

Article

Enhancing Vietnam's Nationally Determined Contribution with Mitigation Targets for Agroforestry: A Technical and Economic Estimate

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Received: 30 October 2020; Accepted: 15 December 2020; Published: 17 December 2020



Abstract: The Nationally Determined Contributions (NDCs) of several non-Annex I countries mention agroforestry but mostly without associated mitigation target. The absence of reliable data, including on existing agroforestry practices and their carbon storage, partially constrains the target setting. In this paper, we estimate the mitigation potential of agroforestry carbon sequestration in Vietnam using a nationwide agroforestry database and carbon data from the literature. Sequestered carbon was estimated for existing agroforestry systems and for areas into which these systems can be expanded. Existing agroforestry systems in Vietnam cover over 0.83 million hectares storing a 1346 ± 92 million ton CO₂ equivalent including above-, belowground, and soil carbon. These systems could be expanded to an area of 0.93–2.4 million hectares. Of this expansion area, about 10% is considered highly suitable for production, with a carbon sequestration potential of 2.3–44 million ton CO₂ equivalent over the period 2021–2030. If neglecting agroforestry's potential for modifying micro-climates, climate change can reduce the highly suitable area of agroforestry and associated carbon by 34–48% in 2050. Agroforestry can greatly contribute to Vietnam's 2021–2030 NDC, for example, to offset the greenhouse gas emissions of the agriculture sector.

Keywords: agriculture sector; carbon sequestration; cost efficiency; land suitability; potential expansion areas; representative concentration pathway

1. Introduction

In 2015, all signatory countries of the landmark Paris Agreement pledged to reduce their national greenhouse gas (GHG) emissions and enhance resilience to climate change. The Nationally Determined Contributions (NDCs) are the blueprints outlining mitigation and adaptation efforts, and the Paris Agreement requires each party to prepare, communicate, and pursue their NDCs with domestic or international support. NDCs describe post-2020 climate programs, and parties can prioritize sectors which substantially contribute to their national emissions. Most signatory countries submitted their first NDCs to the United Nations Framework Convention on Climate Change (UNFCCC) by 2016 [1], with the option to amend before a final submission in 2020.

Agriculture features prominently in the NDCs of non-Annex I countries, which are mostly developing countries [2]. About 40% of 148 non-Annex I countries include mitigation measures for the agriculture sector in their NDCs, with half of these mentioning integrated systems such as agroforestry [3]. However, the NDCs of many countries do not elaborate these mitigation measures into concrete actions and associated targets.

Agroforestry, an integrated agricultural system with crops and trees, can substantially reduce GHG emissions through carbon sequestration [4,5]. Agroforestry also increases farmer adaptation to climate change through, e.g., diversified products and sources of income, resource use efficiency, and improved micro-climates [6–9]. Yet the absence of reliable data, including on types and distribution of existing practices and their carbon storage, partially constrain estimation of mitigation and adaptation potential from agroforestry at national scale [10].

Agriculture is a significant source of emissions in Vietnam. Total GHG emissions from Vietnam's agricultural sector reached an 88.3 million ton CO₂ equivalent (mil tCO₂e) in 2010, accounting for 35.8% of total national emissions [11], and are projected to increase to 109 mil tCO₂e by 2030 under baseline conditions. Vietnam's first NDC submitted to the UNFCCC in 2016 identified 15 mitigation measures for the agriculture sector but excluded agroforestry. The measures focused on improving the efficiency of inputs, plot management practices, such as transforming conventional water management in rice to alternate wetting drying for reducing methane production, and waste treatment, such as converting livestock waste into biogas, and are expected to reduce the projected 2030 baseline emissions by 6–42% [12]. Vietnam has recently included agroforestry in its revised NDC submitted to the UNFCCC in 2020 as part of the Land Use, Land Use Change, and Forestry (LULUCF) sector. However, the revised NDC only specifies the purpose of agroforestry measure, namely for “enhancing carbon stocks and conserving lands”, without elaboration on activities and associated mitigation or adaptation targets.

A methodological framework for estimating mitigation and adaptation potential of agroforestry and associated targets at a national or sub-national scale for climate programs such as NDCs is necessary. In this paper, focusing on the mitigation potential, we describe such a framework that we used to provide a technical and economic estimate of mitigation potential from agroforestry in Vietnam by 2030 by assessing its capacity for offsetting GHG emissions through carbon sequestration. We took into account above-ground carbon (AGC), below-ground carbon (BGC), and soil carbon (SOC) sequestered in existing areas and potential expansion areas of agroforestry across the country. We considered the impact of future climate change scenarios on the expansion area and carbon sequestration potential from agroforestry. The economic estimate accounts for the investment cost required to fulfill the mitigation potential over 2021–2030.

2. Materials and Methods

2.1. Methodological Framework

Agroforestry mitigation potential was estimated at a national scale and can be disaggregated into a sub-national scale using eight ecological regions (Figure 1a), differentiated based on geographical characteristics, topographical features, ecosystem types, and climate [13]. These eight regions are North West, North East, Red River Delta, North Central Coast, South Central Coast, Central Highlands, South East, and Mekong River Delta. The detailed characteristics of each region, including soil condition and dominant land uses, are given in [13].

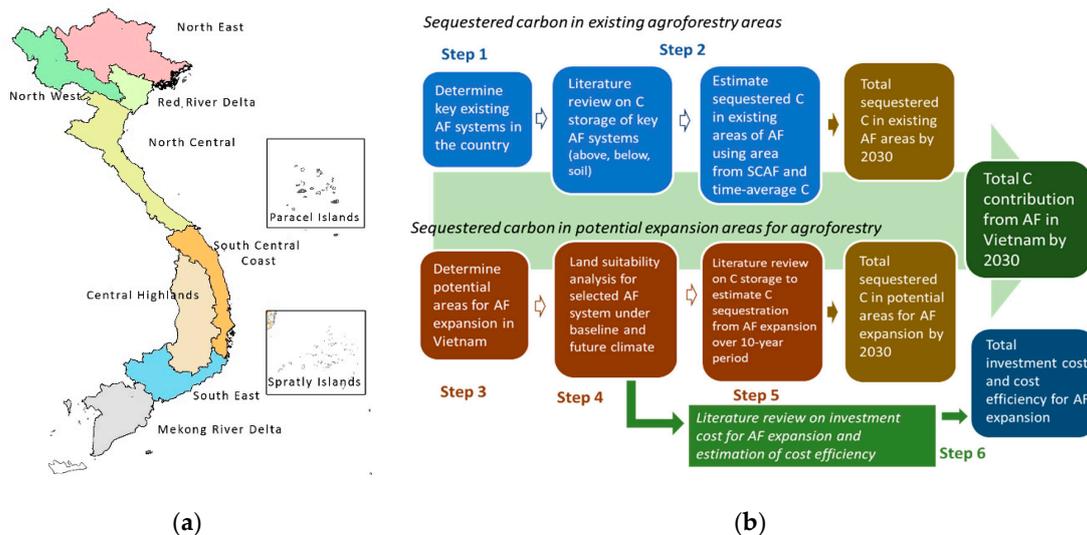


Figure 1. (a) Eight regions of Vietnam. (b) Methodological framework for estimating mitigation potential from agroforestry (AF) in Vietnam.

The assessment of agroforestry mitigation potential consists of six steps (Figure 1b). The first two steps pertain to existing agroforestry areas and the following four pertain to potential expansion areas for agroforestry. The sequestered carbon in the potential expansion areas was assessed over a ten-year period (2021–2030), and the impact of future climate scenarios on extent areas for agroforestry system expansion was investigated using representative concentration pathway (RCP) 4.5 and RCP 8.5 scenarios. The aggregate of sequestered carbon across existing and potential agroforestry areas constitutes the total carbon contribution from agroforestry by 2030.

We used the information on types and distribution of existing agroforestry practices in Vietnam from the Spatially Characterized Agroforestry (SCAF) database (<http://scafs.worldagroforestry.org/>), as a basis for estimating sequestration contributions from existing areas of agroforestry and for selecting agroforestry systems for expansion. For the carbon estimation, we used input carbon storage data reported in the literature or estimated carbon storage per land area using relevant allometric equations, stem diameter, and crop density data from the literature. The input AGC data are species-specific and mostly specific to Vietnam. On the other hand, the input BGC and SOC are system- but not species-specific. For example, the BGC of most of the assessed agroforestry systems was estimated using the BGC/AGC partitioning factor for agroforestry from [14], and the SOC using the SOC sequestration rate from [10].

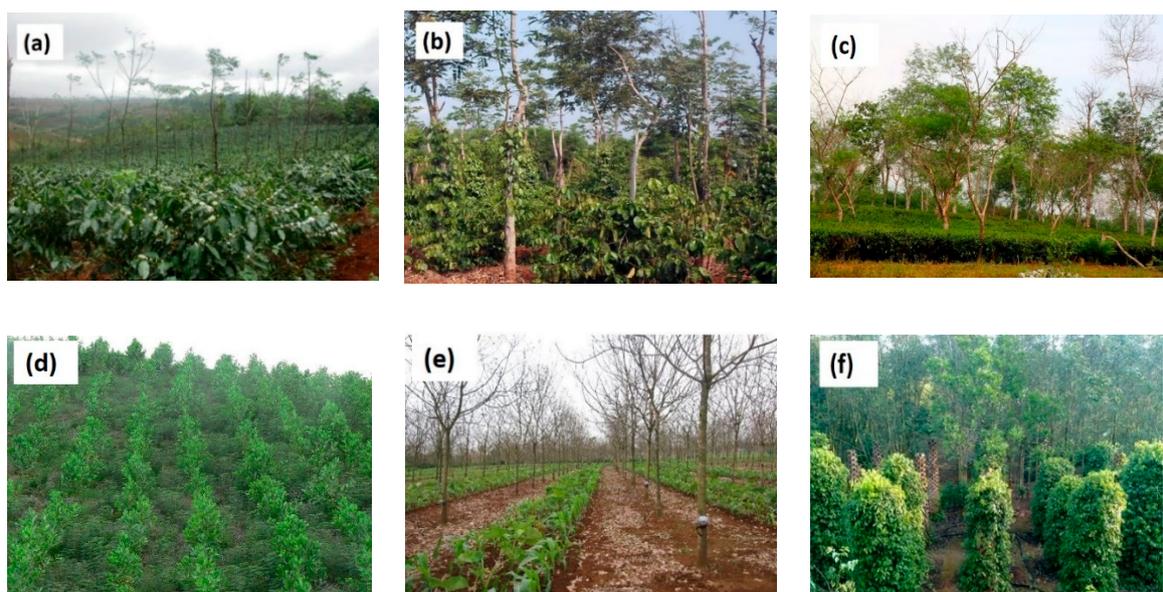
2.1.1. Step 1: Determine Key Existing Agroforestry Systems in Vietnam

The SCAF database provides information on 48 agroforestry practices observed in 2013–2014 across 42 out of the 63 provinces in Vietnam. Most of the 48 practices can be classified into eight key systems based on their main perennial crop component, excluding the “other systems” (Table 1). The total area of the eight key systems is 820,000 hectares (ha) or about 91% of the total agroforestry system area. Examples of the eight key systems are illustrated in Figure 2. We cannot find a more recent database than SCAF for existing agroforestry systems in Vietnam.

Table 1. Existing agroforestry systems in Vietnam.

Agroforestry System *	Total Area (10 ³ ha) **	Common System Components	Main Regions
Melaleuca (<i>Melaleuca cajuputi</i>)-based	245.5	Fresh-water inland forest with paddy rice, sugarcane, bananas, and fish	Mekong River Delta
Robusta coffee (<i>Coffea canephora</i>)-based	245.3	<i>Cassia siamea</i> , black pepper, fruit trees such as durian and avocado, and nuts such as macadamia	Central Highlands, South East
Rhizophora (<i>Rhizophora</i> spp.)-based	149	Mangrove system with shrimp farming	Mekong River Delta
Acacia-based	129.5	<i>Acacia mangium</i> , <i>Acacia auriculiformis</i> , or hybrid (<i>Acacia mangium</i> × <i>Acacia auriculiformis</i>), intercropped with cassava in the early years after tree planting until acacia canopy is closed	North East, Red River Delta, South Central Coast, Mekong River Delta
Rubber (<i>Hevea brasiliensis</i>)-based	20.5	Usually intercropped with cassava or maize in the early years after tree planting until rubber canopy is closed	North West, North Central Coast, Central Highlands
Arabica coffee (<i>Coffea arabica</i>)-based	10.5	<i>Leucaena leucocephala</i> , longan (<i>Dimocarpus longan</i>), mango (<i>Mangifera indica</i>), plum (<i>Prunus salicina</i>) as shade trees	North West
Cashew (<i>Anacardium occidentale</i>)-based	10.4	Intercropped with maize, black pepper, or Robusta coffee	Central Highlands, South East
Tea (<i>Camellia sinensis</i>)-based	9.5	<i>Acacia mangium</i> or hybrid, <i>Cassia siamea</i> , or <i>Illicium verum</i> as shade trees	North East, North Central Coast
Other systems	79.8	Various fruit- or timber tree-based systems with relatively small areas	Spread across regions

* Ordered by total area; ** Total area in the country based on the Spatially Characterized Agroforestry (SCAF) database.

**Figure 2.** Cont.

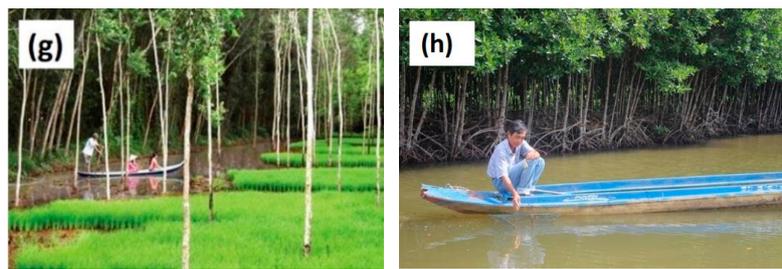


Figure 2. Examples of key common agroforestry systems in Vietnam: (a) Arabica and leucaena in the North West region, (b) robusta, cassia, and black pepper in the Central Highlands, (c) tea and cassia in the North Central Coast, (d) acacia and cassava in the North East, (e) rubber, potato, and maize in the North Central Coast, (f) cashew, robusta, and black pepper in the South East, (g) melaleuca and rice in the Mekong River Delta, and (h) Rhizophora and shrimp farming in the Mekong River Delta. Source of photos, (a–g) (SCAF), (h) (<https://nongnghiep.vn/tom---rung-voi-tang-truong-xanh-d233998.html>).

2.1.2. Step 2: Estimate Sequestered Carbon in Existing Areas of Agroforestry

The existing areas of agroforestry in Vietnam refer to the 820,000 ha occupied by the eight key agroforestry systems. Due to a lack of information on crop ages, the total AGC sequestered in these areas was estimated using time-average AGCs obtained from the literature (Table A1). For the six key agroforestry systems beside the two in wetlands, we generally used the BGC/AGC biomass partitioning factor for agroforestry from [14] to estimate the BGC, and the response ratio from [10] to estimate the time-average SOC assuming all areas of agroforestry were converted from logged-over forests. For the two systems in wetlands, species-specific BGC and SOC are available from the literature (Table A1). The aggregate of AGC, BGC, and SOC from the eight key agroforestry systems constitutes the carbon contribution from existing areas of agroforestry. We assumed the total area and sequestered carbon in the existing agroforestry systems are constant until 2030.

2.1.3. Step 3: Determine Potential Areas for Agroforestry Expansion

Due to the lack of a recent national land cover map from a reliable institution in Vietnam, we used Vietnam's 2018 land cover map from [15] to determine potential areas for agroforestry expansion. Among other land cover types in the map, we selected croplands as potential areas for agroforestry expansion. The croplands are defined by [15] as "lands with herbaceous and shrubby crops followed by harvest and bare soil period". They exclude orchards, annual crops with trees, forest plantations, and wet and low-land paddy fields. We excluded wet paddy lands because they are the main source of staple food for Vietnam, forest plantations and other tree-based systems because they are high-biomass land uses, and barren forest lands because they can be used for forest restoration. Croplands are spread across the country and have a total area of about 3.6 million ha (Figure 3a). Due to the absence of a spatial boundary around existing agroforestry areas, and because croplands exclude all systems with trees, we assumed the existing areas of agroforestry and croplands (hereafter called the expansion domain) are thoroughly separated.

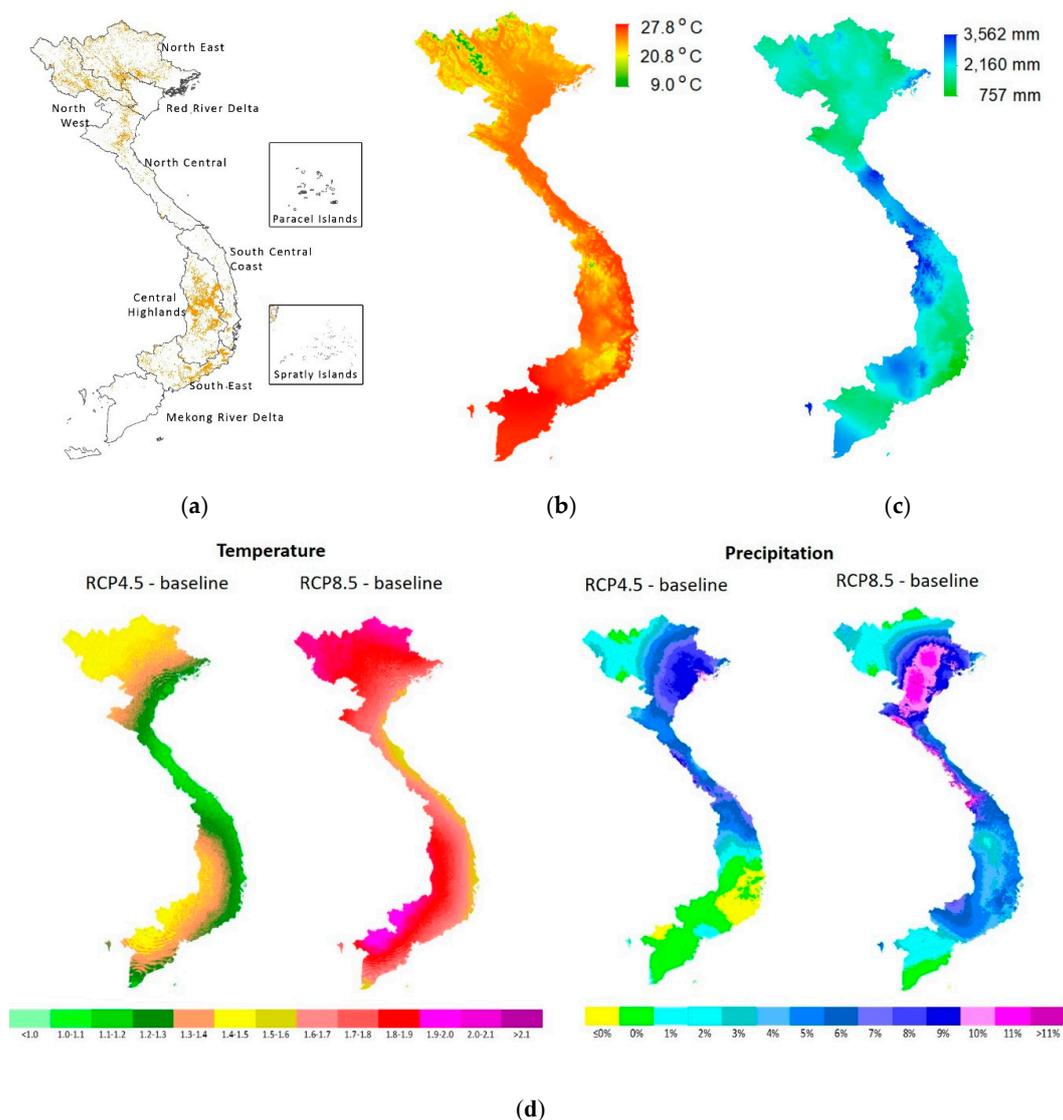


Figure 3. (a) Potential expansion domain of agroforestry in Vietnam; (b) baseline average annual temperature; (c) baseline average annual precipitation; (d) changes in temperature and precipitation under representative concentration pathway (RCP) 4.5 and RCP 8.5.

2.1.4. Step 4: Select Agroforestry Systems for Expansion and Land Suitability Analysis

We selected five out of the eight key agroforestry systems for expansion, excluding rubber-, *Rhizophora*-, and *Melaleuca*-based systems. For rubber, the Vietnam's Master Plan on Agricultural Production Development to 2020 vision to 2030 focuses on strengthening the processing industry instead of area expansion. This orientation also applies to robusta coffee and tea; however, coffee- and tea-based agroforestry provide diverse products such as timber, nuts, or fruits, for which the country is still unable to meet national demand. We excluded *Rhizophora*- and *Melaleuca*-based systems because considerable further research is necessary. Spatial data for determining their potential expansion areas is scarce and we lack information such as inundation frequency, water salinity, and tide intensity, that is crucial for land suitability analysis of wetland systems e.g., see [16]. Moreover, we could not find facts about the suitable growing conditions of these two systems from a reliable institution in the country. The most popular acacia-based system in Vietnam is the short-rotation (3–5 years) type for pulp and paper with annual crops such as cassava in the first or second year after tree planting [17]. However, the system for expansion is long-rotation (8–12 years) for timber purposes to help minimize Vietnam's dependence on timber importation. For the cashew, the selected system for expansion is alley cropping

with annual crops such as maize, not the perennial shade system with coffee. In the alley cropping system, cashew plants have a higher density to maximize production for national and export markets.

Based on the guideline of land evaluation from [18,19] and the available spatial data, the land suitability analysis for each agroforestry system for expansion considered the topographical, soil, and climatic conditions within the expansion domain. We used slope as an indicator for topographical conditions, soil depth and type for soil conditions, and average annual temperature and precipitation for climatic conditions. The suitability of areas within the expansion domain depends on the indicator values. The assignment of suitability levels involved two steps: first, the indicator values within the expansion domain were compared with thresholds of the growing conditions of the agroforestry systems. We utilized thresholds from a three-tiered ranking of growing conditions reported by reliable institutions in Vietnam (Table 2). Ranking s2 implies little to no limitation of enabling factors for sustaining crop productivity; s1 indicates moderate to severe limitation of such factors, requiring modest or substantial additional inputs or plot management practices for sustaining crop productivity; and s0 describes conditions in which the specified crop cannot grow even with any additional inputs or plot management practices. Subsequently, each area was classified as “highly suitable” if all its indicators met the s2 growing condition, “not suitable” if all indicators met the s0 growing condition, and “less suitable” if all indicators met the s1 growing condition, or if not all indicators met the s2 or s0 condition. For simplicity, we only assessed the suitability of the main perennial crop species in each system, e.g., tea for the tea-based system.

Table 2. Growing condition of the main crop species of selected agroforestry systems for expansion.

	Acacia *	Cashew	Robusta	Arabica	Tea
Reference	[20,21]	NIAPP ** (data unpublished)	NIAPP (data unpublished)	NIAPP (data unpublished)	[19]
s2					
Soil type ***	Ac, Fl, RhFe, Gl	RhFe, Fe, Ac	RhFe, XaFe, Fe, Ac	RhFe, Fe	RhFe, Fe
Soil depth (m)	>1	>1	>1	>1	>1
Slope (°)	<8	<8	<8	<8	<8
Annual rainfall (mm)	1500–2500	2100–2500	1600–2000	1000–2000	>1800
Annual temperature (°C)	23–26	22–25	22–24	18–22	>22–25
s1					
Soil type	Lu, Fe	Ac	Ac, Fl	Ac	Ac, HuFe
Soil depth (m)	0.5–1	0.5–1	0.5–1	0.5–1	0.5–1
Slope (°)	8 to 35	8–<25	8–20	8–20	8 to 20
Annual rainfall (mm)	800–<1500; >2500–3500	1300–<2100; >2500	1200–1600; >2000	800–1000; >2000	1000–1800
Annual temperature (°C)	20–<23; >26	18–<22; >25	–8–22, >24	14–<18; >22–24	15–22; >25–35
s0					
Soil type	Others	Others	Others	Others	Others
Soil depth (m)	<0.5	<0.5	<0.5	<0.5	<0.5
Slope (°)	>35	>=25	>20	>20	>20
Annual rainfall (mm)	<800; >3500	<1300	<1200	<800	<1000
Annual temperature (°C)	<20	<18	<18	<14; >24	<15; >35

* Common thresholds for *Acacia mangium*, *Acacia auriculiformis*, *Acacia crassiparva*, or acacia hybrid, ** Vietnam National Institute of Agricultural Planning and Projection (NIAPP), *** Ac: acrisols; Fe: ferrasols; RhFe: rhodic ferrasols; XaFe: xantic ferrasols; Fl: fluvisols; Gl: gleysols; HuFe: humic ferrasols.

We used the 1960–1990 climate data from WorldClim 1.4 [22] as the baseline climate (Table 3). The World Meteorological Organization recommended 1960–1990 as the baseline period [23]. To investigate the impact of future climate on suitable areas for agroforestry expansion, we selected the CNRM-CM5 climate model under RCP 4.5 and RCP 8.5 for the period 2041–2060, also from the WorldClim 1.4, which is available at 30 arc seconds resolution. WorldClim 2.0 provides climate data

for the period 2021–2040 but at coarser resolution, and a stronger impact of climate change on the area for expansion and carbon sequestration potential from agroforestry can be expected using the 2041–2060 data. CNRM-CM5 is one of the best climate models for South East Asia [24]. Because we only considered the main perennial crop component of each agroforestry system for expansion in the land suitability analysis, the impact of future climate was also assessed for the main crop component only to represent the impact on each agroforestry system, neglecting the potential of agroforestry to modify micro-climates through an integration of multiple plant components that can reduce the intensity of climate change impact. Due to the absence of a spatial boundary to existing areas of agroforestry, we only investigated the impact of future climate on the potential expansion areas. All spatial inputs were standardized into one arc second, considered as a suitable resolution for country analysis.

Table 3. Input maps used for the land suitability analysis.

Input Maps	Resolution	Coordinate System	Date	Source
Land cover	1 arc second	Lat/Long World Geodetic System (WGS) 84	2018	[15]
Digital Elevation Model (DEM)	1 arc second	Lat/Long WGS 84	2019	Advanced Land Observing Satellite (ALOS) Global Digital Surface Model (AW3D30) version 2.2
Slope	1 arc second	Lat/Long WGS 84	2019	Generated from DEM
Soil type	1: 1,000,000	WGS 84 UTM Zone 48N	2010	NIAPP
Soil depth	1: 1,000,000	WGS 84 UTM Zone 48N	2010	NIAPP
Baseline average annual precipitation and temperature	30 arc seconds	Lat/Long WGS 84	1960–1990	WorldClim 1.4
Future average annual precipitation and temperature	30 arc seconds	Lat/Long WGS 84	2041–2060	WorldClim 1.4

Based on the baseline climate data from WorldClim 1.4, the northern part of the country generally has lower average annual temperatures and precipitation than the central and southern parts (Figure 3b,c). A similar pattern was reported by, e.g., [13]. This pattern will potentially change in the future, especially under the RCP 8.5 scenario, due to substantial increases in temperature and precipitation in the northern part of the country (Figure 3d).

2.1.5. Step 5: Estimate Sequestered Carbon in Potential Expansion Areas

We estimated the carbon sequestered through agroforestry expansion by subtracting the AGC and BGC stored in croplands from the total carbon accumulated over ten years in areas suitable for agroforestry expansion. We used the average AGC of croplands of 5 tC ha⁻¹ for “cropland containing annual crops” according to the Intergovernmental Panel on Climate Change (IPCC) [25] and a BGC/AGC partitioning factor of 0.05–0.2 for “permanent cropland” [14]. The SOC is 53–158 tC ha⁻¹ for “permanent cropland” [14]. We assumed that the conversion of croplands into agroforestry retained the SOC in the soil, but we excluded this SOC from the estimation of accumulated SOC in the ten-year agroforestry expansion. All input AGC, BGC, and SOC data for the five agroforestry systems for expansion are given in Table A1.

There were five scenarios of agroforestry expansion, one for each agroforestry system. In each scenario, the system expands into highly suitable areas only, or into 10% and, at most, 25% of the less suitable areas. We assumed that agroforestry systems that have expanded into less suitable areas accumulate AGC, BGC, and SOC at the same rates as in highly suitable areas.

The highly and less suitable areas for expansion were gradually converted into agroforestry across the ten years at a constant conversion rate. Therefore, in the first year, only 10% of suitable areas was converted into agroforestry, to reach the total suitable area in the tenth year. For simplification, we applied a constant carbon accumulation rate across the years for AGC, BGC, and SOC.

To assess the advantages of using agroforestry to offset the GHG emissions from the agriculture sector, we compared the accumulated carbon levels in the expansion domains from agroforestry and from sole crop plantations. We used three commodities in the comparison, namely arabica coffee, robusta coffee, and tea. Acacia and cashew crops were not considered because the sole plantation of the two commodities are forestry, not agricultural systems. The comparison was made for highly suitable areas and AGC only because the BGC and SOC input data are not species-specific. All estimated carbon values were converted into CO₂e with a factor of 3.67.

2.1.6. Step 6: Estimate the Cost Efficiency of Agroforestry Expansion

We defined cost efficiency as the investment cost required to sequester one ton of CO₂ equivalent. We calculated cost efficiency using the total investment cost to establish and maintain agroforestry systems for ten years under the baseline climate conditions. The cost efficiency will not change under the future climate conditions because the change in investment cost is proportionate to that in the potential expansion area. We estimated all investment costs according to their monetary worth in 2019 (Table 4) by using the annual inflation rate of Vietnam. We compared cost efficiency among agroforestry expansion scenarios, and between agroforestry and sole plantations of arabica, robusta, and tea.

Table 4. Input investment costs for agroforestry and sole crop expansion.

System	Investment Cost (USD ha ⁻¹ year ⁻¹)	Source
Acacia agroforestry	173 ± 4.6	[26] for the case of South Central Coast
Arabica agroforestry	2587	SCAF database for the case of North West
Cashew agroforestry	213	SCAF database for the case of South East
Robusta agroforestry	2124 ± 574	SCAF for the case of Central Highlands
Tea agroforestry	2806	SCAF database for the case of North East
Arabica sole plantation	1835	[27] for the case of North Central Coast
Robusta sole plantation	941 ± 24	[28] for the case of Central Highlands
Tea sole plantation	2642	[29] for the case of Central Highlands

3. Results

3.1. Sequestered Carbon in Existing Areas of Agroforestry

The total (TOC) of sequestered AGC, BGC, and SOC in the existing areas of agroforestry, from the eight key systems in Vietnam, reaches 1346 ± 92 mil tCO₂e. The two systems in wetlands, namely Rhizophora- and Melaleuca-based, contribute about 82% to the TOC (Figure 4) thanks to their high carbon storage per hectare and large areas. About 52% of the TOC is SOC, 27% is BGC, and 21% is AGC. The share of TOC from BGC is higher than from AGC due to a large contribution from the root biomass of the Rhizophora-based system. The AGC, BGC, and SOC sequestered by agroforestry systems are shown in Table A2.

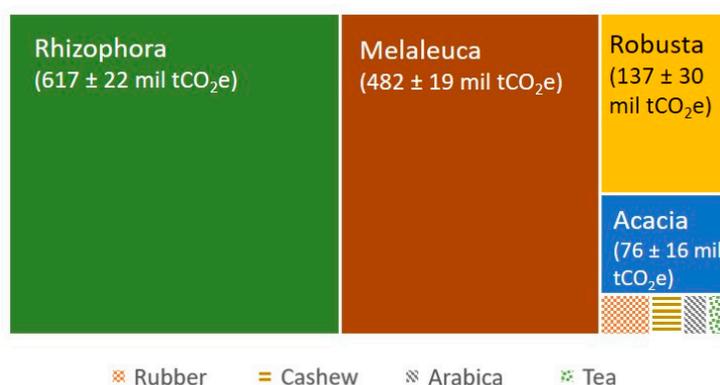


Figure 4. Main contributions to the total sequestered carbon in existing areas of agroforestry.

3.2. Suitable Areas for Agroforestry Expansion

Highly suitable areas for the five agroforestry systems for expansion range from 24 to 419 thousand ha nationwide under the baseline climate (Table 5). Cashew has the most limited area, while acacia has the largest. However, in terms of aggregate of highly and less suitable areas, the most limited is arabica. Neglecting the capacity of agroforestry system to modify micro-climate that can reduce the impact of climate change especially warming climate, the highly suitable areas for agroforestry expansion were substantially affected by the potential change in climate (Table 5). For example, large areas across the country are projected to have an increase in average annual temperature by 1.8–2 °C by 2050 under RCP 8.5, and this reduces the highly suitable area of the arabica coffee-based system by 89% compared to baseline. For most of the agroforestry systems, the change in climate transformed the highly suitable areas into less suitable areas for expansion. The two coffee-based systems are the most severely affected, while acacia is relatively resistant to the climate change. On average, for all agroforestry systems, the highly suitable areas are potentially reduced by 34% and 48% in 2050 under RCP 4.5 and RCP 8.5, respectively.

Table 5. Suitable areas for agroforestry expansion under baseline and future climate conditions.

	Acacia	Arabica	Robusta	Cashew	Tea
Highly suitable (thousand ha)					
Baseline	419	54	189	24	181
RCP 4.5	435	15	36	21	170
RCP 8.5	389	6	32	17	127
Combined (highly and less) suitable (thousand ha)					
Baseline	2407	937	1985	1789	1787
RCP 4.5	2447	362	1980	1761	1784
RCP 8.5	2468	268	1997	1827	1797
Impact of climate change on highly suitable area (%)					
RCP 4.5	4%	−72%	−81%	−14%	−6%
RCP 8.5	−7%	−89%	−83%	−32%	−30%

Among the eight regions, Central Highlands contains the largest area that is highly suitable for agroforestry expansion (Figure 5a) due to favorable soil and climate conditions for crop cultivation. The South Central Coast and Mekong River Delta have the smallest suitable areas due to higher temperatures, lower precipitation, or unsuitable soil types for agroforestry systems’ expansion. These two regions, along with the Red River Delta, also have the smallest suitable area for agroforestry expansion when both highly and less suitable areas are combined (Figure 5b). Suitable areas for agroforestry systems organized by region under baseline and future climate conditions are given in Table A3.

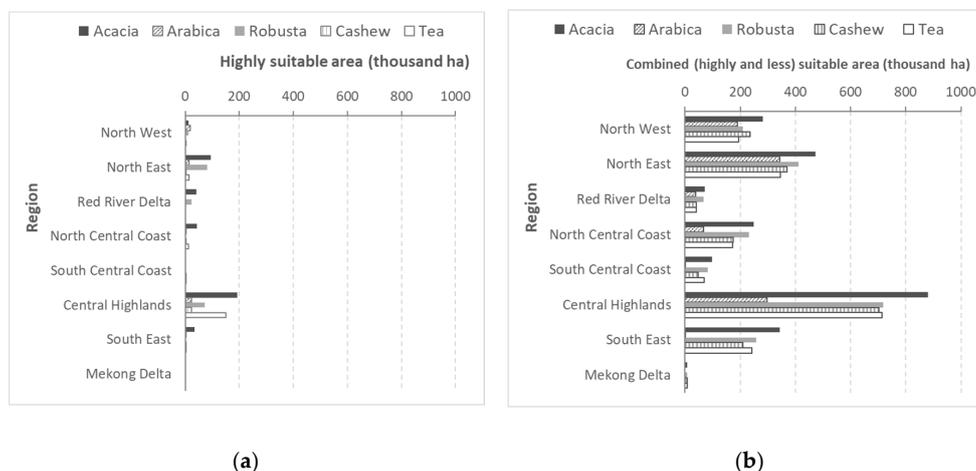


Figure 5. (a) Highly and (b) combined (highly and less suitable) areas by species and region.

3.3. Sequestered Carbon in the Agroforestry Expansion Areas

Among the five scenarios, expansion using arabica- and cashew-based agroforestry in highly suitable areas accumulated the smallest TOC over the ten-year expansion period under baseline climate conditions (Figure 6). Acacia-based AF accumulated the highest TOC that reaches 44 ± 4.5 mil tCO₂e by 2030. The inclusion of 10% or 25% of the less suitable areas substantially increased the TOC on average by a factor of 3.3 and 6.8, respectively (Figure 6b,c), compared to the TOC from highly suitable areas only. The sequestered TOC values under baseline and future climate conditions with or without the inclusion of less suitable areas are provided in Table A4.

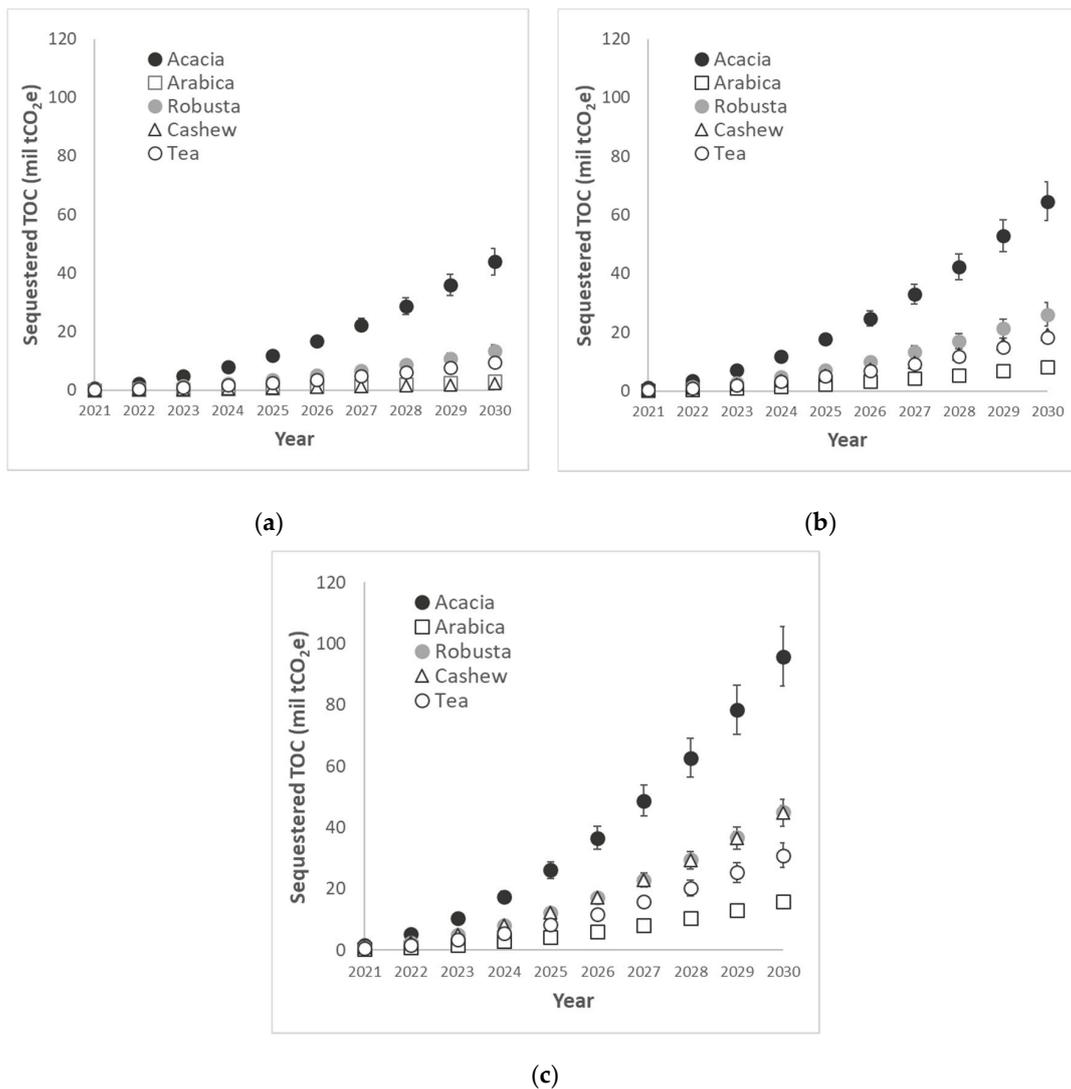
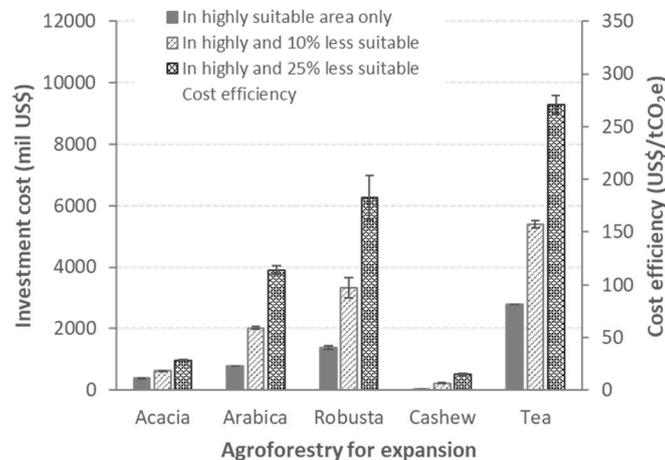


Figure 6. Sequestered total carbon (TOC) over ten-year agroforestry expansion in (a) highly suitable and (b) highly suitable and 10% or (c) 25% of less suitable areas under baseline climate conditions.

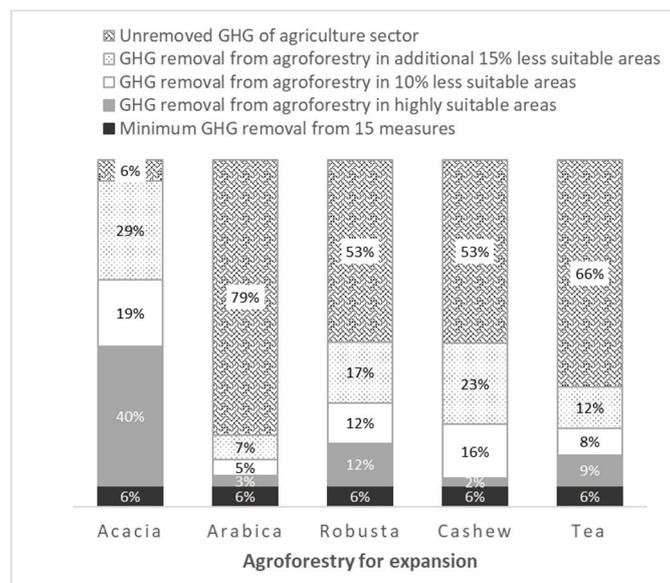
3.4. Cost Efficiency of Agroforestry Expansion

The investment cost for agroforestry expansion in the highly suitable areas under baseline climate conditions ranges from USD 28 to 2790 million for the ten-year period (Figure 7a). The cost doubled when the combined suitable areas were included. Among the five agroforestry systems, the expansion of tea-based systems into the total highly suitable area of 180,000 ha requires the largest investment cost. For the purpose of sequestering carbon, neglecting potential economic returns, acacia- and cashew-based systems are the most cost efficient among the five agroforestry

systems for expansion. The cost efficiency of the two systems is USD 8–12 per tCO₂e. The cost efficiencies of sole crop plantations are USD 9121, 1041, and 934 per tCO₂e for arabica, robusta, and tea, respectively. Agroforestry expansion is 1.3–17 times more cost-efficient for sequestering carbon than sole crop plantations.



(a)



(b)

Figure 7. (a) Total investment cost and cost efficiency of the five agroforestry expansion scenarios, (b) mitigation contribution from agroforestry expansion for removing greenhouse gas (GHG) emission of Vietnam’s agriculture sector.

3.5. Mitigation Contribution to Agriculture Sector

The sequestered TOC in the existing areas of agroforestry that reaches 1346 ± 92 mil tCO₂e can thoroughly offset the projected GHG emissions of the agriculture sector by 2030. However, if only the carbon contribution from post-2020 programs is considered, the sequestered TOC in agroforestry expansion areas under baseline climate can remove 15–88% of the total GHG emissions of the agriculture sector compared to if 25% of the less suitable areas is included in the carbon assessment (Figure 7b). The acacia-based expansion provides the largest contribution, while the arabica-based provides the smallest. If the 15 mitigation measures in Vietnam’s first NDC provide the minimum contribution of

6%, about 6–79% of projected emissions by 2030 would remain unremoved. A higher contribution from agroforestry can be expected if more than 25% of the less suitable areas were considered in the assessment.

4. Discussion

4.1. Agroforestry in Vietnam's 2020 NDCs

In Vietnam's 2020 NDC¹, agroforestry is mentioned in Section 2.4.3 as part of measures for the LULUCF sector. Agroforestry and forest protection and restoration are most likely placed as part of the same sector due to their potential usefulness for carbon sequestration and land conservation. Agroforestry-related activities and targets will likely be elaborated in the NDC action plan that is still under development by the government at this time.

To offset sectoral emissions, it is, however, more effective to include agroforestry as part of the agriculture sector. By 2010, in Vietnam, forests and other land uses, excluding agriculture, such as grasslands had generated a net negative emission of 19.2 mil tCO₂e with a projected emission of −42.5 and −45.3 mil tCO₂e by 2020 and 2030, respectively [11]. Moreover, the country has committed to the UNFCCC's Koronivia Joint Work on Agriculture (KJWA) to promote and enhance investment in climate-smart agriculture such as agroforestry [30]. Enhancing terrestrial and soil carbon is among the priorities of the KJWA [31], along with improved nutrient and water management for food security and resilience to climate change, for which agroforestry can also generate relevant benefits.

As in its first NDC, Vietnam's 2020 NDC focused on improving the efficiency of inputs, plot management practices, and waste treatment as mitigation measures for the agriculture sector.

4.2. Agroforestry Systems for Expansion and Impact of Climate Change

Several studies in the literatures [32–35] also projected a strong impact of climate change on suitable area and production of arabica and robusta coffee. Globally, climate change potentially reduces the suitable area for coffee by 50% across climate scenarios, and Vietnam is one among several coffee producing countries that will be severely affected [32,34]. The change in climate, especially warming temperature beyond the optimal threshold for growth, affects the coffee biological process that results in reduced photosynthesis, a slower or halted ripening process, or flower abortion [36]. In addition, the change in temperature can trigger pest and disease outbreak. The impact of climate change on suitable area and production of other species, such as tea, has also been reported in the literature [37–39].

Our study only assessed the impact of climate change on the main perennial crop species of each agroforestry system for expansion. However, the projected impact does not necessarily represent impact on agroforestry that uses that species as the main crop. The presence of other plant components in agroforestry can potentially modify the micro-climate, which reduces the intensity of climate change impact. For example, shading trees or ground cover crops in coffee agroforestry systems can keep soil moisture high and soil temperature low, and these benefits are absent in sole coffee plantation [40–42]. The role of coffee agroforestry systems for mitigating the impact of a warming climate has been demonstrated in the southeast Brazil [33]. The suitable area for sole coffee plantation is projected to decrease by 60% in 2050, driven by a 1.7 °C ± 0.3 increase in the average annual temperature. However, coffee agroforestry systems with a 50% shade cover can reduce the average annual temperatures within the systems, and 75% of the total area of coffee agroforestry in the region will still be suitable for production by 2050. Therefore, the strong impact of the warming climate on robusta and arabica coffee projected in our study clearly suggests the need for prioritizing coffee agroforestry rather than sole

¹ https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Viet%20Nam%20First/Viet%20Nam_NDC_2020_Eng.pdf submitted on September 2020.

coffee plantation for expansion in Vietnam and promoting a gradual conversion of existing sole coffee plantations into agroforestry. The projected impact of the warming climate on other species such as tea, as shown in our study, also suggests the need for modifying the micro-climate through agroforestry.

Vietnam's Master Plan on agricultural production development to 2020, vision to 2030, specifies the Central Highlands, South East, and North Central Coast as the main production regions for robusta coffee. Our land suitability analysis shows that the three regions have suitable, both highly and less suitable combined, areas for robusta coffee, each above 200,000 ha, and thus supports the specification. The other regions such as the North West and North East also have large suitable areas for robusta coffee. However, the Central Highlands has been the production house of robusta coffee in Vietnam for decades, with strong market access, role of private sectors, and supporting infrastructure, including the processing industry [43]. Therefore, the Plan is likely focusing the production of robusta coffee in regions around the Central Highlands. The Plan also specifies main production regions for tea, namely the North East, North West, and Central Highlands. Our land suitability analysis suggests that the South East and North Central Coast are also suitable for tea expansion. Therefore, aside from existing infrastructures and market access for tea that are currently concentrated in the North East, North West, and Central Highlands [44], expansion of tea agroforestry in the other two regions can become an option. For cashew, the Plan specifies the Central Highlands, South East, and South Central Coast. As for robusta coffee and tea, the specification likely considers existing infrastructures and access to market as main factors. Putting those factors aside, our analysis shows that other regions such as North West, North East, and North Central Coast have larger suitable areas for cashew than that of the South Central Coast. Another factor that drives the Plan to consider the South Central Coast is likely its territorial bordering with the Central Highlands. The Plan does not specify regions for arabica coffee and acacia. According to our analysis, three regions, namely the North West, North East, and Central Highlands, have suitable areas for arabica coffee, each above 180,000 ha, and according to [43], the main arabica cultivations in Vietnam can be found in the North West and Central Highlands. Therefore, the expansion of arabica-based agroforestry can target the North West and Central Highlands, with the North East as an option. Acacia can grow in a wide range of terrain, soil, and climate conditions and is relatively easy to manage [45]. In addition, it is a nitrogen-fixing species that can help restore soil fertility. Our analysis shows that acacia is suitable in all regions except the Mekong River Delta.

Rhizophora-based agroforestry should be considered as an agroforestry system for expansion, although our study could not assess its potential area for expansion and sensitivity to climate change due to lack of input data. Rhizophora-based agroforestry can potentially reconcile mangrove restoration and livelihood improvement through combining mangrove plantation and shrimp farming. The area of mangrove forests in Vietnam, especially in the Mekong River Delta, has decreased by 35,000 ha, or 32% of their initial area, during the past three decades (1988–2018) [46], mainly due to anthropogenic activities. About 7300 ha of degraded mangrove forests have been regenerated from 2013 to 2018, but stronger efforts for mangrove restoration in Vietnam are necessary to counter the escalated impact of sea water intrusion amidst livelihood pressure from surrounding populations. By 2050, about 13% of existing rice agricultural areas in the Mekong River Delta are likely to be converted to shrimp farms due to the high economic benefit and impact of sea water intrusion [47]. An effective land share between mangrove plantations and shrimp farms within Rhizophora-based agroforestry systems has been suggested by several studies, e.g., [48,49], for the purpose of optimizing economic return from the shrimp farming and ecological contribution from the mangrove. A recent study [49] claims that mangrove density has no ecological impacts on shrimp farming, and the recommended mangrove coverage for shrimp farming is about 60%. Rhizophora-based agroforestry systems are also a solution for restoring mangrove biodiversity and coastal food chains [49], apart from their substantial contribution to carbon sequestration for GHG removal.

4.3. Advantages of Using Agroforestry Rather than Sole Crop Plantation for NDCs

Our study shows that agroforestry is more cost efficient in sequestering carbon than sole crop plantation (see also [12]). Consequently, the cost required to remove GHG emissions is lower when using agroforestry than sole crop plantation. For example, expansion of robusta-based agroforestry in Vietnam can potentially remove 41% of total GHG emissions of the country's agriculture sector by 2030 (see Figure 7b), equivalent to about 45 mil tCO₂e. The expansion requires an investment cost of about USD 6.3 billion (see Figure 7a). Removing a similar amount of GHG emissions using sole robusta plantations will require an additional cost of about USD 41 billion. For the case of arabica coffee and tea, the required additional costs are about USD 145 billion and 20 billion, respectively.

Agroforestry can offer more climate change mitigation and adaptation co-benefits as compared to sole crop plantations. For example, robusta-based agroforestry systems in the Central Highlands region were reported to sequester, on average, 0.16 tCO₂e per ton coffee produced thanks to sequestered carbon in shade trees and contribution from nitrogen-fixing trees to reduce chemical inputs. On the other hand, sole coffee plantations were net GHG emitters with, on average, 0.37 tCO₂e per ton coffee produced [50]. In terms of economic return, crop diversification in agroforestry can increase and stabilize farmers' incomes [7]. For example, in the Central Highlands, the net income of a robusta-macadamia (*Macadamia integrifolia*) system reached USD 2500 ha⁻¹ year⁻¹ compared to USD 1793 ha⁻¹ year⁻¹ for sole robusta plantations [29]. For tea, the net annual income from a sole tea plantation in the Central Highlands was USD 720 ha⁻¹ year⁻¹ [29], while a tea-*Acacia mangium* system in the North East generated USD 1688 ha⁻¹ year⁻¹, as reported in the SCAF database. There is also evidence of agroforestry's role in stabilizing farmers' annual incomes from fruit tree-based systems in the North West [51] and acacia-based systems in the North Central Coast [26,52]. Higher and more stable incomes from agroforestry mean that farmers can reinvest in improved adaptation strategies.

4.4. Caveats in the Carbon and Cost Assessment for Agroforestry

In our study, due to limited information from the literature, we assumed that the sequestered carbon per ha of agroforestry in highly and less suitable areas, when used as inputs for the national-scale estimation of carbon potential from agroforestry expansion, are comparable. Likewise, the input investment costs per ha for agroforestry expansion were assumed to be comparable for all suitable areas. To overcome the scarcity of input data, future studies can consider the use of tools for simulating soil–climate–crop interaction in agroforestry—e.g., see [53]—to obtain projection of plot-level sequestered carbon and investment cost in different growing conditions, for example, in highly and less suitable areas. The projected carbon and cost per ha can be used to better estimate carbon sequestration potential and associated cost of agroforestry expansion. For example, if the projected carbon per ha of agroforestry in less suitable areas is reduced by 10% compared to that in highly suitable areas, agroforestry expansion under baseline climate can remove 13–83% instead of 15–88% of the total GHG emissions of the agriculture sector by 2030 if 25% of the less suitable areas were included in the calculation. Future studies on the return on investment from agroforestry that include sensitivity analyses of climate change impacts are also necessary. For such assessment, the studies can use the projected impact of future climate on suitable areas for agroforestry expansion as described in the current study and the projected plot-level investment cost, including level of crop production from the simulation tools for highly and less suitable areas of agroforestry.

4.5. Ways Forward to Foster Agroforestry in Vietnam's NDC

Vietnam's 2020 NDC outline national climate programs spanning from 2021 to 2030, with an update to the UNFCCC required by 2025. Among efforts needed to enhance the role of agroforestry in climate mitigation and adaptation informed by the revised NDC, including the inclusion of agroforestry as part of measures for the agriculture sector, are continuous improvement of the database on agroforestry practices, further investigation on their potential mitigation and adaptation benefits,

and the development of reliable monitoring, reporting, and verification systems. Vietnam's 2020 NDCs also emphasize that proposed measures need to demonstrate synergy and co-benefits among climate change adaptation, mitigation, and sustainable development goals, including the promotion of gender equality. For the agriculture sector, Section 3.1.4 of the country's NDC underlines that "women's decision-making power within the family is often limited which constrains them to apply their experience and knowledge to selecting varieties and cultivation techniques". Additional scientific evidence is needed to demonstrate advantages of agroforestry over other agricultural practices in contributing to such synergies, including empowering women in decision making. Several studies have shown certain gendered preferences when selecting tree species for agroforestry, e.g., [54–56]. Similar studies for investigating such preference in Vietnamese farmers are necessary. Understanding the reasoning and factors that drive these preferences can have long-term impacts on interventions for climate change mitigation and adaptation, as well as enabling progress on gender equality.

The inclusion of agroforestry in mechanisms that can reward carbon sequestration can also foster agroforestry in Vietnam's NDC. For example, some studies claimed that agroforestry can be a direct or indirect target of Reducing Emissions from Deforestation and Forest Degradation (REDD+) [57], which, to date, remains as the UNFCCC's sole framework that suggests a carbon-reward mechanism. Globally, about half of the 73 developing countries that have REDD+ strategies cited agroforestry as a potential measure for reducing forest degradation and deforestation [58]. Vietnam's REDD+ action plan for 2030 does not, however, explicitly mention agroforestry. Agroforestry is likely relevant for measure 4.1.2 on "promoting sustainable and deforestation-free agriculture"², but no elaboration of that measure is provided in the action plan, which creates uncertainty on the relevancy. Recently, Vietnam's national policy on payments for forest ecosystem services is under amendment to include forest carbon in addition to water services. The policy applies a mandatory payment to beneficiaries of forest water service and, very much in the same way, the proposed scheme of payment for carbon services suggests large GHG emitters such as the cement industry and coal-generated power plants would have to pay forest communities and landowners to support forest protection and expansion [59]. Some types of agroforestry, such as acacia-based systems for timber purposes with temporary intercroppings, probably classify under the category of forestry land uses that can receive such payments. A verification from relevant authorities is, however, necessary for timber-based systems with permanent intercroppings. Furthermore, a feasible monitoring, reporting, and verification system to track progress towards agroforestry mitigation and adaptation targets should be developed to foster agroforestry in Vietnam's NDC. In the current study, the variety and areas of existing agroforestry practices in Vietnam were known from the SCAF database, relying on provincial partners as the principal data sources. Technical, financial, and institutional challenges for developing a monitoring, reporting, and verification system for agroforestry in Vietnam should be identified and properly addressed.

5. Conclusions

The suitable area of each agroforestry system for expansion at the national and sub-national scales and the estimated mitigation potential under baseline and future climate conditions described in this study can support Vietnam in specifying agroforestry activities, mitigation targets, and associated costs for developing the action plan of its 2020 NDC. Among the crop species assessed for = agroforestry expansion, the two varieties of coffee, namely robusta and arabica, will be the most severely affected by climate conditions in 2050. To reduce the impact of climate change, future agricultural expansion in Vietnam should consider these crop species in agroforestry, which has potential to modify micro-climates and has other co-benefits such as being more cost efficient in sequestering carbon compared to sole crop plantation. Thanks to these benefits, agroforestry will bring less investment risks than sole crop plantation.

² <http://vietnam-redd.org/Upload/CMS/Content/Library-GovernmentDocuments/419%20NRAP%202030%20En.pdf>

The 2020 NDC for Vietnam includes agroforestry as part of measures for the LULUCF sector. However, for the purpose of offsetting sectoral GHG emissions, it is more effective to include agroforestry as part of agriculture sector. Excluding the sequestration contribution from the existing areas of agroforestry, the total AGC, BGC, and SOC sequestered in the potential areas for agroforestry expansion can remove 15–88% of the total GHG emissions of the agriculture sector. This is achieved when both highly suitable and 25% of less suitable areas for agroforestry expansion were included in the carbon assessment.

Efforts to foster the implementation of Vietnam's NDC through agroforestry would benefit from continuous data provision for estimating agroforestry's mitigation and adaptation benefits, capacity to achieve synergy and co-benefits between climate change adaptation, mitigation and sustainable development goals, and to promote gender equality. In addition, a reliable monitoring, reporting, and verification system is necessary to track progress towards agroforestry's mitigation and adaptation targets. If all these further efforts generate at least preliminary outputs accessible to relevant authorities within the next 3–4 years, we can expect agroforestry to have a broader role in climate mitigation and adaptation, informed by Vietnam's revised NDC by 2025.

Author Contributions: Conceptualization, R.M., M.P.N., P.S. and T.R.; data curation, R.M., D.D.N., M.P.N., P.S., V.T.P., H.A.L., T.R. and E.S.; formal analysis, D.D.N., M.P.N. and P.S.; funding acquisition, R.M. and T.R.; investigation, R.M., D.D.N., M.P.N., P.S. and V.T.P.; methodology, R.M., D.D.N., M.P.N., P.S., V.T.P. and E.S.; software, D.D.N.; validation, R.M., D.D.N., M.P.N., P.S., H.A.L., T.R. and E.S.; visualization, D.D.N. and V.T.P.; writing—original draft preparation, R.M.; writing—review and editing, R.M., D.D.N., M.P.N., P.S., V.T.P., H.A.L., T.R. and E.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. We specifically thank the United States Agency for International Development (USAID) for the bilateral funding. The views expressed in this document cannot be taken to reflect the official opinions of these organizations. The APC was funded by CCAFS.

Acknowledgments: This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. We specifically thank USAID for funding this work. For details, please visit <https://ccafs.cgiar.org/donors>. The views expressed in this document cannot be taken to reflect the official opinions of these organizations. We sincerely thank Delia Catacutan, Nguyen Quang Tan, Vu Tan Phuong, Chu Van Chuong, Bui My Binh, Nguyen Phu Hung, and Meine van Noordwijk for numerous and valuable inputs to the study. We also thank valuable comments from three anonymous reviewers.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Input data for estimation of sequestered carbon in agroforestry systems.

Agroforestry System	Tree Density (trees ha ⁻¹) *	AGC **	BGC	SOC ***	Source
Tea-based	Agroforestry (AF): 17,000 (tea), 150–200 (shade trees) Sole: 18,000–25,000	TA: 13.3 tC ha ⁻¹ SR AF: 1.7 ± 0.18 tC ha ⁻¹ year ⁻¹ SR sole: 1.4 ± 0.14 tC ha ⁻¹ year ⁻¹	BGC/AGC: 0.10–0.34	RR-TA: 1.0 ± 0.2 SR: 1.59 ± 0.4 tC ha ⁻¹ year ⁻¹	AGC-TA and AGC-SR AF: [60] for the case in North East Vietnam. AGC-SR sole: calculated from [61]. BGC/AGC for AF [14]. RR-TA from ‘forest to shade perennial’ for tropical region [10]. SOC-SR from ‘croplands to multistrata system’ for tropical region [10]
Coffee robusta-based	AF: 500–1100 (coffee), 85–150 (shade trees) Sole: 750–1500	TA: 13.4 ± 0.3 tC ha ⁻¹ SR AF: 2.63 ± 0.55 tC ha ⁻¹ year ⁻¹ SR sole: 0.75 ± 0.01 tC ha ⁻¹ year ⁻¹	BGC/AGC: 0.10–0.34	RR-TA: 1.0 ± 0.2 SR: 1.59 ± 0.4 tC ha ⁻¹ year ⁻¹	AGC-TA [50]. AGC-SR AF: calculated from [62]. AGC-SR sole and calculated using allometric equation from [63]. All for the case in Central Highlands. BGC/AGC for AF [14]. RR-TA and SOC-SR similar as for tea.
Coffee arabica-based	AF: 3000–5000 (coffee), 100–200 (shade trees) Sole: 4000–8000	TA: 13.5 ± 5.5 tC ha ⁻¹ SR AF: 1.9 ± 0.24 tC ha ⁻¹ year ⁻¹ SR sole: 0.5 ± 0.06 tC ha ⁻¹ year ⁻¹	BGC/AGC: 0.10–0.34	RR-TA: 1.0 ± 0.2 SR: 1.59 ± 0.4 tC ha ⁻¹ year ⁻¹	AGC-TA and AGC-SR AF: [64] for the case in North West. AGC-SR sole: calculated using allometric equation from [65] for the case in North West. RR-TA and SOC-SR similar as for robusta.
Cashew-based	100–200	TA: 54.2 tC ha ⁻¹ SR: 4.2 ± 0.35 tC ha ⁻¹ year ⁻¹	TA: 9.2 tC ha ⁻¹ SR: 0.7 ± 0.06 tC ha ⁻¹ year ⁻¹	RR-TA: 0.95 SR: 0.84 ± 0.26 tC ha ⁻¹ year ⁻¹	AGC-TA, AGC-SR, BGC-TA, BGC-SR: stem diameter from [66] and allometry equation from [67]. RR-TA from forest to silvoarable for tropical region [10]. SOC-SR from ‘croplands to silvoarable’ for tropical region [10].
Rubber-based	500	TA: 25.3 ± 2.76 tC ha ⁻¹	TA: 4.5 ± 0.3 tC ha ⁻¹	RR-TA: 0.95	AGC-TA: stem diameter [68], allometric equation: [69]. BGC-TA: using AGC-BGC relation from [69]. RR-TA is similar as for cashew [10]
Acacia spp.-based #	Short-rotation (3–5 years): 4500–8000 Long-rotation (8–12 years): 600–1200	TA: 25.3 ± 6.2 tC ha ⁻¹ SR: 4.0 ± 0.37 tC ha ⁻¹ year ⁻¹	BGC/AGC: 0.10–0.33	RR-TA: 0.95 SR: 0.84 ± 0.26 tC ha ⁻¹ year ⁻¹	AGC-TA and AGC-SR: [26] for the case in South Central Coast. BGC/AGC for tree plantation [14]. RR-TA is similar as for rubber [10]. SOC-SR similar as for cashew.
Rhizophora-based	8000–10,000	TA: 156.4 tC ha ⁻¹	TA: 568.4 tC ha ⁻¹	TA: 386 tC ha ⁻¹	AGC-TA and BGC-TA calculated based on [70] for the case in Mekong River Delta. SOC-TA [71]
Melaleuca-based	5500–6500	TA: 178.4 ± 14.6 tC ha ⁻¹	TA: 44.6 ± 4.3 tC ha ⁻¹	TA: 312.2 ± 25.4 tC ha ⁻¹	AGC-TA, BGC-TA, SOC-TA: calculated based on [72] for the case in Mekong River Delta

* Common tree density, not specifically those reported in the cited literature, ** TA: time-average, SR-AF: sequestration rate of AF system, SR-sole: sequestration rate of sole crop system. In the C estimation, for the AGC inputs without standard error, we applied a 10% standard error from the mean. AGC input without standard error *** RR-TA: response ratio to estimate SOC of the eight key existing AFs. The land cover before conversion into those AFs was assumed as logged over forest with SOC ranges from 68–205 tC ha⁻¹ [14]. # AGC-TA is for short-rotation (3–5 years) as the current most popular acacia systems in Vietnam. AGC-SR is for long-rotation (8–12 years), for expansion.

Table A2. Sequestered carbon in the existing areas of agroforestry.

Agroforestry System *	Area (10 ³ ha)	AGC (mil tCO ₂ e)		BGC (mil tCO ₂ e)		SOC (mil tCO ₂ e)		TOC ** (mil tCO ₂ e)	
		Total	SE	Total	SE	Total	SE	Total	SE
Melaleuca-based	246	161	6.19	40	1.83	281	10.8	482	18.8
Robusta-based	245	12	0.12	2.4	0.57	123	29.1	137	29.5
Rhizophora-based	149	86	4.04	320	8.93	211	9.97	617	22.4
Acacia-based	130	12	1.40	2.4	0.57	62	14.6	76.1	15.6
Rubber-based	21	1.9	0.10	0.4	0.09	9.8	2.3	12.0	2.4
Arabica-based	11	0.5	0.06	0.1	0.02	5.3	1.25	5.9	1.3
Cashew-based	10	2.1	0.10	0.4	0.03	4.9	1.17	7.4	1.25
Tea-based	10	0.5	0.04	0.1	0.02	4.8	1.13	5.4	1.17
All systems	820	275	12.0	366	12.1	701	70.4	1343	92.4

* ordered by the total area in the country, ** total of AGC, BGC and SOC.

Table A3. Suitable areas for agroforestry expansion by species and region under baseline and future climate.

ER *	Acacia			Arabica			Robusta			Cashew			Tea		
	Baseline	RCP 4.5	RCP 8.5	Baseline	RCP 4.5	RCP 8.5	Baseline	RCP 4.5	RCP 8.5	Baseline	RCP 4.5	RCP 8.5	Baseline	RCP 4.5	RCP 8.5
	Highly suitable area (thousand ha)														
NW	12	22	23	19	6	3	11	8	6			0.01	4	8	6
NE	94	112	109	13	3	1	81	9	5	0.01	0.01	0.01	13	38	32
RRD	41	42	42				23	0.01						8	1
NCC	42	55	47	0.01			3			0.01	0.01	0.01	12	1	1
SCC	2	0.01	1				0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CH	192	202	166	23	6	2	72	19	21	23	20	16	150	114	86
SE	35	1	1	0.01			0.01		0.01	1	0.01		2	0.01	
MRD	0.01														
Total	419	435	389	54	15	6	189	36	32	24	21	17	181	170	127
	Combined (highly and less) suitable area (thousand ha)														
NW	282	307	309	190	141	120	210	210	210	236	236	236	194	194	194
NE	472	491	493	342	102	80	411	413	414	369	373	373	345	345	345
RRD	72	72	72	39			68	68	68	41	41	41	40	40	40
NCC	250	250	250	66	5	2	232	232	232	175	176	176	173	173	173
SCC	99	99	99	1	0	0	82	77	84	48	42	52	69	68	72
CH	881	884	885	298	114	65	718	718	718	704	679	723	715	715	715
SE	344	337	353	1	0	0	257	254	263	209	207	218	243	241	251
MRD	8	8	8				8	8	8	8	8	8	7	7	7
Total	419	435	389	54	15	6	189	36	32	24	21	17	181	170	127

* North West (NW), North East (NE), Red River Delta (RRD), North central Coast (NCC), South Central Coast (SCC), Central Highlands (CH), South East (SE) and Mekong River Delta (MRD).

Table A4. Sequestered TOC in highly suitable with/out partial less-suitable areas under baseline and future climate.

Scenario **	Sequestered TOC (mil tCO ₂ e) by 2030 *								
	Highly Suitable			Highly and 10% Less Suitable			Highly and 25% Less Suitable		
	Baseline	RCP4.5	RCP8.5	Baseline	RCP4.5	RCP8.5	Baseline	RCP4.5	RCP8.5
1	44 ± 4.5	46 ± 4.5	40 ± 4.1	65 ± 7.1	67 ± 7.2	62 ± 6.6	96 ± 11	98 ± 11	95 ± 11
2	3.2 ± 0.4	0.9 ± 0.1	0.4 ± 0.1	8.3 ± 1.1	3.0 ± 0.4	1.8 ± 0.2	16 ± 2.1	6.0 ± 0.8	4.0 ± 0.5
3	13 ± 2.1	2.5 ± 0.4	2.3 ± 0.4	26 ± 1.9	16 ± 1.8	16 ± 1.9	45 ± 4.5	37 ± 4.4	37 ± 4.5
4	2.3 ± 0.2	1.9 ± 0.2	1.6 ± 0.2	19 ± 4.2	19 ± 2.5	19 ± 2.5	45 ± 7.4	44 ± 5.7	45 ± 5.7
5	9.6 ± 1.2	8.9 ± 1.1	6.7 ± 0.9	18 ± 2.4	18 ± 2.3	16 ± 2.1	31 ± 4.2	31 ± 4.1	29 ± 3.8

* Average and standard error ** 1: expansion of acacia-, 2: arabica-, 3: robusta-, 4: cashew-, and 5: tea-based AF over the country.

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