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CARBON DIOXIDE (CO2) STORAGE AND SEQUESTRATION IN THE LEYTE GEOTHERMAL RESERVATION, PHILIPPINES

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ABSTRACT

The study estimated the existing stored carbon (C) and rate of sequestration by vegetation that can potentially serve as sink for the carbon dioxide emitted from eight geothermal plants in Leyte Geothermal Reservation, Philippines. For the 20,438 ha watershed in the vicinity of the power project, the total C storage is 3.84 Mt C (14.10 Mt CO_2) while C sequestration based on biomass change was 47.35 Kt C (173.77 Kt CO_2). Relative to power plant emission, the C stored in the reserve is equivalent to more than 22 years of CO_2 emission. Annual C sequestration is 27% of CO_2 emission per year. For the next 25 years, two scenarios were projected. Under Scenario I ("Business as usual"), the forest reserve will be able to store and sequester more than 32 years of CO_2 emission from the power plants. Under Scenario II (Accelerated Reforestation), the reserve can store and sequester about 34 years of CO_2 emission

In addition, the rate of C sequestration based on biomass change in vegetation was recorded to assess the optimum land use that can absorb the carbon dioxide emitted by the power project. These are as follows*:* tree plantations (10.09 tC/ha/yr) > coconut (4.78 tC/ha/yr) > brushland (4.29 tC/ha/yr) > natural forest (0.92 tC/ha/yr).

In terms of cost, the power project operator is spending P 1.22 per t CO_2 (P4.4 or /US$ 0.12 per tC) for every year of C storage and sequestration. For 25 years, the total cost is P 30.40 per tCO_2 (P 111.5 or/US$ 2.94 per tC) which is comparable to the cost of C offset in other tropical countries.

1. INTRODUCTION

Climate change or global warming due to the rise in greenhouse gases, primarily carbon dioxide (CO_2), is one of the most urgent global problems.. The uncontrolled emission of greenhouse gases (GHGs) if not addressed properly can cause irreversible and disastrous damage to the whole biosphere. Rising concentration of GHGs in the atmosphere could lead to a change in energy balance and consequently the world's climate. Among anthropogenic GHGs, CO_2 is the most abundant and is responsible for more than half the radiatiion associated with the greenhouse effect (Solomon and Srinivasan, 1996).

One of the options being considered to mitigate the rise of CO_2 in the atmosphere are tropical forest conservation and establishment (Brown et al., 1996; Trexler and Haugen, 1994; Frumhoff et al., 1998). This is because of the ability of forests to absorb carbon in the biomass. In the Philippines, the role of forest land cover in the national C budgets has been quantified by previous studies (Lasco, 1998; Lasco and Pulhin, 1998; Lasco and Pulhin, 1999 and Lasco et al., 1999). Information on C stocks and fate of C sequestration of specific land cover is still lacking. This study addresses this data gap.

The PNOC is managing a largely forested watershed as part of its geothermal reserve in Leyte. The World Bank awarded the PNOC-EDC Leyte geothermal project a Global Environmental Facility (GEF) grant to conduct a study on the CO_2 absorption capacity of the vegetation cover in the study area.

2. OBJECTIVES OF THE STUDY

The main objectives of the study were to (a) estimate quantitatively the carbon (C) stocks and the rate of C sequestration of the different vegetative cover in the Philippine National Oil Canopy (PNOC) geothermal reservation in Leyte, and (b) determine whether the CO_2 emissions of the geothermal power plants could be offset by C stored in the vegetative cover and soil. It is envisioned that the forest vegetation in the reservation will serve as carbon sink that will offset the C emission of the geothermal power.

3. MATERIALS AND METHODS

The study was conducted from April 1998 to June 1999 in the 20,438 ha watershed area inside the PNOC geothermal block located in the island of Leyte, Philippines. The newly-constructed geothermal power plants in the site have a current generating capacity of 640 MWe emitting 644,389 tCO_2/yr.

Five vegetative cover were studied: natural forests, forest plantations, bush/shrublands, mixed agriculture farms and grasslands. The following major C pools were measured: a) above-ground biomass, b) below-ground biomass, c) litter, .and d) soil. For natural forest stands, ten 10m by 100m transects were laid out in forest areas representing the range of forest conditions in the forest reserve primarily elevation. Complete enumeration of all trees (≥ 10 cm dbh) was conducted in each transect. For each tree, the following data were obtained: a) species name, dbh (stem diameter at 1.3m above the ground), b) total height, and c) height of first branch. Tree biomass was computed using the following allometric equation (Brown, 1997):

(1) $Y = \exp\{-2.134 + 2.530*\ln(D)\}$

where: Y = biomass per tree (kg) and D = dbh (cm).

For understorey vegetation (saplings and seedlings ≤ 10cm dbh), three 1m x 1m plots were randomly laid out in each transect. All individual trees and woody species were harvested. Fresh weight of leaves, branches and stems were determined in the field. Oven dry weight of the different plant parts and wood density were determined in the laboratory. Carbon contents of plant tissues were analyzed. Herbaceous vegetation were collected in three 2m by 2m plots randomly scattered in each transect. The fresh weight, oven dry weight and C contents were determined. C stored in the litter layer on the forest floor was obtained by randomly laying out 50cm by 50cm frame at 5 locations in each transect. Fresh weight, oven dry weight and C content were determined. Root biomass was estimated by digging three 100 x 100 x 50cm pits in each transect. All roots in the pit were collected and weighed. Oven dry weight and C content were determined in the laboratory. Soil samples were collected from the same pits where the roots were taken. Soil organic C (SOC) and bulk density were analyzed in the laboratory. The total C stored by the forest ecosystem was determined by adding the C in the biomass, litter and soil.

The above-ground tree biomass measurements were conducted twice: at the beginning and towards the end of the study to be able to estimate C sequestration per year. It was assumed that litter biomass and soil organic C will remain unchanged during the observation period.

Brushlands are areas with relatively open canopy and shrub species predominate with a few scattered trees. A similar methodology as described for natural forests was used for brushlands. Ten 10 by 10 m plots were established in representative brushland areas in the forest reserve. C storage and sequestration of above ground biomass, below-ground biomass, litter and soil was estimated following the same procedure outlined above.

Three 10 x 10 m plots were laid out in each of the following plantation species established by PNOC in the reserve: *Gmelina arborea*, *Swietenia macrophylla* and *Acacia mangium*. C storage and sequestration were determined following the same procedures as above.

Two swards were identified in the grassland area. Of the two swards, cogon (*Imperata cylindrica*) occupies a relatively large space within the geothermal block. Old and young swards of talahib (*Saccharum spontaneum*) occupy small patches usually found along roadsides Two 2m x 2m plots were marked and divided into eight 1m x 1m subplots for quarterly sampling. Aboveground (shoot) and underground parts (rhizomes and roots) were collected for the determination of total dry matter, dead shoot dry weight, rhizome-to-total dry matter ratio, and carbon content. Shoot growth rate was determined from a separate sampling plot.

For wetland rice, three sites were selected for the wet season but only one site was available during the dry season. Three 2m x 2 m plots were marked in each study site for the determination of total dry matter and partitioning, and carbon content.

For banana, two study sites representing slightly contrasting light environments were chosen. A small block of 4 clumps was marked in each site for non-destructive estimation of dry matter. Additional clumps, however, were marked later to replace typhoon-damaged clumps. Total dry weight of each clump was recorded as the sum of the dry weight of individual plants in the clump.

For coconut, two sites were marked for the study. A block of 4 nut-bearing palms and another block of 3 juvenile palms were marked in each study site for non-destructive determination of dry matter and carbon content. Dry weight of the trunk was calculated using the formula adopted from Friend and Corley (1994) .

Root dry weight was not determined. Hence, total plant dry weight (TPDW) herein recorded refers to the sum of the dry weight of aboveground parts.

All plant tissue samples were brought to the Analytical Service Laboratory of the International Rice Research Institute (IRRI) in Los Banos, Laguna where duplicate laboratory analyses for carbon were carried out.

The total costs incurred by PNOC in protecting, maintenance and rehabilitation of the forest reserve was determined. The total cost was divided by the total C stored in the forest reserve to arrive at the cost per C sequestered.

4. RESULTS AND DISCUSSION

4.1 Carbon Storage of Various Land Cover

Table 1 presents the results of C analysis. Total mean C storage in the natural forests of the study area amounts to 393 t/ha (Table 1). These are almost equally divided into the biomass (51 %) and the soil (49 %). The findings are in agreement with those reported in literature where the soil has been found to store at least 30% of total forest C or as much as the biomass (Muora-Costa, 1996 and Lugo and Brown, 1993). Soil organic carbon (SOC) is important because it has the longest residence time among the organic C pools in the forest (Lugo and Brown, 1993 and IGBP Terrestrial Carbon Working Group, 1998). The soil values of this study is reasonable considering that forest soils up to 1 m depth in Venezuela, Papua New Guinea and Colombia could have up to 300 tC/ha (Lugo and Brown, 1993). The total C storage obtained in this study is much higher than earlier estimates for tropical forests in Mt. Makiling, Luzon island (255 tC/ha) and Mindanao island (262 tC/ha) (Lasco *et al*., 1999; Lasco and Pulhin, 1999). The Mindanao data however did not include SOC.

As shown in table 1, three plantation species were monitored in this study: *Sweitenia macrophylla*, *Gmelina arborea*, and *Acacia mangium*. Tree plantations store 192-294 tC/ha (mean = 254 tC/ha) with A. *mangium* having the highest C storage. This is higher than reported values for tree plantations in Mindanao with a mean of 124 tC/ha (Lasco and Pulhin, 1999) because the latter does no include SOC.

C density of brushlands is equal to 186 tC/ha (Table 1). Of this amount, a greater portion (82.7 %) is found in the soil. This could be attributed to the lower vegetative cover compared to forested lands.

Undisturbed *I. cylindrica* swards store about 4.7 – 12.1 tC/ha with a mean of 8.5 tC/ha, 60% of which was stored in the aboveground tissues. Accidental fire or deliberate burning will release the carbon stored in the tissues back to the atmosphere. The remaining 40% was stored in the modified stems (rhizomes), a fraction of which might have been metabolized *in situ* or re-translocated to the growth points of emerging young shoots.

The carbon storage capacity of *S. spontaneum* was greater than that of *I. cylindrica*. Undisturbed swards stored 7.7 – 20.9 t C/ha (mean= 13.1). Similar to imperata, the shoots stored greater amount (87.5%) of carbon than the roots. Hence, *S. spontaneum* has more C per unit ground area to release back to the atmosphere in case of accidental or deliberate burning.

The average grasslands have a C density of 10.8 t/ha . The results of the study is consistent with the IPCC (Intergovernmental Panel on Climate Change) default value of 10 t/ha of dry matter for crop lands and pasture lands (Houghton , 1997).

The C storage capacity of wetland rice in the project area ranges from 1.9 to 4.4 t C/ha/crop cycle or an average of 3.1 t C/ha/crop cycle. The C storage capacity of banana 114.72 tC/ha (Table 1). While the carbon storage capacity of nut-bearing coconut palms is 197 tC/ha.

The total C storage of the geothermal reserve is calculated to be 3.84 MtC which is equivalent to 14.10 Mt of CO_2 (Table 1). This is about 22 times the annual CO_2 emission from the 653.5 MWe geothermal power plants. Thus, by conserving the C stored in the reserve, the PNOC is preventing the release of CO_2 equivalent to about 22 years operation of the power plants.

4.2 Carbon Sequestration Potential of Various Land Cover

Table 2 presents the C sequestration of plants in the geothermal reserve. Based on biomass accumulation, the C sequestration rate of natural forests is equal to 0.92 tC/ha/yr (Table 2). This is a little lower than the earlier estimate of 1.5 t/ha/yr for Philippine forests (Lasco and Pulhin, 1998).

As expected, fast-growing tree plantations accumulated C faster than natural forests. Mahogany plantations have a C sequestration rate of 3.28 t/ha/yr (Table 2). Mangium plantations accumulate C at the rate of 18.77 t/ha/yr which is much higher than the other plantations species. Gmelina plantations have a C sequestration rate of 15.45 t/ha/yr. Overall, tree plantations have an average sequestration of 10.01 tC/ha/yr.

Brushland areas have a C sequestration rate of 4.29 t/ha/yr . It has been conservatively assumed that grasslands have a net zero sequestration because of regular burning prevents natural succession from proceeding. However, the potential of grassland areas lies in transforming them to either of the following: natural forest through natural succession, tree plantation or agroforestry farm.

Among all the agricultural farms, only coconut actively sequesters C being a woody perennial. For the annual and non-woody crops such as rice and banana no sequestration is expected because their biomass remain more or less constant.

For the whole study area, the total C sequestration rate based on biomass change is equal to 47 MtC/yr which is equivalent to 174 $MtCO_2$/yr. This is 27 % of total annual CO_2 emission (644,389 t) of the geothermal power plants. This implies that to sequester all of the emission in one year, an area 3.7 times the same reserve is needed, i.e., about 75,696 ha. Since the PNOC is maintaining more than 100,000 ha area of geothermal reserve in Leyte, this area is likely to be more than sufficient to sequester the annual C emission of the power plants.

The determination of C sequestration rate was constrained by the duration of the study. Ideally, biomass change should be observed for a number of years to increase accuracy. For the same reason, change in SOC was not monitored since this requires a long period of time. However, it is expected that soils in areas that are recovering from disturbance such as reforestation/tree plantations and brushlands are accumulating SOC. This could range from 0.3 to 2 tC/ha/yr in the tropics (Lugo and Brown, 1993). If this is true for the Leyte study area, then the estimated C sequestration rate is still very conservative.

4.3 Future C Storage and Sequestration Rate

<u>Scenario I: "Business as Usual"</u>

This scenario assumes that the reserve is being managed based on present trends and management input, i.e. the various land uses and their respective land area is to essentially maintained throughout the 25-year life of the power plants as well as their C sequestration rates. This scenario also takes into account the PNOC plan to reforest 200 ha per year of grasslands and brushlands. Under this scenario, the forested areas, brushlands and coconut plantations will account for most of the increase in annual sequestration rates.

At the end of 25 years, total C storage will be 5.61 Mt C equivalent to 20.6 Mt CO_2. Thus, the amount of C stored in the biomass 25 years hence will be equal to 32 years of plant operation. This implies that by simply letting natural process takes its course through adequate forest protection supported by a modest reforestation program, PNOC could conserve more than enough C to offset all of its C emission from the power plants.

<u>Scenario II: Accelerated Reforestation</u>

An alternative scenario is to accelerate the reforestation activities in grassland and brushland areas so that all of them are under tree plantation cover within about 10 years. The other landuses are assumed to remain constant. Under such a scenario, the study area will be able to increase C storage to 6.02 MtC at the end of the 25-year period equivalent to 22.10 tCO_2. This is comparable to 34 years of plant operation.

Many other scenarios could be envisioned involving various levels of management input. The purpose of the above is simply to illustrate how C storage will change over time under a given scenario.

4.4 Cost of Carbon Storage and Sequestration

At present, the total forest management cost of the reserve is P 17,601,400 per year. In one year's time, the total C in the entire reserve is equal to the sum of C stored at the beginning plus the total C sequestered for the year. For 1999, this amounts to 3.94 Mt C (or 14.47 Mt CO_2). Thus, the cost of a unit of CO_2 stored and sequestered in one year is P 1.22 per t CO_2 (P 4.46 per tC). Assuming the same cost of maintenance, it will cost P 30.40 to keep a ton of CO_2 for 25 years (P 111.58/ or S$ 2.94 per tC).

This unit cost is relatively cheap compared to Thailand where a teak plantation costs US$ 13-26 per tC (Brown *et al*., 1996). However, in most other tropical countries the cost of C offset projects is estimated to be US$ 2-4 per tC (Dixon *et al*., 1993) which is consistent with the results of the study.

5. CONCLUSIONS AND RECOMMENDATIONS

The results show that while the study area cannot absorb all the annual CO_2 emission of the power plants, the amount of C stored in the biomass of the reserve as well as the C to be sequestered for 25 years will more than offset the total C that the power plants will emit in 25 years. Thus, the PNOC-EDC operation in Leyte will not exacerbate the problem of global warming.

To sustain the stored C and the sequestration capacity of the geothermal reservation vegetation, it is important for the project operator to: a) pursue protection of existing natural forests and plantations, b) to manage reservation settlers in place and provide them livelihoods to prevent encroachment of forests, c) to reforest brushlands and grasslands, and d) to encourage the revegetation of built-up areas.

Plant species of higher C sequestration indices can be screeened for each land use so that those with greater capacity to absorb C can be prioritized in planting activities.

A land use master plan in consultation with the stakeholders with bias towards vegetation establishment that can serve as carbon sink can be formulated.

An inventory of the natural and anthropogenic sources of carbon dioxide inclusive of geothermal plants can be conducted by government to determine the total C sink requirement so that responsible parties can be assigned to revegetate areas equivalent to their emissions. Thus, while PNOC as administrator of the reservation shall maintain the stored C in existing natural forests, the incremental C sink required for the geothermal plants and other industries can come from reforestation quota of the project proponent.

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Table 1 Total C storage of the Leyte geothermal reservation

Land use	C density (t/ha)	Area (ha)	Total C Stored (t)
Forests	392.96	4672.0	1835925.9
Shrubs/Brushlands	186.31	5304.0	988213.2
S. macrophylla plantation	192.09	15.0	2881.3
A. Mangium plantation	275.42	122.0	33601.7
G. arborea plantation	294.16	58.0	17061.1
Grasslands	10.79	2988.0	32240.5
Coconut	196.75	3657.0	719496.5
Rice	3.11	1811.0	5635.75
Abaca/Banana	114.72	1811.0	207759.7
Total		20438.0	3842815.7
Total CO_2 equivalent			14103133.5

Table 2 Total C sequestration based on biomass change of the Leyte geothermal reserve

Land use	C Sequestration (t/ha)	Area (ha)	Total C Sequestration (t/yr)
Forests	0.92	4672.0	4298.2
Shrubs/Brushlands	4.29	5304.0	22754.2
*S. macrophylla p*lantation	3.28	15.0	49.2
A. mangium plantation	18.77	122.0	2289.9
G. arborea plantation	8.21	58.0	476.2
Grasslands	0.00	2988.0	0.0
Coconut	4.78	3657.0	17480.5
Rice	0.00	1811.0	0.0
Abaca/Banana	0.00	1811.0	0.0
Total		20438.0	47348.2
Total CO_2 equivalent			173767.8

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