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Value Modelling Spatiotemporal Changes of Carbon Storage in the Philippine Agriculture, Forestry, and Other Land Uses (AFOLU) Sector from 2003–2010

Nico R. Almarines[a]

ABSTRACT

Agriculture, Forestry, and Other Land Uses (AFOLU) are vital in the issue of climate change due to their role as natural carbon sinks. However, land conversion at the expense of natural ecosystems has resulted to steady changes of carbon storage in the country which have not been fully quantified. Integrated ecosystem services value mapping has tremendous potential to aid policy and decision makers by incorporating carbon storage and sequestration values in the decision–making process. This would allow them to make more objective decisions involving land conversion based on the aggregate values and the economic trade–offs between the various allocations of natural ecosystems and agroecosystems which would not have been considered otherwise. Changes in agriculture, forestry, and other land uses in the Philippines from the years 2003 to 2010 have resulted to a decrease in carbon stock in the country's AFOLU sector. Using the InVEST Carbon Storage and Sequestration model, the mean estimate for the total carbon lost from aboveground biomass, belowground biomass, soil organic matter, and detritus carbon pools due to spatial changes in the AFOLU sector is 246.4 Tg C. The mean estimated value of the carbon lost and emitted into the atmosphere is around PhP 311.1 billon using the market price of carbon, PhP 1,017.4 billion using the average social cost of carbon at 3% discount rate, and PhP 3,026.8 billion for the 95th percentile social cost of carbon at 3% discount rate. The study suggests the need for more effective management of the country's AFOLU sector to improve net carbon storage and sequestration in the country.

Keywords: carbon sequestration, carbon storage, InVEST model, land conversion, spatial value model

INTRODUCTION

The Philippines is perceived to be one of the most climate–vulnerable countries in the world. Sönke and Eckstein (2013) ranks the country as the 7th most affected nation by climate variability and extremes in the Long–Term Climate Risk Index, and second in the Climate Risk Index for 2012. Climate change could negatively impact the country's water supply, agricultural productivity and food supply, human and ecosystem health, current and planned infrastructures, and the economy as a whole (Confalonieri *et al*. 2007; Adger *et al*. 2007; Field *et al.* 2014).

Agriculture, Forestry, and Other Land Uses (AFOLU) play a vital role in the issue of climate change (Smith *et al.* 2014) because the plants and ecosystems therein function as a carbon sink through the process of photosynthesis. The loss of these ecosystems is a significant contributing factor to climate change, and the expansion of carbon storage in AFOLU has been identified as a potential measure in mitigating climate change (FAO 2001; De Fries *et al*. 2002; Smith *et al*. 2014).

The study aimed to estimate and valuate carbon storage in the Philippine AFOLU sector, and quantify the changes to the spatiotemporal distribution and values of the said carbon storage from 2003 to 2010. The study will provide greater insight to the implications of current patterns of land cover change in the country in terms of carbon dynamics. The study will also provide preliminary information on the national level cost of lost carbon storage in the AFOLU sector that may be utilized by policy makers and AFOLU managers for more effective carbon –related decision making.

[a]Teaching Associate, Institute of Renewable Natural Resources,
College of Forestry and Natural Resources
University of the Philippines Los Baños
Email address: nics.almarines@gmail.com

Carbon Accounting

The increasing concentration of carbon dioxide and other greenhouse gases in the atmosphere has been identified as a major cause of global warming and subsequent climate change. The natural carbon cycle helps regulate carbon in the atmosphere through the continuous flux of carbon between and among terrestrial, marine, and atmospheric reservoirs (Sulzman 2000; Nabuurs *et al*. 2007). The role of ecosystems for carbon storage in ecological carbon pools is potentially significant especially if other co–beneficial ecosystem services are taken into account (IPCC 2014).

The general processes involved in the fluxes among the carbon pools are similar in various ecosystems (Bergamaschi *et al*. 2010). Atmospheric carbon is imbibed in the ecosystem through photosynthesis and is converted into organic carbon; carbon dioxide is released through respiration (Levin 2009). Hence, carbon is transferred and stored in the aboveground biomass (AGC) and belowground biomass (BGC) carbon pools of the ecosystem while most of the living biomass is eventually transferred to the dead organic matter carbon pool (DOMC) such as dead wood and litter (Hairiah 2001). This will eventually decompose and transform into soil organic matter (SOM) which in turn contains the soil organic carbon (SOC). SOM includes biomass residues in all stages of decomposition within the soil, and its decomposition releases CO_2 back into the atmosphere (Post & Kwon 2000; Chapin *et al*. 2006). Due to very long turnover rates, the soil is also seen as a stable long–term terrestrial reservoir for carbon (Buell & Markewich 2001).

Carbon stock is essentially the amount of carbon in an ecosystem or its parts, which is typically derived by assuming carbon as a percentage of dry–weight biomass (Bergamaschi *et al*. 2010).The most accurate method for the estimation of carbon stock in biomass is through destructive sampling (Wang *et al*. 2003). However, it would be very inappropriate and inefficient to clear–cut an entire forest and weigh each tree in order to estimate the biomass. Non–destructive methods such as remote sensing and modeling are often used to validate (Clark *et al*. 2001).

Carbon stock densities tend to vary with different ecosystems, their age, and their location. In the Philippines, terrestrial ecosystems have carbon storage densities ranging from less than 5 Mg ha^{-1} in grasslands to more than 200 Mg ha^{-1} in old growth forests, while carbon sequestration rates ranged from approximately 1 Mg $ha^{-1}yr^{-1}$ for old growth forests to greater than 15 Mg $ha^{-1}yr^{-1}$ for industrial tree plantations (Lasco & Pulhin 2003). Soils as a carbon pool has also been studied in the Philippines. Research by Dela Cruz (2010), Ilao *et al*. (2010), and Salang (2010) focused more on the role of soils in carbon sequestration and storage. Studies of Lasco *et al*. (2005), Gevaña *et al*. (2008), and Gevaña and Pampolina (2009) also included soil carbon aside from aboveground biomass in the computation of the carbon stock of their respective ecosystems.

The estimation of carbon over large areas, like countries, regions, continents and even worldwide has been of interest in recent years. Using remote sensing, regional and national carbon stock assessments are possible within a relatively short period of time. These studies are supported by correlating the reflection of the canopy recorded at the sensor to the carbon measured directly or estimated indirectly on the ground (Gibbs *et al*. 2007). Some studies of this essence were done by Wicks and Curran (2003), Sheng *et al*. (2004), Chiesi *et al*. (2005), Myeong *et al*. (2006), and Garbulsky *et al*. (2007).

Carbon modeling is done in order to assess and predict the carbon densities of ecosystems given different scenarios which may provide information for practitioners and policy makers (Keenan *et al*. 2007). Sulistyawati *et al*. (2007), used the CENTURY model, developed by Parton *et al*. (1993), to estimate the capacity of reforestation forests to sequester carbon and the effect of plant characteristics on the pattern of carbon sequestration of two hypothetical species. Lasco *et al*. (2005) studied the Carbon budgets of terrestrial ecosystems in the Pantabangan–Carranglan Watershed by sampling carbon stocks in above–ground biomass, necromass, and soil using field and laboratory techniques, and using the derived values in a CO_2–Fix Model simulation.

Valuation of Carbon Storage

The Philippines has been undergoing rapid urbanization in the past half century. The total urban population of the country in 2010 is 92.3 million or 45.3% of the entire population. Along with the increase in urban population, comes an increase in urban areas and increasing pressures on natural ecosystems. Land conversion for residential, commercial, industrial, or agricultural purposes at the expense of natural ecosystems is one of the biggest issues of urbanization. This conversion of natural ecosystems to agroecosystems has negative effects on the quantity and quality of ecosystem services and their values (Zang 2011).

Thus, the valuation of ecosystem services has gained importance because of its ability to quantify and compare the economic, social, and environmental benefits of natural ecosystems to human society relative to that derived from agroecosystems (Troy & Wilson 2006; Boyd 2007). Because of the spatially implicit nature of ecosystem services like carbon storage, integrated ecosystem services value mapping is able to provide accurate and detailed information which enables the extrapolation, analysis and visualization of inherent spatial patterns useful for scenario building and modelling (Bagstad *et al*. 2013; Crossman *et al*. 2013). Hence, this has tremendous potential to aid policy and decision makers as a decision support system because it would incorporate ecosystem services values in the decision–making process. This would allow more objective decisions involving land conversion based on the economic tradeoffs between the various allocations of natural ecosystems and agroecosystems which would not have been considered otherwise.

However, there are very few researches that integrate ecosystem valuation, mapping, and accounting and the studies that attempt to do so are mostly in their early stages of development (Brouwer *et al*. 2013). Some of these researches are the TEEB project, the ARIES project, the UK NEA, the WAVES initiative, and the InVEST tool (Isely *et al*. 2010; TEEB, 2010; Schagner *et al*. 2013). In the Philippines, the literature is even scarcer. Of the aforementioned researches, only TEEB and WAVES have been applied in the country to some extent.

METHODOLOGY

The study utilizes the InVEST 3.3.3 Carbon Storage and Sequestration model in the estimation of AFOLU carbon stock and its valuation. The model calculates the amount of carbon in the aboveground biomass (AGC), belowground biomass (BGC), soil organic carbon (SOC), and dead organic matter (DOMC) carbon pools of land cover classes using a simplified carbon cycle that assumes linear change in carbon storage over time. The InVEST Carbon Storage and Sequestration model sums up the carbon in each raster cell across the Philippine spatial extent for the 2003 scenario and the 2010 scenario. It computes for the net change in carbon storage between 2003 and 2010 simply by getting the difference in carbon density of each raster cell in the 2003 scenario to each raster cell in the 2010 scenario.

The study uses rasterized versions of the 2003 and 2010 land cover maps of National Mapping and Resource Information Authority (NAMRIA) to estimate the net amount of carbon stored in the four carbon pools over time. Each land cover raster was generated to have a 10m x 10m spatial resolution. These land cover maps were reclassified into 19 different land cover classes, each with its unique land cover code. Table 1 lists the land cover codes assigned to each land cover class (Table 1).

Table 1. List of land cover classes used to reclassify land cover maps in the study.

Land Cover Code	Land Cover Classes
1	Closed forest, broadleaved
2	Closed forest, coniferous
3	Closed forest, mixed
4	Forest plantation
5	Inland water
6	Mangrove forest
7	Open forest, broadleaved
8	Open forest, coniferous
9	Open forest, mixed
10	Other land, built–up area
11	Other land, cultivated, annual crop
12	Other land, cultivated, perennial crop
13	Other land, fishpond
14	Other land, natural, barren land
15	Other land, natural, grassland
16	Other land, natural, marshland
17	Other wooded land, fallow
18	Other wooded land, shrubs
19	Other wooded land, wooded grass-land

To account for variations in carbon stocks in the four carbon pools among similar land cover classes, the study utilized the model's uncertainty analysis capabilities. This incorporates into the computation of carbon stock not only the average estimated amount of carbon in a particular carbon pool, but also the upper and lower limits in carbon stock represented by its standard deviation, assuming the probability distributions of carbon in different carbon pools is normally distributed.

The uncertainty analysis of the carbon model produces a confidence raster, which shows areas most likely to either increase or decrease in carbon density. A 90% confidence threshold was used for the confidence raster. Uncertainty analysis constructs probability distributions for the current and future carbon storage in each raster cell using the provided means and standard deviations of carbon stock. Thus, the probability that future carbon storage is greater than current carbon storage is computed for a particular raster cell which is used to determine the percent confidence on either an increase or decrease in carbon storage for the particular cell using the equation:

$$p = \Phi\left(\frac{\mu_{fut} - \mu_{cur}}{\sqrt{\sigma_{cur}^2 + \sigma_{fut}^2}}\right)$$

Where Φ = the cumulative distribution function of the normal distribution

μ_{curr} = mean carbon stock of 2003 land cover
μ_{fut} = mean carbon stock of 2010 land cover
σ_{cur} = standard deviation of carbon stock in 2003 land cover
σ_{fut} = standard deviation of carbon stock in 2010 land cover

The uncertainty model also undertakes a Monte Carlo simulation to determine the standard deviations of carbon storage, carbon sequestration, and the values of sequestered carbon. This involves about 10,000 iterations of the model, with each iteration utilizing random values within a generated normal distribution function of carbon density as determined by the carbon density means and standard deviations of each land cover class for each raster grid cell. Hence, for each iteration, the model computes the amount of carbon stored in both 2003 and 2010 scenarios then computes sequestration by subtracting the computed 2003 carbon storage values from the 2010 values. The results of each iteration were logged onto a temporary database then analyzed to extrapolate means and standard deviations of carbon sequestration and carbon storage costs or carbon storage values across the Philippine landscape. The study used IPCC Tier 1 default values for biomass and carbon densities (IPCC 2006) and Lasco and Pulhin's density estimates (Lasco & Pulhin 2003) for the carbon stock means and standard deviation for each land cover class (Table 2).

Table 2. Summary of means and standard deviations of carbon stock in the different carbon pools for each land cover class in Mg ha^{-1} .

LC Code	AGC Mean	AGC SD	BGC Mean	BGC SD	SOC Mean	SOC SD	DOMC Mean	DOMC SD
1	180.0	36.0	120.0	24.0	120.0	24.0	55.0	11.0
2	165.0	33.0	110.0	22.0	115.0	23.0	50.0	10.0
3	200.0	40.0	130.0	26.0	130.0	26.0	65.0	13.0
4	88.0	17.6	59.0	11.8	96.0	19.2	29.0	5.8
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	135.0	27.0	50.0	10.0	75.0	15.0	1.0	0.2
7	80.0	16.0	50.0	10.0	100.0	20.0	25.0	5.0
8	90.0	18.0	60.0	12.0	95.0	19.0	29.0	5.8
9	90.0	18.0	60.0	12.0	110.0	22.0	30.0	6.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	2.0	0.4	1.0	0.2	10.0	2.0	0.0	0.0
12	5.0	1.0	5.0	1.0	15.0	3.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	6.0	1.2	6.0	1.2	20.0	4.0	2.0	0.4
16	10.0	2.0	5.0	1.0	20.0	4.0	0.0	0.0
17	1.0	0.2	1.0	0.2	10.0	2.0	0.0	0.0
18	8.0	1.6	8.0	1.6	25.0	5.0	3.0	0.6
19	10.0	2.0	3.0	0.6	90.0	18.0	1.0	0.2

Note: LC = Land Cover; SD = Standard Deviation; AGC = Aboveground Carbon; BGC = Belowground Carbon; SOC = Soil Organic Carbon; DOMC = Dead Organic Matter Carbon

The valuation function of the model estimates the economic value of sequestration as a function of the value per unit of carbon, the discount rate, and the change in the value of carbon sequestration over time. Thus, valuation in the carbon model is only applicable to sequestration rather than storage , because current prices of carbon only relate to carbon sequestration. The amount of carbon sequestered is simply the difference in carbon stock in the 2010 land cover and the 2003 land cover. The value of sequestration is computed using the following formula:

$$TPV_{seq_x} = v \frac{seq_x}{yr_{fut} - yr_{cur}} \sum_{t=0}^{yr_{fut}-yr_{cur}-1} \frac{1}{\left(1+\frac{r}{100}\right)^t \left(1+\frac{c}{100}\right)^t}$$

Where TPV_{seqx} = total present value of the carbon sequestered over an x time period

seq_x = total carbon sequestered over an x time period

yr_{fut} = year of the later land cover map

yr_{cur} = year of the earlier land cover map

v = value of carbon

t = year number

r = discount rate

c = cost of carbon per Mg

The study used and compared three values of carbon to estimate the total value of sequestration (Table 3).

Table 3. Carbon prices used in the valuation represented in 2014 USD values.

California Carbon Dashboard Market Price	Social Cost of Carbon 3% Average	Social Cost of Carbon 3% 95th Percentile
$ 12.22	$ 42.37	$ 124.82

These are the market price of carbon taken from the California Carbon Market on November 25, 2014 , the average social cost of carbon at 3% discount rates and the 95th percentile social cost of carbon at 3% discount rate as computed by the US EPA (2013). The values taken from EPA are adjusted to 2014 dollar value equivalents. The market price of carbon is useful for estimating the value of sequestered carbon in the Philippine landscape under current carbon cap and trading schemes at current market conditions. On the other hand, the social cost of carbon (SCC) expresses the total value of sequestration to society. The social cost of carbon considers the social damage of releasing more units of carbon into the atmosphere. The average SCC at 3% represents the value of sequestration to society if the potential impacts of climate change is similar to the average projected impacts in the A1B scenario while the 95th percentile SCC at 3% represents the value of sequestration to society if the potential impacts of climate change is at least 2 standard deviations above the projected mean impacts.

Discount rates typically reduce the value of carbon sequestration over time. It reflects the fact that people usually value immediate benefits more than future benefits. However, the discount rate may also affect the social value of carbon sequestration over time. This will change as the impact of carbon emissions on expected climate change–related damages changes. The study used a 3% discount rate throughout its analysis.

The model simplifies the carbon cycle which leads to the following limitations: this is a Tier 1 carbon model which uses generalized equations and datasets which typically underestimates changes in carbon storage due to the one–dimensional linear nature of its algorithms. The model also assumes static land cover classes, thus changes in carbon storage is only a result of the conversion of one land cover class to another. Hence, changes in carbon stock in a single land cover class over time as well as the movement of carbon from one carbon pool to another is not reflected. The model's economic valuation and carbon sequestration assumes a linear change in carbon stock which also tends to undervalue the carbon sequestered.

Furthermore, the results are only as detailed and reliable as the degree of detail and accuracy of classification in the land cover map used. The 2003 land cover map used satellite images with a 30m spatial resolution from Landsat 5 and 7. The 2003 land cover was not ground–validated when it was being generated. However, later comparison of field data from 87 1km x 1km tracts provided by the National Forest Assessment Project of the FAO–funded Philippine Forest Resources Assessment Programme, showed that NAMRIA achieved a 91% accuracy rate in their land classification (FAO–FRAP 2005). Similarly, the 2010 land cover map mostly used Landsat 7 images, but also incorporated images from higher resolution satellites like ALOS, AVNIR, and SPOT. According to a presentation by Manuel (2014) in the 5th UN–REDD Regional Lessons Learned Workshop on Monitoring Systems and Reference Levels for REDD+, the 2010 land cover map had undergone field validation during its development which resulted in an average accuracy of 89%.

RESULTS AND DISCUSSION

The model run on the 2003 land cover scenario estimated the total carbon stored in the Philippine AFOLU sector as 3,260 Tg C. This is the equivalent of 9.1% of the total carbon emissions from fossil fuel use and cement production in 2013 (Olivier *et al*. 2016). On the other hand, the model run on the 2010 land cover scenario estimated the total carbon stock from the Philippine AFOLU sector to be around 3,013.8 Tg C. This means that in all the seven years, from 2003 to 2010, the country has lost 251.97 Tg C. This is approximately 35.9 Tg C lost to land cover change per year or the equivalent of burning around 4,175,690 m^3 of gasoline per year (Table 4).

Figure 1 reveals the underlying distribution of carbon stock across the Philippine landscape. Most of the higher carbon

Table 4. Summary of changes in AFOLU related carbon storage and sequestration from 2003–2010.

Scenario	Total carbon stock (Mg of carbon)	Sequestered carbon from 2003 to 2010 (Mg of carbon)
2003	3,260,035,755	–
2010	3,013,842,476	–251,975,190

density carbon stock in the country (300–550 Mg C ha^{-1}) are located along the eastern seaboard of Luzon and in the areas of Palawan, with vast but isolated patches across the islands of Mindanao, Negros, Panay, Samar, Mindoro, and Northern Luzon. These high carbon density areas are typically covered by either closed forest, broadleaved closed forests, coniferous closed forests, mixed closed forest, or mature forest plantations. Figure 2 reflects the evident loss of carbon due to land cover change. Unsurprisingly, many of the losses in carbon stock coincide with areas with high density carbon stock in 2003. More than 70% of the decrease in carbon storage was primarily due to the five land conversion categories: 1) closed forests to open forests (23.1%), 2) natural forests to shrublands (19.2%), 3) wooded grasslands to agriculture (11.2%), 4) natural forests to wooded grasslands (10.1%), and 5) natural forests to agriculture (7.6%). Most of the decrease in carbon stock are concentrated in the areas of Palawan, Negros, Northern Samar, Cebu, Mindoro, Northern Bicol Region, and Northern Luzon.

Increases in carbon storage were also evident, but it was more scattered and covered lesser spatial extent. Increases in carbon stock concentrated around Masbate, Bicol, Leyte, Romblon, and scattered patches in Central to Northern Luzon and Mindanao. Most of the significant increases in carbon stock came from conversion of shrublands to natural forests (20.9%), open forests to closed forests (15.2%), shrublands and grasslands to wooded grasslands (10.9%), agriculture to wooded grasslands (9.5%), and agriculture to forests (8.8%).

For the uncertainty analysis of the sequestration data, results across all 10,000 Monte Carlo iterations were analyzed to produce mean and standard deviation values of carbon storage and sequestration, assuming that the true carbon pool values are independently distributed with no systematic bias. If there is systematic bias in the carbon pool estimates, then actual standard deviations for results may be larger than reported in Table 5. This affects the computation of uncertainty in the carbon model which is also used in the valuation.

The analysis of sequestration in 90% confident cells revealed that many of the increases in carbon density in the grid cells did not pass the confidence threshold, resulting to higher estimates of carbon stock loss when only confident cells were considered in the estimation (Figure 3). In terms of valuation, the loss of carbon stock resulted to negative valuations which represent the cost of carbon emission (Table 6). The estimated cost of carbon lost from land cover change ranges from around 318 billion pesos, using the market price, to around 3 trillion pesos for the 95th percentile social cost of carbon at 3% interest. To put this in context, the 2013 Philippine National Budget allotted PhP 97.8 billion for agriculture and environment, PhP 347.3 billion for general public services, while its total budget is around 2 trillion pesos.

Table 6. Estimated costs of lost carbon stock due to land cover change from 2003–2010.

Scenario	Sequestered Carbon (Mg C)	NPV (USD)	NPV (PhP)
Market Price	–251,975,190.00	–11,269,640,767.79	–318,141,958,874.66
Market Price (Confident Cells)	–252,538,724.00	–11,294,844,938.64	–318,853,472,617.94
SCC 3% Average	–251,975,190.00	–36,852,278,648.18	–1,040,339,826,238.23
SCC 3% Average (Confident Cells)	–252,538,724.00	–36,934,697,524.41	–1,042,666,511,113.99
SCC 3% 95th Percentile	–251,975,190.00	–109,634,606,749.15	–3,094,984,948,528.56
SCC 3% 95th Percentile (Confident Cells)	–252,538,724.00	–109,879,800,843.38	–3,101,906,777,808.59

Note: SCC = Social cost of carbon NPV = Net present value

Uncertainty analysis for the resulting NPV of carbon sequestration using the three prices of carbon used in the valuation were also done. The uncertainty analysis resulted to slightly lower values of carbon loss and NPV of costs (Table 7). The mean net present values of carbon lost due to land cover change from 2003 to 2010 using the market price, SCC average and the SCC 95th Percentile are PhP –311.13 billion, PhP–1.017 trillion, and PhP –3.026 trillion, respectively. These have standard deviation values of PhP 42.623 billion, PhP 139.379 billion, and PhP 414.65 billion respectively. These give upper value and lower value estimates for each of the prices used in the valuation process.

SUMMARY AND CONCLUSION

Land cover changes in the Philippines from the years 2003 to 2010 has resulted to a decrease in carbon stock in the country's AFOLU sector. The total carbon lost during this time period is estimated to be around 212.67 Tg to 280.18 Tg or the equivalent of 778.36 Tg to 1,025.47 Tg CO^2. The average annual rate of loss is averaged at 35.20 Tg C or 129.20 Tg CO^2. However, this only accounts for 1.6% of the global CO^2 loss from the AFOLU sector in 2010 (Tubiello *et al*. 2014). This carbon was valued using the market price of carbon, the average social cost of carbon at 3% discount rate, and the 95th percentile social cost of carbon at 3% discount rate. The value of the carbon emitted to the atmosphere was estimated to cost around PhP 268.51 billion to PhP 353.76 billion using the market price of carbon while the

Table 5. Statistical results of the Monte Carlo simulation of the biophysical carbon model.

	Total carbon (Mg of carbon)		Sequestered carbon from 2003 – 2010 (Mg of carbon)	
Scenario	Mean	Standard deviation	Mean	Standard deviation
2003	3,259,670,344.17	183,634,715.43	–	–
2010	3,013,244,881.71	173,023,855.34	–246,425,469.70	33,758,344.71

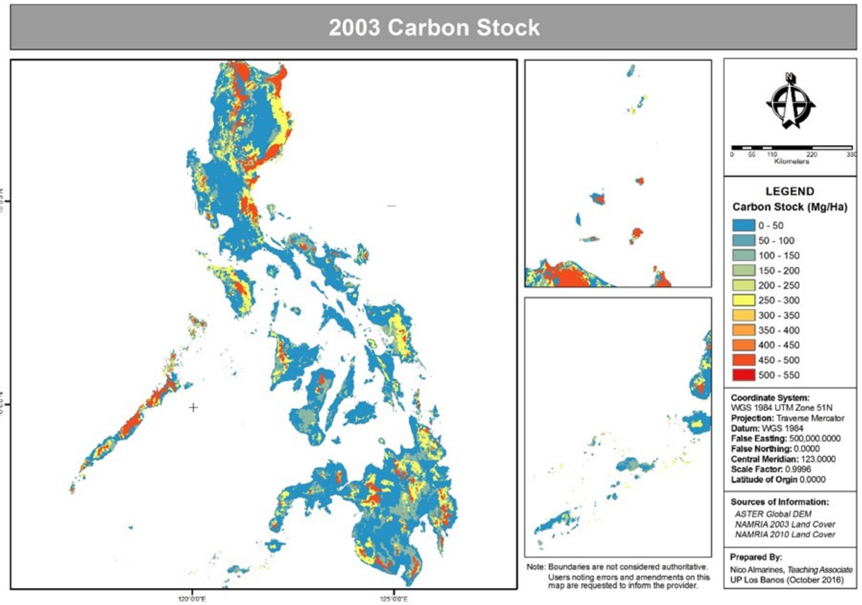

Figure 1. Map of 2003 carbon density in AFOLU as computed by the InVEST model

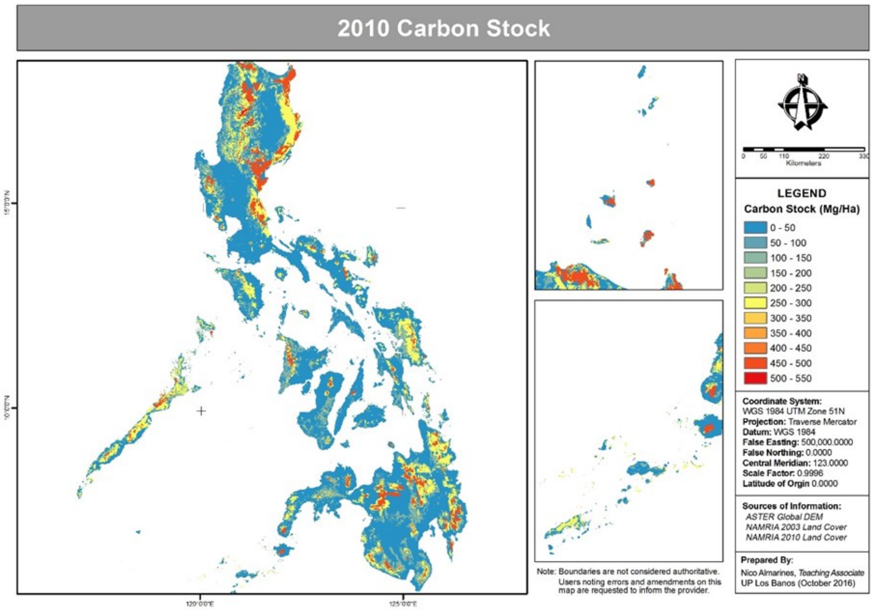

Figure 2. Map of 2010 carbon density in AFOLU as computed by the InVEST model

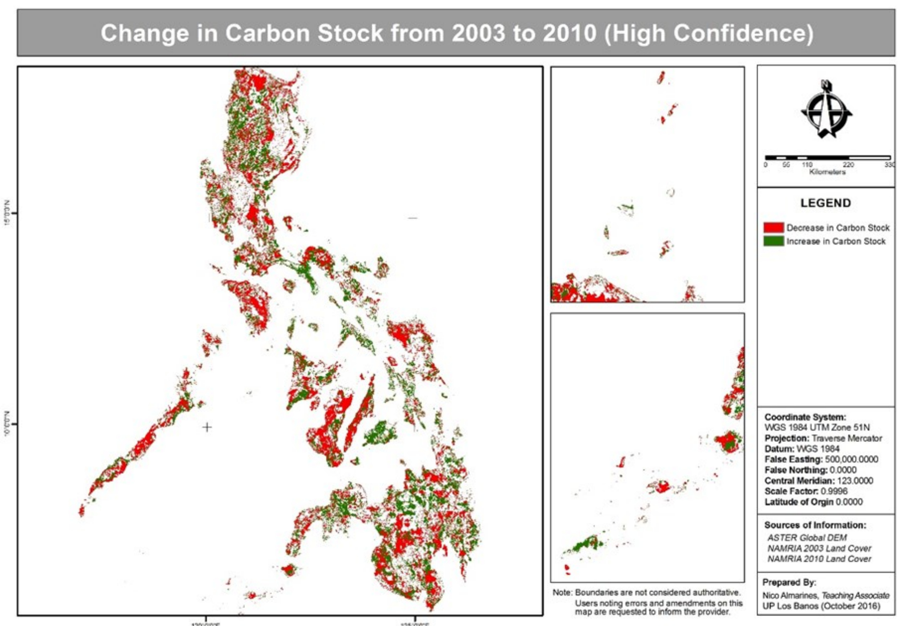

Figure 3. Map of changes in AFOLU carbon stock from 2003–2010 in confide cells only

Table 7. Uncertainty statistics of the value of carbon lost due to changes in land cover.

Scenario	Sequestered carbon (Mg C)		Net present value (PhP)	
	Mean	Standard Deviation	Mean	Standard Deviation
Market Price	–246,425,469.70	33,758,344.71	–311,134,924,223.95	42,623,029,332.39
SCC 3% Average	–246,425,469.70	33,758,344.71	–1,017,426,478,886.17	139,379,398,700.69
SCC 3% 95th Percentile	–246,425,469.70	33,758,344.71	–3,026,818,313,563.26	414,650,223,161.61

estimated cost using the average social cost of carbon at 3% discount rate is approximately PhP 878.05 billion to PhP 1,156.81 billion. To account for possible higher than expected impacts from climate change, a cost estimate using the 95th percentile social cost of carbon at 3% discount rate was also computed and is estimated to be about PhP 2,612.17 billion to PhP 3,441.47 billion. This equates to estimated losses of around PhP 44.45 billion to PhP 430.18 billion per annum, or an annual loss equivalent to between 16.4% to 163.2% of the country's Gross Domestic Product (GDP) in 2013.

While the results of the study provide a rough approximation of the impacts of the AFOLU sector to the value and spatiotemporal dynamics of carbon storage in the country, its general findings show the importance of effective carbon management as a necessary strategy to minimize losses in the AFOLU sector. This essentially needs to be site specific and requires an understanding of the underlying effective AFOLU carbon management should be able to prioritize high impact projects in the forestry subsector due to its significant contribution to both emissions and sequestration in a national scale. Changes in forest land uses contributed more than 65% of the carbon lost in AFOLU from 2003–2010. The conversion of closed forests to open forests was also the single highest contributing land conversion category to the loss in carbon storage, comprising almost a fourth of the total AFOLU emissions. Conversely, over half of the local increases in carbon storage is attributed to the forestry subsector. This subsector has considerable potential for carbon storage and sequestration due to the high biomass density of forest ecosystems and the relatively long turnover rate of woody biomass. Hence, high impact projects should be able to: 1) prevent the release of stored carbon by: a) preventing conversion of forest areas to other land uses, and b) protecting forest areas from activities that reduce forest carbon density and release stored carbon into the atmosphere; 2) increase carbon storage potential by: a) expanding the land area of forests onto low density land uses, and b) enhancing the carbon assimilation in current stands; and 3) address underlying factors that drive land conversion at the outset.

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