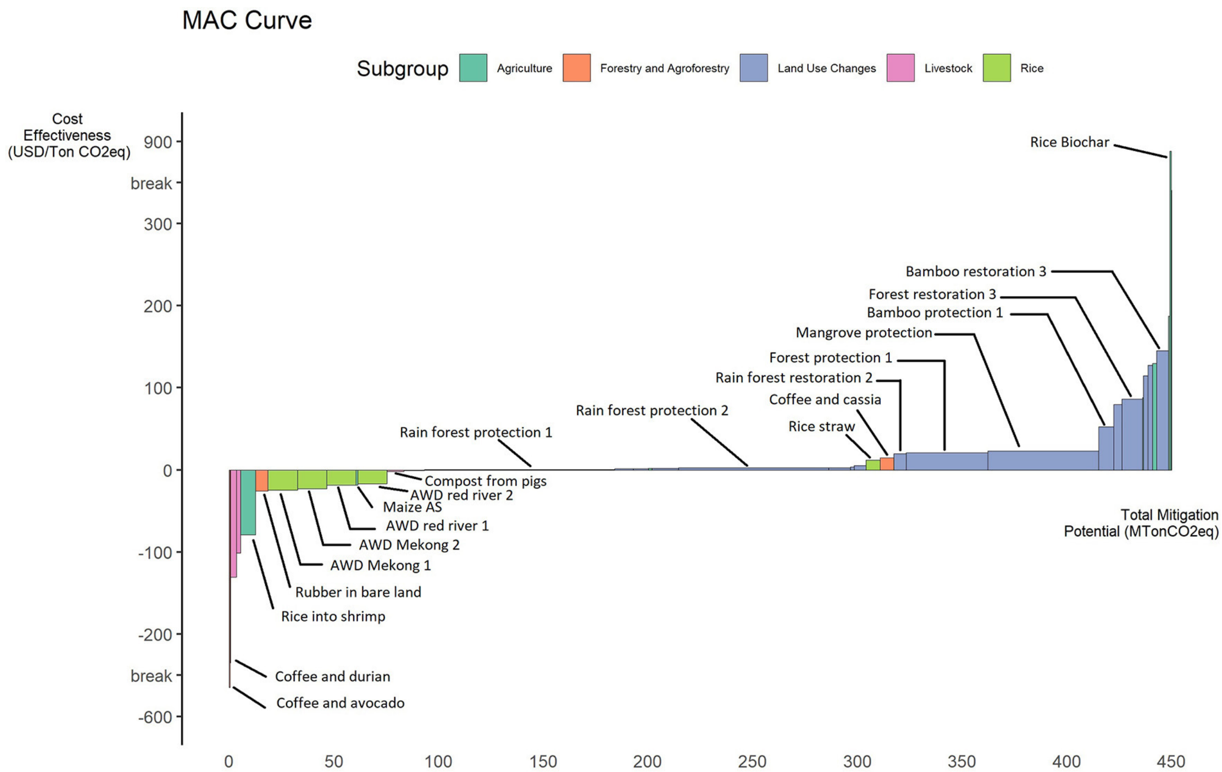

Table A2: Description of all 20 mitigation pathways described in Griscom et al. 2017 with updated data from Griscom et al. 2020 (unpublished). Some text in pathway description column is taken verbatim from Griscom et al. 2017 Supplemental Information. For pathways where country-level data is not available, a description is provided here of available data. Pathways are ranked from largest to smallest in their total estimated potential globally. Green rows represent forest-sector pathways, yellow are agriculture sector, and blue are wetlands and coastal. The right-most column is an indicator of uncertainty in the estimation of each potential – it presents the ratio between the upper and lower bounds of the 95 percent confidence interval in the estimate.

Pathway	Description and activities included	Vietnam maximum potential (Griscom)	Vietnam cost-effective potential (Griscom)	Additional information for estimating potential in Vietnam	Global maximum potential (million tons CO2e / year)	Uncertainty in global estimate (ratio of upper: lower bounds)
Avoided Forest Conversion	Emissions of CO2 avoided by avoiding forest conversion. Baseline emissions derived from Tyukavina et al. (1), which defined "forest" as >25% tree cover.	54.59	43.67		3,603	1.4
Reforestation	Conversion of land from non-forest (< 25% tree cover) to forest (> 25% tree cover) in areas ecologically appropriate and desirable for forests	n.d.	18.41		10,124	6.6
Natural Forest Management	Additional carbon sequestration (aboveground and belowground) in native forests managed non-intensively for wood production. Maximum scenario is defined as the deferral of all harvests for 50 years (meets safeguard by assuming that plantations can cover fiber needs)	15.53	11.83		1,470	8.9
Improved Rice Cultivation	Avoided CH4 and N2O emissions in from rice cultivation resulting from periodic draining of rice paddies and from the removal of crop residues from flooded and upland rice production lands.	12.16	7.296		265	1.4
Trees in Croplands	Carbon sequestration in both aboveground and belowground tree biomass and soil carbon that results from the integration of trees into croplands at levels that do not reduce crop yields. This pathway includes farmer-managed natural regeneration (FMNR)	9.63	3.64		1,040	4

Pathway	Description and activities included	Vietnam maximum potential (Griscom)	Vietnam cost-effective potential (Griscom)	Additional information for estimating potential in Vietnam	Global maximum potential (million tons CO2e / year)	Uncertainty in global estimate (ratio of upper: lower bounds)
Cropland Nutrient Management	Avoided N2O emissions due to reduced fertilizer use and improved application methods	2.65	2.95	At present, average efficiency globally of N-uptake resulting from fertilizer application is about 53%, with that number likely lower in developing countries (Bodirsky et al. 2014). Assumptions are that this efficiency can be increased to 75%, effectively halving N2O emissions (25% vs 47%). However, data on fertilizer use at national scales is lacking, making it difficult to estimate the scale of this potential at national scales	706	2.4
Avoided Woodfuel Harvest	Avoided emissions, all gases, due to reduced harvest of woodfuel used for cooking and heating, without reducing heating or cooking utility	6.76	2.03		367	1.2
Peatland Restoration	Re-wetting of freshwater wetlands (tropical, temperate, and boreal peatlands) to avoid oxidation of soil carbon and to enhance soil carbon sink.	3.81	1.83		815	3.5
Avoided Coastal Wetland Impacts	Avoided emissions from loss of above- and belowground biomass as well as from loss of soil carbon that would result from degradation or loss of coastal wetlands (mangroves, salt marshes, and seagrass beds)	1.13	1.02	National-scale or regional data is not available on emissions from conversion of salt marshes or seagrass beds. However, conservative global estimates are that in 917 and 512 tons of CO2e per hectare for salt marshes and	304	3.3

Pathway	Description and activities included	Vietnam maximum potential (Griscom)	Vietnam cost-effective potential (Griscom)	Additional information for estimating potential in Vietnam	Global maximum potential (million tons CO2e / year)	Uncertainty in global estimate (ratio of upper: lower bounds)
				seagrass beds are vulnerable to being emitted on conversion of the land cover (Pendleton et al. 2012)		
Avoided Peatland Impacts	Avoided emissions from loss of above- and belowground biomass as well as from loss of soil carbon that would result from degradation or loss of freshwater wetlands (tropical, temperate, and boreal peatlands)	0.76	0.68		754	5.1
Grazing - Legumes in Pastures	Additional soil carbon sequestration due to sowing legumes in planted pastures	0.63	0.378		147	107.1
Grazing - Optimal Intensity	Additional soil carbon sequestration due to grazing optimization on rangeland and planted pasture. Prescribes a decrease in stocking rates in areas that are over-grazed and an increase in stocking rates in areas that are under-grazed	0.21	0.13		148	4.7
Fire Management	Additional sequestration and avoided emissions in above- and below- ground tree biomass due to three forms of additional fire management: (i) prescribed fires, (ii) fire control practices (e.g. fire breaks) applied to edges of forests, and (iii) use of early season fires in savanna ecosystems to avoid higher emissions from late season fires,	n.d.	0		212	2.5
Biochar	Carbon sequestration by amending agricultural soils with biochar derived from crop residue	n.d.	n.d.	Estimate is 0.66 tons CO2e sequestered long-term for every dry ton of available crop residue feedstock	1,102	2.3

Pathway	Description and activities included	Vietnam maximum potential (Griscom)	Vietnam cost-effective potential (Griscom)	Additional information for estimating potential in Vietnam	Global maximum potential (million tons CO2e / year)	Uncertainty in global estimate (ratio of upper: lower bounds)
				(Griscom et al. 2017). The Griscom global maximum estimate assumes half of global feedstock that is not fed to livestock is used for biochar.		
Coastal Wetland Restoration	Re-wetting of coastal wetlands (mangroves, salt marshes, seagrass beds) to avoid oxidation of soil carbon and to enhance soil carbon sink.	n.d.	n.d.	Carbon burial rates in these ecosystems is very high, but there is limited information on areal extent by country which makes estimating national potential difficult. Burial rates, in tons CO2e per hectare per year, are estimated to be 8.0, 8.3, and 5.1 for salt marshes, mangroves, and seagrasses, respectively (McLeod et al. 2011).	841	1.7
Grazing - Improved Feed	Avoided methane emissions due to reduced enteric fermentation from the use of more energy dense feed and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand.	n.d.	n.d.		680	29
Improved Plantations	Additional carbon sequestratation achieved by extending harvest rotations to biologically optimal rotation lengths	n.d.	n.d.	Griscom et al. 2017 estimate additional 0.47 tons carbon (= 1.72 CO2e) sequestered per year per hectare by extending rotation lengths. [[TIM to complete re plantations in VN]]	443	6

Pathway	Description and activities included	Vietnam maximum potential (Griscom)	Vietnam cost-effective potential (Griscom)	Additional information for estimating potential in Vietnam	Global maximum potential (million tons CO2e / year)	Uncertainty in global estimate (ratio of upper: lower bounds)
Conservation Agriculture	Additional soil carbon sequestration by planting cover crops during the part of the year when the main crop is not growing, where appropriate given climate factors and cropping systems	n.d.	n.d.	1.36 tons CO2e / ha*yr estimated by Eagle et al. 2012.	413	1.7
Grazing - Animal Management	Avoided methane emissions due to reduced enteric fermentation as a result of improved livestock breeds and management techniques that increase reproductive performance, animal health, and weight gain, and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand	n.d.	n.d.		200	2.9
Avoided Grassland Conversion	Avoided soil carbon emissions by avoiding the conversion of grasslands (including savannas and shrublands) to cropland	n.d.	n.d.		116	5

U.S. Agency for International Development
1300 Pennsylvania Avenue NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov