Project report

Potential mitigation contribution from agroforestry to Viet Nam's NDC

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Abstract

Viet Nam is among the 196 Parties in the Paris Agreement that has committed to low-emission development pathways. The country has formulated national climate change mitigation strategies that relate to forestry and agricultural sector, with a potential revision in 2019 that can include agroforestry (AF), provided that the potential mitigation contribution from this sector can be monitored and reported. This paper presents two approaches to measurement and reporting of AF, based on potential expansion domain (PED) of main AF systems in different regions across the country and the spatial distribution of trees outside forests (TOF), to estimate the potential mitigation contribution from AF, represented by total aboveground carbon (C) sequestration at national scale. Based on the PED approach, the total PED area of different AFs such as coffee, rubber or acacia-based, not including natural forest lands, is ≈10.1 million ha, or about 1/3 of the total land area in the country. Assuming the baseline land uses in the PED can be classified as "cultivated and managed lands," which according to the Intergovernmental Panel on Climate Change (IPCC) has an average C stock 5 ton ha^{-1}, expansion of the main AF systems across the country results in 262 ± 77 million tons of sequestered C per year, for ten years after plantation. The related total establishment cost for the expansion is USD 24.3 ± 11.3 billion. Using the TOF approach to estimate total tree coverage outside natural forest lands in 2010, total C storage of AF in Viet Nam is ≈355 million ton C, with an average of ≈21.8 ton C ha^{-1} from ≈20 million ha or about 2/3 of the total land area in the country. Comparing the PED and TOF approach under similar land coverage area of ≈10.1 million ha, the latter estimates a total C storage of ≈ 220 million ton C. By assuming it as total baseline C storage for the PED approach, the potential C gain from AF expansion is ≈92 million ton C, compared to ≈262 million ton C under the assumption of 5 ton ha^{-1} as average C stock for baseline land uses. This potential mitigation contribution from AF can be reported to relevant authorities, such as the Ministry of Agriculture and Rural Development (MARD) and its sub-institutions, that have a mandate to revise the potential mitigation contribution from the Agriculture and Land Use, Land Use Change, and Forestry sector to the country's Nationally Determined Contribution (NDC). The challenges in integrating the potential contribution from AF to the agriculture sector or land use sector that focuses on forestry, or as a segregated land use category, should be further discussed with the relevant authorities.

Keywords: agroforestry, carbon, expansion domain, mitigation, tree cover, climate change mitigation, agriculture

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Introduction

In 2015, 196 Parties including Viet Nam had become part of the Paris Agreement (PA) and committed to transform their development pathways towards low-emission and sustainable development, to contribute to global climate change mitigation. The Parties also committed to a long-term climate change adaptation target, namely to enhance adaptation and resilience to adverse impacts of climate change, that at the same time not compromising national and global food security. Additionally, they agreed to work towards making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

These commitments should be clearly outlined as Nationally Determined Contribution (NDC), as required by the Article 4 and paragraph 2 of the PA, in contrast to the 'Intended NDC' or INDC set up previously, and provide framework and targets of the post-2020 country's climate change mitigation and adaptation efforts to contribute to long-term climate goals of the United Nations Framework Convention on Climate Change (UNFCCC). The Parties shall pursue the targets with domestic or international support. For developing countries grouped as non-Annex 1 countries, it is understood that the emission mitigation can take longer than Annex 1 countries, and it should be undertaken on the basis of equity, in line with the context of sustainable development and poverty alleviation, which are priorities of most developing countries.

The NDCs will cover projected emission reduction pathways and targets from multi-sectors mainly energy, transport, industry, agriculture, as well as land use and land use changes and forestry (LULUCF). Depending on more specific condition, for example, related to the sources of emissions and opportunities for emission reduction and resources, the countries can choose and prioritize certain sectors and should provide ways to monitor, report and verify (MRV) the potential mitigation contribution, and further adaptation contribution, from the selected sectors.

Viet Nam has submitted INDC to UNFCCC in 2015, with a signed PA and NDC ratification in 2016. The Plan for Implementation of the PA was approved by the Prime Minister through Decision No.2053/QĐ-TTg dated 28/10/2016. The Implementation Plan is set up into two periods namely 2016-2020 and 2021-2030. As mitigation component, the national greenhouse gas (GHG) emission reduction is targeted to reach up to 8% as an unconditional option and 25% as conditionally option, as compared to the business as usual condition. As an adaptation component, the country's NDC will identify adaptation gaps in terms of institutional and policy arrangements, financing, human resource capacity and technology, and also will prioritize adaptation measures.

Following the National INDC submitted to UNFCCC in 2015, and the implementation plan formulated by Ministry of Agricultural and Rural Development (MARD) in 2016, the country's LULUCF expert recently (in April 2018) reviewed the mitigation strategies and provided a revision to the plan. The revised mitigation strategies cover agricultural as well as LULUCF that focuses on forestry sectors, with a subsequent review and revise a plan that can potentially include agroforestry (AF), provided that the potential mitigation contribution from this sector can be monitored and reported. The Government of Viet Nam (GoV) plans to promulgate the revised NDC plan in March 2019.

AF can be simply defined as the integration of trees into farms or non-forest lands, and has been identified as a potentially significant contributor to global climate change mitigation and adaptation goals through several ways (Duguma et al. 2017): first, through C sequestration especially from the perennial or tree components; second, by reducing the use of chemical fertilizer by integrating the nitrogen fixing plants or trees that results in maintained or enhanced soil fertility; and indirectly, AF could also help reducing leakage of C emission from adjacent forests, so it can also become a sustainable intensification option by contributing to reducing deforestation and forest degradation (Minang et al. 2014; Mbow et al. 2014). In Viet Nam, AF is one of traditional farming systems that has been practiced by the smallholder farmers in the country since decades. However, in the national land use policy, it has not been officially classified as an independent land use category from the agricultural and forestry sector. Therefore, besides the need to monitor the potential mitigation contribution from AF, there is a challenge in the ways to integrate the contribution to the existing agricultural and/or LULUCF sectors, or reporting AF as an isolated land use category.

In this paper, we present two approaches in estimating the potential mitigation contribution from AF at national scale, namely the potential expansion domain (PED) and tree outside forest (TOF) approach, with estimations that can be reported to relevant provincial authorities mainly MARD and its sub-institutions such as Viet Nam Administration of Forestry (VNFOREST) and Viet Nam Academy of Forestry Science (VAFS). The paper also discusses the challenges in integrating the potential contribution from AF into the current land use categories included in the Viet Nam's mitigation strategies namely agriculture and LULUCF that focuses on forestry sectors, with the aim to include the substantial contribution from AF into the revised NDC.

Materials and Methods

Eight regions of Viet Nam

The country has 63 provinces and five centrally-governed cities, which in terms of administration level is equivalent to province namely Ha Noi, Ho Chi Minh City, Can Tho, Da Nang and Hai Phong. These provinces and cities are further grouped into regions mainly based on geographical, climatic, biophysical and land cover distribution as well, used widely in the agriculture and forestry sectors namely Northeast (NE), Northwest (NW), Red River Delta (RRD), North Central Coast (NCC), South Central Coast (SCC), and Central Highlands (CH), Southeast (SA), and Mekong River Delta (MRD) (Fig. 1).

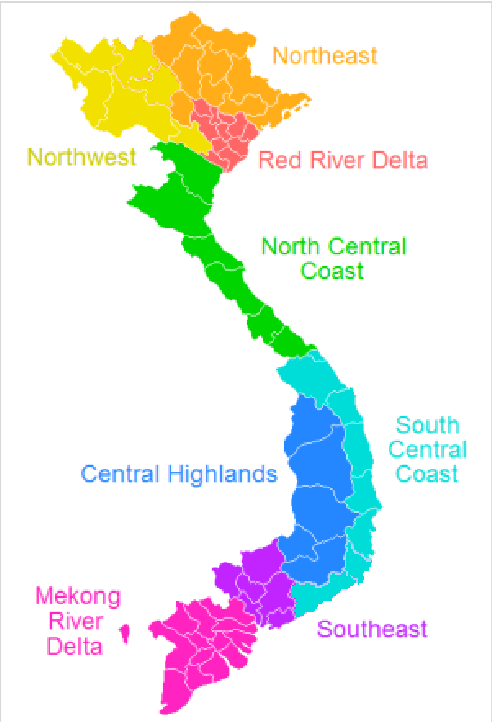


Figure 1. Eight regions in Viet Nam

In terms of geographical and demographical condition, the NE region covers mountainous provinces that spread to the north of the Red River lowlands. The NW region covers inland provinces in the west of the country's northern part. It has two provinces border with Laos, and three borders with China. These two regions (NE and NW) are commonly referred to as the northern mountainous regions of Viet Nam. The RRD region is dominated by small but populated provinces along the Red River. Among other regions, the RRD has the smallest area but the highest population and population density. The NCC region covers the coastal provinces in the northern half of Viet Nam's central part. The provinces spread from the coast in the eastern part to Laos in the western part. The SCC comprises of coastal provinces in the southern half of the country's central part. The CH consists of mountainous inland provinces of south-central Viet Nam. As in the NE and NW, the region is home of different ethnic minorities. The SE region covers the lowland parts of southern Viet Nam, north of the Mekong Delta; and the MRD region is the country's southernmost region, dominated by small but populated provinces in the Mekong Delta. In terms of climatic condition, the four regions in the North (NE, NW, RRD, and NCS) have four seasons with a cold winter from December to March while the other regions in the south (SCS, CH, SE, and MRD) only have rainy and dry seasons.

Identifying main AF system in the regions

In the PED approach, we identified the main AF systems in the eight regions using the the Spatial Characterized Agroforestry Database (SCAF) produced by World Agroforestry Centre (ICRAF)[1], which provides a valuable source on dominant AF systems in the eight regions of Viet Nam. The database covers 48 AF systems in 42 provinces and provides information on the occupation area, plot management option, productivity as well as profitability of the systems. The information contained in the database was provided by provincial authorities or relevant non-government institutions such as research institutions, as well as universities.

The representative tree-based AF systems from the regions were selected based on their actual occupation area in 2012-2013 as informed in the database, and based on their socio-economic contribution to the smallholder farmers as well as to the provinces in the regions, and whether they are still promoted by the national or sub-national authorities due to their economic and environmental benefits. The selected tree-based AF systems for the eight regions are as follow:

- Acacia-based either with *Acacia mangium* or Acacia hybrid mainly *Acacia mangium* x *Acacia auriculiformis* for RRD and SE region. These systems usually have cassava as intercrops in the first year of plantation, and Acacia is still promoted by the authorities as fast growing timber and nitrogen-fixing tree species, that can restore soil fertility. This species is widely cultivated in degraded and sloping lands across the country.
- Rubber-based (*Hevea brasiliensis*) for NCC region. In this system, this tree species is also commonly intercropped with cassava in the first year of plantation, and still popular among smallholder farmers in Viet Nam because of its product (i.e. latex) market.
- Arabica coffee-based (*Coffea arabica*) for NW region. In the region, the AF arabica coffee systems commonly have *Leucaena leucocephala* or fruit trees such as longan, mango or plum as shading tree species. This coffee variety can grow well with the biophysical and climatic condition of NW region, and its cultivation area has increased rapidly during the last decade.
- Robusta coffee-based (*Coffea robusta*) for CH region. The common shading tree species in the AF robusta coffee systems in the region is *Cassia siamea*, a nitrogen-fixing tree species that can also provide as living trunk for pepper. This coffee variety has been cultivated since decades in CH region both in the form of monoculture and agroforestry, with market supported by local and international private sectors.
- Cashew-based (*Anacardium occidentale*) for SCC region, usually intercropped with annual crops such as maize or rice. Recently, cashew becomes important product for the country's export, and Viet Nam is currently the biggest exporter of cashew globally. The biophysical and climatic condition in the SCC region are suitable for this tree species. In other regions such as CH, smallholder farmers also cultivate cashew but not as the main component in the system, but usually integrated in coffee systems as shading tree species.
- Tea-based (*Camellia sinensis*) for NE region. The system commonly has low density acacia trees as shading tree species. The tea AF has been cultivated for decades in this region with Thai Nguyen as a leading province in terms of cultivation area and market.
- Mangrove with *Rhizophora*-based (*Rhizophora apiculata*) for MRD region. The system is considered as AF since it is commonly integrated with shrimp farming. It also has a function to halt saline intrusion that recently becomes a serious issue in the MRD region due to degradation of the mangrove forest and long drought.

Identifying potential expansion domain of AF in the regions

The PED analysis for the different tree-based AF systems has been conducted by Nguyen et al. (2016) with a series of biophysical, climatic, and socio-economic indicators (Table 1 and 2), for all areas in

[1] http://scafs.worldagroforestry.org/

the country isolating natural forest lands, water body and settlement area. Based on the data availability and guideline of land evaluation provided by VAFS, six biophysical and climate indicators are selected to determine the potential expansion domain or land suitability areas for the different tree species namely soil type, soil layer thickness, elevation, land slope, annual temperature, and annual precipitation. The sources of data and spatial resolution for these indicators are described in Table 1. The climate characteristic is important as indicator since some species such as cashew and coffee cannot adapt to cold weather. The six indicators are assumed to determine the quality of *growing condition* of the tree species in the selected AF systems.

Table 1. Biophysical and climate indicators used in the potential expansion domain analysis

Indicators	Source	Date	Resolution
Annual average temperature (°C)	World Climate	1950-2000	1 km x 1 km
Annual average precipitation (mm)	World Climate	1950-2000	1 km x 1 km
Elevation (m)	ASTER	2000	90 m x 90 m
Slope (°)	ASTER	2000	90 m x 90 m
Soil type (FAO standard)	Vietnam National Institute of Agricultural Planning and Projection (NIAPP)	2010	1:1,000,000
Soil layer thickness (m)	NIAPP	2010	1:1,000,000
National forest map	Ministry of Agricultural and Rural Development (MARD)	2010	1:1,000,000

To determine the potential expansion domain, we also considered socio-economic condition in the regions and there are several possible indicators of socio-economic condition proposed by VAFS, that can be used for this purpose. Due to limited access to national data, however, we used four socio-economic indicators namely distance to road and to settlement assumed to determine the extent of farmers' socio-economic activities such as product selling, and two others namely the province's GDP per capita and poverty index, that represent the provinces' socio-economic condition. The four indicators are assumed to determine the extent of *expansion* and *adoption* of the tree-based AF systems, but not species specific.

Table 2. Indicators of socio-economic condition for the potential expansion domain analysis

Variables	Source	Date	Resolution
National, provincial and district road network	Viet Nam administrative map	2010	1: 1,000,000
National, provincial and district settlement map	Viet Nam administrative map	2010	1: 1,000,000
Map of provincial GDP per capita	General Statistics Office of Viet Nam (GSO)	2013	1: 1,000,000
Map of provincial poverty index	General Statistics Office of Viet Nam (GSO)	2013	1: 1,000,000

The potential expansion domain constitutes the areas suitable to develop the AF especially to cultivate the tree species component of the systems. Due to this, we need to compare the biophysical and climatic requirement of each tree species, that can be obtained from literature, with the biophysical and climatic condition in the landscape. For example, according to VAFS, Acacia species can grow best on Ferralsols soil with soil layer thickness greater than 1 m, slope less than 15°, elevation less than 300 m, annual rainfall more than 2,000 mm, and air temperature from 23-28 °C. It can also adapt to less favorable soil conditions having layer thickness less than 1 m, slope from 15-35°, elevation from 300-700 m, annual rainfall from 1000-2000 mm, and air temperature from 16-23 or 28-32 °C. Comparing these requirements with the spatial biophysical and climatic condition across the country, each land parcel of 1 km x 1 km spatial resolution within the country will have three categories of qualification namely highly meet the biophysical/climatic requirement (R2), moderately meet the requirement (R1), or do not meet the requirement (R0). This procedure was conducted for each biophysical and climatic indicator, and for each tree species. Specifically for the two acacia varieties, however, we assumed they have similar biophysical and climatic requirements. Table 3 describes the criteria that we used to determine the tree species' land suitability level based on the three meeting requirement levels.

Table 3. Criteria to determine land suitability based on biophysical and climatic requirement

Suitability level	Criteria
Highly suitable (BC2*)	• All indicators meet the R2 qualification, or • At least three indicators (i.e. 50% from the total number of indicators) meet the R2 qualification and other variables meet R1 qualification, and • No indicators belong to R0 qualification
Moderately suitable (BC1)	• All indicators meet the R1 qualification, or • Less than three indicators meet the R2 qualification and other indicators meet R1 qualification • No indicator belongs to R0 qualification
Not suitable (BC0)	Any of six indicators belongs to R0 qualification

**biophysical-climatic (BC)*

Each land parcel also has a suitability level related to socio-economic condition, calculated based on the four socio-economic indicators. Table 4 describes the criteria used to determine the suitability level.

Table 4. Criteria to determine land suitability based on socio-economic condition

Indicator	Highly suitable (SE2*)	Moderately suitable (SE1)	Not suitable (SE0)
Distance to road	< 5 km	5-10 km	> 10 km
Distance to settlement	< 5 km	5-10 km	> 10 km
Poverty Index	< 10%	10-30%	> 30%
Provincial GDP per capita	> 1	0.5-0.7	< 0.5

**socio-economic (SE)*

The final land suitability level integrates the suitability level based on the biophysical-climatic and socio-economic condition, and it is specific to each tree species. It provides the suitable areas for the tree species cultivation and determines the potential expansion domain of the related AF systems.

The latter consists of the final highly suitable (S2) and moderately suitable (S1) areas, not the non-suitable (S0) areas.

Table 5. Final suitability level integrating biophysical-climatic and socio-economic condition

Suitability level	Criteria
Highly suitable (S2)	BC2 and SE2, or BC2 and SE1, or BC1 and SE2
Moderately suitable (S1)	BC2 and SE0, or BC1 and SE1, or BC1 and SE0
Not suitable (S0)	BC0 and SE0, natural forests, water body, and settlement areas

C storage estimation for the tree species

The estimation of national C storage from AF with the PED approach assumed a condition of conversion of all baseline land uses within the potential expansion domain for AF, into the different AF systems, depending on the region. The baseline land uses were assumed to belong to the category of 'cultivated and managed lands', that according to IPCC, have 5 ton C ha^{-1} as an average C stock. The potential C gain from the conversion was estimated for the time context of 10 years after the conversion that can be suitably linked to the discussion of potential mitigation contribution for 2020-2030. It was calculated as the total C storage from the different 10-year old AF systems corrected by the baseline land use C, within the potential expansion domain.

For all tree species other than coffee, the aboveground biomass (AGB) and C storage estimation of a single tree were conducted with the allometric equation given by Kettering et al. (2011):

$$AGB = 0.11 * \rho * (Dbh)^{2.62}$$

Where ρ is tree wood density (g cm^{-3}), and Dbh is diameter at breast height (cm). For arabica coffee, as a common variety in NW region, and exists in some provinces in the CH region, the AGB of single arabica coffee tree was estimated according to allometric equation given by Segura et al. (2006):

$$Log\ (AGB) = 1.181 + 1.991 * Log\ (d_{15})$$

Where d_{15} is the diameter at 15 cm from the soil surface. For robusta coffee, the AGB of single robusta coffee tree was estimated according to allometric equation given by Guillemot et al. (manuscript under review):

$$Ln\ (AGB) = -4.033 + 1.408 * ln\ (Ci) + 0.818 * ln\ (PCA)$$

Ci is the stem circumference at 30 cm above soil surface (cm) and PCA is projected crown area (m^2).

The average stem diameter of 10-year old tree species used in the Kettering et al.'s equation and of coffee trees, were based on the figures found in the literature and based on interviews with farmers. We also applied a range of diameter values that covers the average to provide a range of AGB and C estimation. The wood density of each tree species was obtained from several sources including the ICRAF library on tree species wood density[2]. Both for coffee and other tree species, C stock was estimated as 46% from the AGB. The common density of tree species in the seven main AF systems, were obtained from the SCAF database, except for arabica and robusta coffee collected through primary data collection in the NW and CH region, with household survey and focus group discussions (Pham et al. 2018).

[2] http://db.worldagroforestry.org/wd

Estimating investment cost for AF expansion

In the PED approach, the investment in terms of establishment cost per hectare required to establish the different AF systems across the country was obtained from the SCAF database, namely data from provincial partners. The estimation of total investment cost required to establish the AF systems in the potential expansion domain assumed that the investment costs per hectare for new areas within the potential expansion domain are still within the range of investment costs reported by the provincial partners integrated into the database.

Estimating AF contribution based on tree cover outside forests

The TOF approach identifies AF practices by the presence of tree cover outside natural forest lands. This is because most of natural forests in Viet Nam are protected by law and possible existence of AF systems can be found on agricultural or production forest lands. The approach used a global tree cover map with a spatial resolution of 1 km x 1 km and projected C of the tree cover as applied in Zomer et al. (2016). They produced the global map based on the Global Land Cover 2000 (GLC2000) and MOD44B MODIS Vegetation Continuous Field - Collection 5 (2000–2010), while the projected C from the geographically and bio-climatically stratified IPCC Tier 1 default estimates of C storage.

In their study, however, Zomer et al. adopted the classes of 'agricultural lands' to estimate the global C storage from AF according to GLC2000 that cover cultivated and managed areas (agriculture — intensive), cropland/other natural vegetation (non-trees namely mosaic agriculture/degraded vegetation), and cropland/tree cover mosaic (agriculture/degraded forest). In our study, the criteria of 'agricultural lands' are those outside the natural forest lands, waterbody, and settlement areas. The global tree cover map was overlaid by the Viet Nam's national and provincial boundary with the GADM administrative map version 3.6. Fig. 2 illustrates the distribution of natural forest lands across the country in year 2010 based on the national forest cover's map provided by Forest Inventory and Planning Institute (FIPI).

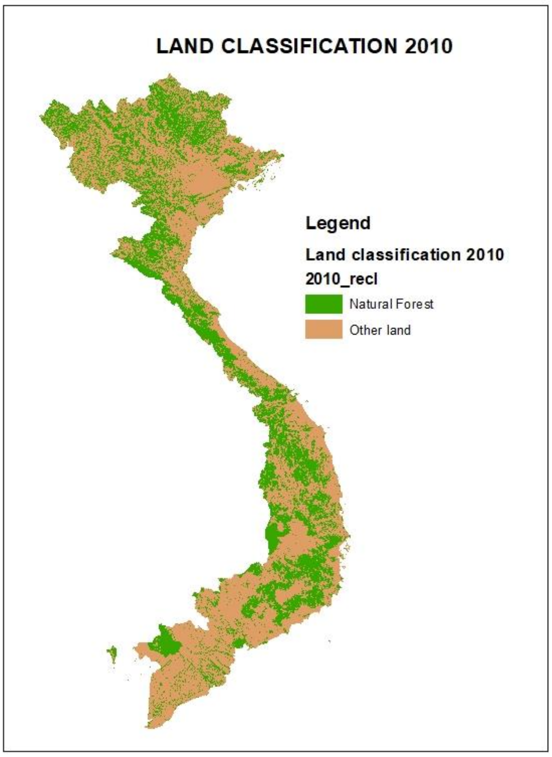


Figure 2. The land classification into forest lands and other lands in 2010

Results

Potential expansion domain for AF and C gain

The total area of potential AF expansion domain in the country is estimated about 10.1 million ha (Table 6) or about one third of total land area of the country. The expansion domain across the regions range from 600 thousand to 2.2 million ha, with the largest in SE region for the Acacia-based systems. The total C gain 10 years after plantation is 262 ± 77 million ton C (Table 6). The annual C gain from the different AF systems ranges from 0.98 to 4.17 ton ha^{-1} $year^{-1}$, with an average of 2.25 ton ha^{-1} $year^{-1}$.

Table 6. The potential expansion domain for AF and C gain ten years after conversion

Region	Tree species in the AF system	Total suitable area for AF (10^3 ha)	Averaged C stock in the system (ton ha^{-1})*	C gain from expansion (10^3 ton)	Annual C gain (ton ha^{-1} $year^{-1}$)
North West	Coffea arabica	618	14.85	6.1 ± 0.2	0.98 ± 0.04
North east	Camellia	1,762	15.02	17.6 ± 2.8	1.00 ± 0.16
Red river Delta	Acacia spp.	858	37.70	28.1 ± 3.6	3.27 ± 0.42
North central coast	Hevea	756	26.36	16.2 ± 7.7	2.14 ± 1.01
South central coast	Anacardium	1,589	34.07	46.2 ± 20.8	2.91 ± 1.31
Central highlands	Coffea robusta	745	17.95	9.6 ± 3.7	1.29 ± 0.50
South East	Acacia spp.	2,184	37.70	71.4 ± 9.3	3.27 ± 0.42
Mekong river Delta	Rhizophora	1,599	46.75	66.7 ± 28.7	4.17 ± 1.8
Total		**10,111**		**261.9 ± 77**	

**C stock when the trees are 10 years old.*

Total investment cost for the AF expansion

The average investment cost of the different AF systems across regions range from USD 613-5,300 ha^{-1} $year^{-1}$ (Table 7). The highest investment cost relates to establishing coffee robusta system. The total investment cost required for converting the whole potential expansion domain into the AF systems reaches USD 24.3 ± 11.3 billion (Table 7).

Table 7. Investment cost of different AF systems across regions

Eco-region	Tree species in the AF system	Average investment cost (USD ha^{-1} $year^{-1}$)	Total investment cost (billion USD)
North West	Coffea arabica	1,892	1.17 ± 0.02
North east	Camellia	917	1.62 ± 0.28
Red river Delta	Acacia spp.	2,554	2.19 ± 1.16
North central coast	Hevea	1,400	1.06 ± 0.43
South central coast	Anacardium	4,900	7.78 ± 4.38
Central highlands	Coffea robusta	5,227	3.89 ± 1.92
South East	Acacia spp.	2,554	5.58 ± 2.96
Mekong river Delta	Rhizophora	613	0.98 ± 0.14
Total			**24.27 ± 11,29**

C estimation based on tree cover

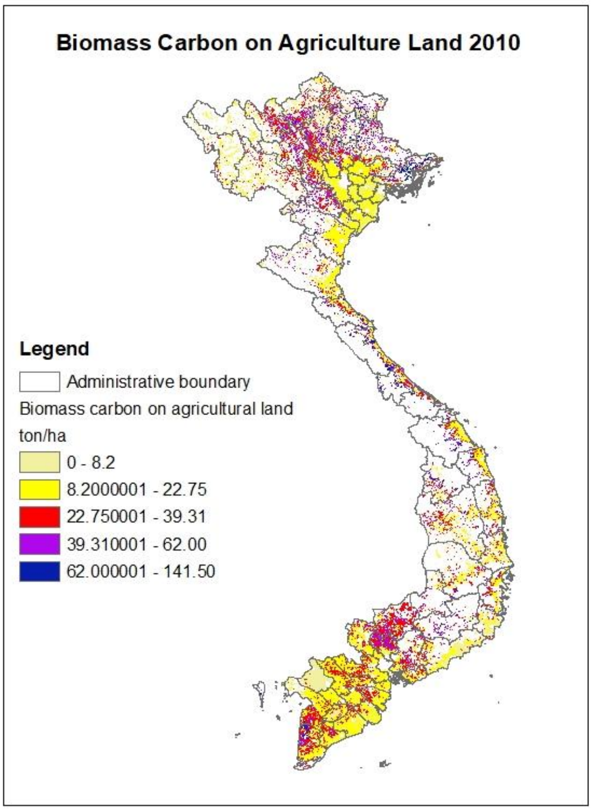
The total area without natural forest lands, water body and settlement areas is about 19.95 million ha or about 2/3 from the total area in the country (Table 8). Based on the TOF approach, the estimated average C stock across the provinces range from 9 to 47 ton C ha^{-1} with an average of 21.85 ton C ha^{-1}. The total C storage of all trees outside natural forest lands that represent potential C storage from AF in the country is ≈ 355 million ton C from the ≈20 million ha of land.

Table 8. The national and provincial C storage based on the TOF approach

Province	Average C stock (ton ha^{-1})$^{+}$	Land area (10^3 ha)*	Provincial C stock (10^6 ton)	Province	Average C stock (ton ha^{-1})$^{+}$	Land area (10^3 ha)*	Provincial C stock (10^6 ton)
National	21.85	19,954	354.54	Khanh Hoa	19.77	251	5.09
An Giang	17.66	341	0.21	Kien Giang	19.02	558	8.73
Ba Ria-Vung Tau	17.92	166	2.44	Kon Tum	29.95	351	8.18
Bac Giang	17.61	322	4.40	Lai Chau	14.44	571	5.04
Bac Kan	45.40	246	7.46	Lam Dong	35.34	363	11.66
Bac Lieu	18.08	235	3.02	Lang Son	36.75	644	15.75
Bac Ninh	9.42	77	0.47	Lao Cai	27.15	460	7.05
Ben Tre	16.63	203	2.72	Long An	16.65	388	5.55
Binh Dinh	20.98	400	6.95	Nam Dinh	11.41	115	0.99
Binh Duong	27.50	261	5.84	Nghe An	23.72	935	15.35
Binh Phuoc	26.90	524	12.64	Ninh Binh	13.15	104	0.88
Binh Thuan	11.95	429	5.10	Ninh Thuan	13.80	169	2.04
Ca Mau	25.12	416	9.17	Phu Tho	25.26	261	5.01
Can Tho	14.12	126	1.44	Phu Yen	17.96	300	4.55
Cao Bang	37.79	391	10.75	Quang Binh	34.67	298	8.72
Da Nang	39.09	47	1.46	Quang Nam	23.53	610	11.87
Dac Nong	27.81	629	17.49	Quang Ngai	23.54	350	7.86
Dak Lak	20.55	263	6.41	Quang Ninh	46.25	384	15.99
Dien Bien	16.30	656	8.17	Quang Tri	36.93	333	8.91
Dong Nai	23.54	430	7.52	Soc Trang	13.43	286	2.80
Dong Thap	16.28	324	4.17	Son La	22.10	1,018	14.37
Gia Lai	22.28	829	14.97	Tay Ninh	18.54	341	4.83
Ha Giang	30.30	511	9.54	Thai Binh	9.99	152	0.89
Ha Nam	12.06	69	0.53	Thai Nguyen	28.27	249	5.29
Ha Noi	13.96	234	2.53	Thanh Hoa	19.85	666	11.34

Province	Average C stock (ton ha^{-1})+	Land area (10^3 ha)*	Provincial C stock (10^6 ton)	Province	Average C stock (ton ha^{-1})+	Land area (10^3 ha)*	Provincial C stock (10^6 ton)
Ha Tinh	28.31	267	6.92	Thua Thien - Hue	28.38	288	6.23
Hai Duong	10.85	158	0.89	Tien Giang	17.20	217	2.76
Hai Phong	10.44	108	0.47	Tra Vinh	13.03	167	1.60
Hau Giang	17.03	132	1.84	Tuyen Quang	34.06	291	6.83
Ho Chi Minh	14.84	134	1.40	Vinh Long	15.41	124	1.51
Hoa Binh	32.54	312	8.17	Vinh Phuc	14.45	103	1.17
Hung Yen	9.28	77	0.44	Yen Bai	20.28	444	6.80

**without natural forest lands, water body and settlement areas.+aboveground C stock, converting from the C reported in Zomer et al. (2016) using the average ratio of root:shoot equals 0.32 (Good Practice Guidance for LULUCF by IPCC, Annex 3A.1)*



The provinces in the northern and southern of Viet Nam have higher tree cover and C storage density compared to those in the central areas (Fig.3). This is because the latter were more dominated by the natural forest lands compared to the other two regions as described earlier in Fig. 2. Most of the C storage density range from 8 to 40 ton C ha^{-1}, but tree-based systems with higher C storage were also found in the northern, central, and southern part of the country (Fig. 3).

Figure 3 Distribution of C storage density across the country based on TOF approach

Discussion

The potential mitigation contribution from AF, represented by the total C storage of trees outside natural forest lands estimated with the TOF approach, is 355 million ton C, which is much higher than the total estimated with the PED approach. However, this figure is the total from ≈20 million ha of lands, while the total of potential expansion domain for AF in the PED approach is ≈10.1 million ha, or about half of the TOF area. Under the same area of land as in PED approach, the total C storage with the TOF approach is ≈220 million ton C, which is still in the range of C storage estimation with the PED approach.

Another way to link the results of PED and TOF approach is to assume that the baseline C storage within the potential expansion domain before conversion to AF equals ≈220 million ton C, namely the C storage estimation with the TOF approach, not 50.5 million ton C, the result of assuming the baseline land uses can all be classified as "cultivated and managed lands". Using the TOF estimation of the total baseline C storage, the potential C gain from AF expansion in the country is ≈92 million ton C after 10 years of plantation, not as high as ≈262 million ton C. In this case, we can also interpret that TOF approach provides *current* potential mitigation contribution from AF in the country, while the PED approach provides *future* potential mitigation contribution, namely ≈92 million ton C gained 10 years after the AF expansion.

Related to the C estimation with the TOF approach, based on the global estimation provided by Zomer et al. (2016), Viet Nam had higher C storage density of trees in 'agricultural lands' (≈21.85 ton C ha^{-1}) than Cambodia (≈14 ton C ha^{-1}) but lower than Laos (≈42 ton C ha^{-1}). Its C storage density was slightly higher than Myanmar (≈19.5 ton C ha^{-1}). Globally, there was a marked difference among countries in terms of this C storage density, ranging from ≈4.4 ton C ha^{-1} in Kazakhstan to ≈90.5 ton C ha^{-1} in Congo. In terms of the total area of 'agricultural lands', countries with the highest coverage include Brazil, China, India and United States.

Current mitigation target in Viet Nam LULUCF sector

The targeted national mitigation contribution from the LULUCF sector is expected to result from implementation of different strategies that relate mainly to natural and plantation forests, either with merely domestic or with international support (Table 9). The total area of intervention is expected to reach 1.5 million ha with merely domestic support and 2.8 million ha with international support, according to the national INDC submitted to UNFCCC in 2015. In the implementation plan for the agricultural INDC in 2016, the targeted area related to domestic support is comparable with that formulated in the 2015 national INDC, and the total area with international support is 2.5 million ha.

The national LULUCF mitigation strategies mainly rely on forest protection and regeneration programs and establishment of large timber plantations in production forests (Table 9), with accumulated C expected to offset GHG emissions. The total targeted GHG emission reduction from the LULUCF sector is 22.67 million ton CO_2 eq. $year^{-1}$, or 6.2 million ton C $year^{-1}$ with domestic support, and 43.43 million ton CO_2 eq. $year^{-1}$ or 11.8 million ton C $year^{-1}$ with international support (Table 9). According to the implementation plan of the agricultural INDC in 2016, the targeted emission reductions are 24.62 million ton CO_2 eq. $year^{-1}$, or 6.7 million ton C $year^{-1}$ with domestic support and 43.2 million ton CO_2 eq. $year^{-1}$ or 11.8 million ton C $year^{-1}$ with international support, which is similar to the target according to 2015 national INDC.

Table 9. The targeted emission from each LULUCF strategies

No	Strategies	Unit	In National INDC submitted to UNFCCC (2015)		In implementation plan of Agriculture INDC (2016)	
			Area	**Potential GHG reduction to 2030 ($MtCO_2$eq. year^{-1})**	**Area**	**Potential GHG reduction to 2030 ($MtCO_2$eq. year^{-1})**
With domestic support				-22,67		-24,62
1	Protection of natural forest	10^3 ha	1000	-14,83	1000	-14,0
2	Protection of coastal forest	10^3 ha	100	-3,04	100	-4,8
3	Plantation of coastal forest	10^3 ha	10	-0,16	20	-0,2
4	Natural forest regeneration	10^3 ha	200	-2,24	200	-3,1
5	Plantation of large timber production forest	10^3 ha	150	-2,40	150	2,1
With international support				-43,34		-43,2
1	Protection of natural forest	10^3 ha	2200	-36,13	2000	-28,0
2	Protection of coastal forest	10^3 ha	-	-	200	-9,5
3	Plantation of coastal forest	10^3 ha	30	-0,49	20	-0,23
4	Natural forest regeneration	10^3 ha	200	-2,24	250	-3,9
5	Plantation of large timber production forest	10^3 ha	-	-	100	-1,4
6	Production forest regeneration from natural forest	10^3 ha	400	-4,48	-	-

Comparing the potential C gain from AF based on the PED approach, 262 ± 77 million ton C for ten years after the plantation with the targeted emission reduction in the LULUCF sector under the similar time context of ten years, the latter targets an emission reduction of about 67 million ton C with domestic support and 118 million ton C with international support. This indicates that AF expansion across the country has a potential to meet the current national target of reducing emission from the LULUCF sector.

Among the current 5-6 mitigation strategies in the sector, with domestic or international support, most relate to natural forest lands, and only one relates to production forest lands, namely to establish large timber plantations. Furthermore, the expected mitigation contribution from this category of forest land is relatively small compared to the total emission target, for example 'only' 2.4 ton C year^{-1} from 22.67 ton C year^{-1} or about 10% of the mitigation contribution is expected from production forest lands to the national LULUCF mitigation target. This indicates that a huge potential mitigation contribution can be expected from AF expansion, while protecting and regenerating natural forest lands.

Challenges in integrating AF into agriculture or LULUCF sector

In the national land use policy, AF is not an isolated land use category from agriculture or forestry. Regulations related to some AF practices such as integrating understory component into the forestry systems are included in the forest policy. Due to this, there is a need of further discussion with relevant authorities especially MARD and its sub-institutions such as VNFOREST and VAFS on the ways to integrate the potential mitigation contribution from AF into the Viet Nam's NDC.

Furthermore, according to the expected sectoral mitigation contribution based on the country's 2015 INDC, agriculture is not considered as part of LULUCF sector. Since AF suitability areas also cover the agricultural and forestry lands, without isolating AF as a land use category, the total potential mitigation contribution from AF should be partly integrated into LULUCF sector and partly to the agricultural sector.

In terms of practice, especially compared to forestry systems, some of the main AF systems such as the acacia-based or rubber-based that integrate annual crops or understories at least in the first year of a plantation, are also commonly considered as forest plantation systems. The latter however, covers both the systems with or without the intercrops namely pure monoculture plantation. The AF practice of Rhizophora in the mangrove forest lands combined with the shrimp farming is also commonly considered as mangrove forest system, although the latter covers both the cases with or without the shrimp or other farming. Furthermore, depending on various condition such as socio-economic condition, smallholder farmers can easily alternate the systems with intercrops, with the pure monoculture plantation, and vice versa.

In terms of the title of cultivated lands, the lands in Viet Nam are basically entitled as forest or agricultural lands. Furthermore, since the lands in the country are largely entitled as forest lands, some common AF systems such as coffee-based systems with shading tree species, either with robusta or arabica coffee, can be commonly found in degraded forest lands. This is also the case with the other AF systems involved in this study such as the cashew-based or tea-based, let alone the acacia-based and rubber-based known as common forest plantation systems. Therefore, the challenges to segregate AF with forestry systems are not only related to similarity in practice, but also in terms of cultivated lands.

Reporting the potential mitigation contribution

As part of reporting, the estimated potential mitigation contribution from AF with the PED approach has been informed to VAFS as a sub-institution of MARD. They are responsible to report a reasonable estimate of mitigation contribution from AF related to the current NDC review and plan for revision. The approaches used in this study have also been informed to VNFOREST, and the subsequent step is to inform the estimation results, and further discuss on the ways to include AF and its potential mitigation contribution into the country NDC.

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