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Vegetation diversity and carbon stock in gold mining reclamation area in Pongkor, West Java, Indonesia

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Abstract. *Habib S, Karuniasa M, Setyaningsih L. 2025. Vegetation diversity and carbon stock in gold mining reclamation area in Pongkor, West Java, Indonesia. Biodiversitas 26: 4932-4945.* Global greenhouse gas emissions set a new record of 57.1 $GtCO_2e$ in 2023, an increase of 1.3 percent from 2022 levels. One of the efforts to mitigate carbon dioxide emissions in the mining industry can be done by reclaiming ex-mining land through revegetation. The objective of study was to analyze vegetation diversity and carbon dioxide absorption in the reclamation area of gold mining in Pongkor, West Java Province, Indonesia. The method used for this study was quantitative observation by measuring the number of species, density, frequency and growth of vegetation to calculate diversity index (H'), vegetation biomass and its ability to absorb carbon in the post-mined area reclaimed from 2014 to 2023 covering an area of 21.6 ha. The results of the study showed that the Shanon-Wiener diversity index (H') of tree, pole, sapling and lower-level plant was in the moderate category ($1<H'<3$). The reclamation area of 21.56 ha was able to absorb carbon dioxide cumulatively of 3,237.98 tons or contributed 5.89% of CO_2 emissions by the mining company. Reclamation in the gold mining area is able to restore the ecology of vegetation and absorb carbon dioxide emissions generated from mining activities. However, 10 years of reclamation and revegetation activities still does not offset carbon emissions resulted from the mining activities, suggesting a longer period of restoration with strong monitoring efforts to fully compensate the carbon footprint.

Keywords: Carbon sequestration, emission, greenhouse gas, Indonesian Standard National Number 7724 of 2019, mining

INTRODUCTION

Since the industrial revolution, the Earth's surface temperature has been warming because of the continuing increase of greenhouse gases (GHGs) concentration due to human activities to meet economic and development interests (Fua et al. 2019; IPCC 2023). In 2023, global GHG emissions was 57.1 $GtCO_2e$, increased 1.3% compared to 2022 (UNEP 2023). These emissions are caused by the uses of fossil energy, industrial activities, transportation, and changes in forestry and other land uses. Deforestation and forest degradation result in between 10 and 15% of global greenhouse gas emissions (Pratiwi et al. 2021; Han et al. 2022; Quispe et al. 2024).

Reducing carbon emissions in combination with increasing carbon sink capacity and improving environmental quality are essential for building green and low-carbon economies (Chen et al. 2024). Reducing emissions from the forestry and other land uses can be contributed from mining sector by maximizing CO_2 absorption and managing carbon storage in reclaimed areas (Ministry of Environment and Forestry of Republic of Indonesia 2022). Mining sector has been a major concern in public policy and economic development for several years. Mining causes various ecological problems at the landscape level, resulting in the loss of vegetation cover, soil degradation and toxic soil due to tailings stockpiling activities. To mitigate the ecological impacts of mining activities, post-mined area can be restored to rebuild the degraded ecosystem as well as to sequester carbon to achieve the 13th sustainable development goal (Zhang et al. 2021; Serafimova and Dedelyanova 2024; Setyaningsih 2024). In doing so, land reclamation and revegetation must be carried out to recover the vegetation and soil (Timsina et al. 2021; Hartati and Sudarmadji 2022; Shi et al. 2023; Zhou et al. 2024). Efforts such as increasing soil pH levels, increasing ground cover species and planting native species can restore fragile ecosystems caused by mining operation (Ahirwal et al. 2020; Banerjee et al. 2021; Milkias et al. 2022).

Tropical forests as terrestrial ecosystems are important component in the Earth system as they comprise a great level of biodiversity (e.g., 63% of the world's tree species) and store the largest amount of carbon stock. When mining operation occurs in tropical forest, reclamation using local and native plant species is prioritized to restore ex-mining land in a sustainable manner (Pratiwi et al. 2021; Xiang et al. 2022; Wos et al. 2024). Climate change mitigation in the mining industry can be done by increasing carbon stocks stored in vegetation biomass, one of which is through planting local species with fast-growing properties (Pietrzykowski 2019; Jinman et al. 2024). Nonetheless, the amount of carbon stock varies among locations, depending on the diversity and density of vegetation, soil type and management method (Ananda and Sutrisno 2022).

In Indonesia, the highest contributors to GHG emissions are from deforestation and forest degradation (Alviya et al. 2021). Indonesia is committed to reducing GHG emissions by 31.89% in 2030 through its own efforts (unconditional) and by 43.2% with international supports (conditional) compared to Business as Usual (BAU). The target to reducing emissions from the forestry and other land uses (so called FOLU) is 60% with a calculation of 500 MtonCO_2e (17.4% of the target of 31.89%) or 54.7% of the overall sector target (915 MtonCO_2e) with own efforts and 729 MtonCO_2e (25.4% of the target of 43.2%) or 58.7% of the overall sector target (1,240 MtonCO_2e) with international supports (Ministry of Environment and Forestry of Republic of Indonesia 2023).

Reclamation programs are very important in mitigating greenhouse gas emissions. There have been several studies which looking at vegetation diversity and carbon sequestration generated from post-mining activities in Indonesia. For example, Farosandi et al. (2024) reported that 10 years old vegetation composed by 14 trees species in post-mining reclamation area of open coal mining in PT Berau Coal, Berau, East Kalimantan, Indonesia, was able to store carbon 0.53-60.3 $MgHa^{-1}$ and absorption of CO_2 1.95-221.32 $MgHa^{-1}$. Similarly, Ahirwal and Maiti (2017) reported that after 14 years of revegetation of a large open cast coal project in Central Coal Fields Limited in Jharkhand, India SOC concentrations increased 3 fold, and total ecosystem C sequestered increased from 30-333 Mg CO_2 Ha^{-1} with an average rate of 6.4 $MgCHa^{-1}year^{-}$.

This study aims to analyze vegetation diversity and carbon dioxide absorption in the reclamation area of a gold mining company in Pongkor, West Java, Indonesia. The company has carried out post-mining land reclamation activities which included local and non-local plants with a planting distance of 2x2 meters. Initial observations showed that the growth rate and diameter of local plants grew faster than non-local plants, which is a promising start to study further regarding its capacity in carbon sequestration. Further, this study analyzes the correlation between vegetation diversity and carbon sequestration from upper plants (trees, poles, saplings), and understorey. The research was conducted using a quantitative method to answer the first research objective (i.e., vegetation diversity analysis) and the second research objective (i.e., carbon dioxide absorption analysis). The hypotheses of this study are: (i) Vegetation diversity in the mine reclamation area is correlated with vegetation density; (ii) The use of local plants (fast growing and slow growing species) has a higher impact on carbon dioxide absorption than non-local species (fast growing and slow growing species) for mine reclamation.

MATERIALS AND METHODS

Research location

This study was conducted in the area of PT Aneka Tambang (Persero) Tbk. Gold Mining Business Unit Pongkor, West Java, Indonesia (Figure 1). The research was conducted in Nanggung Sub-district, Bogor District, West Java, with coordinates 106°31'57.000"-106°33'40.200"E and 6°39'3.400"-6°39'37.400"S. Annual rainfall ranges from 3,500 to 4,000 mm, with an average monthly temperature between 24.7°C and 26.3°C, and an elevation ranging from 400 to 800 m asl. The research was carried out at the post-mined area reclaimed from 2014 to 2023 which had a total extent of 21.56 hectares.

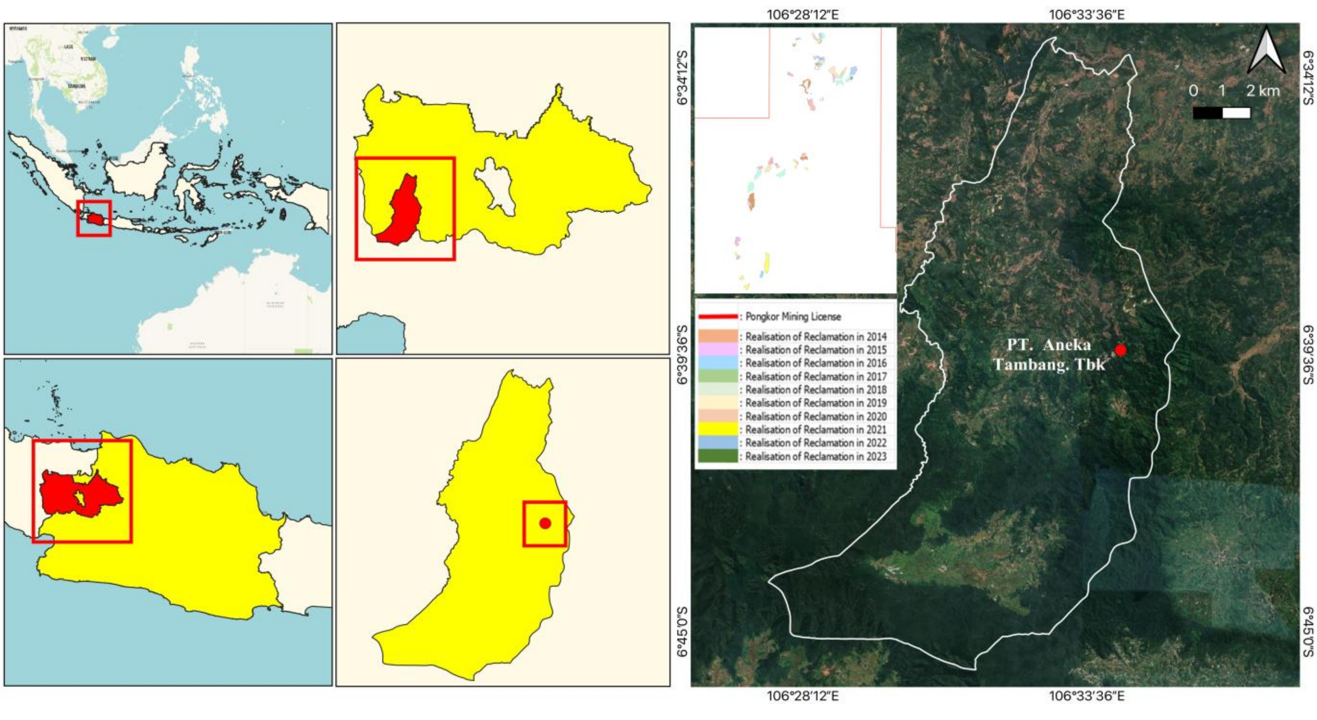

Figure 1. Map of research location in a gold mining company in Pongkor, West Java, Indonesia, showing area reclaimed in 2014-2023

Research procedure

Population and sample in the mining reclamation area

The vegetation sampled in this study was located in the reclaimed area from 2014 to 2023. The samples were determined using non-probability sampling with the purposive sampling technique, which is a selection technique based on the researcher's consideration to obtain more representative data (Creswell 2014). The sampling technique chosen was stratified systematic sampling or simple random sampling with a maximum sampling error tolerance of 20% (Indonesian Standard National Number 7724 of 2019). As many as 23 plots were established to represent the reclaimed area of 21.56 hectares with size of each sample plot was 400 m^2 (20 meters x 20 meters).

The tools used in the study were the Global Positioning System (GPS), meters, sticks, label paper, sewing meters, hypsometer bags, plastic bags, digital scales, and ovens. The material used in this study was vegetation in the reclamation area with ages 1 to 10 years.

Vegetation sampling

Data on vegetation was collected through direct observation and field measurements. The measurement used non-destructive method on upper vegetation (i.e. sapling, poles and trees) and destructive method on lower vegetation (understory). Sampling plot with size 20x20 m was used to measure trees (diameter of ≥20 cm), while within this plot, nested plots were created with size 10x10 m to record poles (diameter of 10 cm to <20), size 5x5 m to record sapling (diameter of 2 cm to <10) and size 1x1 m to record seedlings and understory (Indonesian Standard National Number 7724 of 2019) (Figure 2).

Data analysis

Vegetation diversity

Vegetation data was analyzed using quantitative method to produce the Important Value Index (IVI) (Soerianegara and Indrawan 1998) using the equations below:

$$\text{Density (D)} = \frac{\text{Number of individuals of a species}}{\text{Plot area}}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of a species}}{\text{Density of all species}} X\ 100\%$$

$$\text{Frequency (F)} = \frac{\text{Number of plot with the presence of a species}}{\text{Total number of plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} X\ 100\%$$

$$\text{Dominance (D)} = \frac{\text{Base area of a species}}{\text{Plot area}}$$

$$\text{Relative Dominance (RDc)} = \frac{\text{Dominance of a species}}{\text{Dominance of all species}} X\ 100\%$$

$$\text{Tree and Pole Important Value Index (IVI)} = \%RD + \%RF + \%RDc$$

$$\text{Sapling and Undergrowth Important Value Index (IVI)} = \%RD + \%RF$$

The level of vegetation diversity (H') was measured using the Shannon-Wiener diversity index (Odum 1993) with the following formula:

$$H' \sum_{i=1}^{s} (pi)(\ln pi)$$

Where, H': Shannon-Wiener Diversity Index (H'<1: low, 1<H'<3: medium, H'>3: high); S: Number of plant types; ni: Density of type i; N: Total density

Carbon dioxide absorption

The carbon dioxide absorption value was obtained from several carbon pools (Purnawan 2016) and calculated by the following formula

$$CO_2 \text{ absorption per plot} = \text{Carbon stock of each plot x } 3.67$$

$$\text{Total } CO_2 \text{ absorption} = \text{Total area x total } CO_2 \text{ absorption per plot}$$

The calculation of carbon stock of each pool was described as follow:

Carbon of sapling, poles and trees:

$$Bov = v \times BJ \times BEF$$

$$Cv = Bov \times \%C$$

Where, Bov: Total biomass of sapling, poles and trees (kg); V: Volume of branch-free wood in cubic meters (m^3); BJ: Specific gravity of wood (kg/m^3); BEF: Biomass Expansion Factor (3.4); Cv: Carbon stock (kg); Bov: Total biomass of sapling, poles and trees (kg); %C: Percentage of carbon content (0.47).

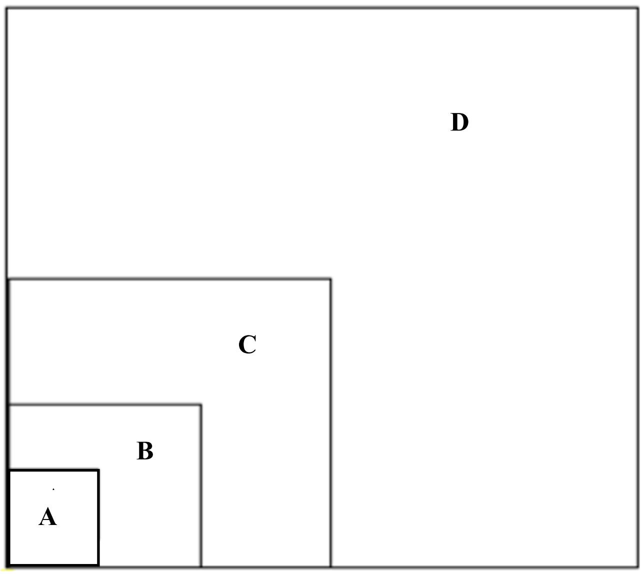

Figure 2. Diagram of sampling plot to document vegetation at understory, sapling, pole and tree levels

Carbon of understory plants:

$$Botb = (Bks \times Bbt)/(Bbs)$$

$$Ctb = Botb \times \%C$$

Where, Botb: Total biomass of understory plants (kg); Bks: Dry weight (kg); Bbt: Total wet weight (kg); Bbs: Wet weight (kg); Ctb: Carbon stock of understory plants (kg); Botb: Total biomass of understory plants (kg); %C: Percentage of carbon content (0.47)

Carbon of roots:

$$Boav = NAP \times Boap$$

$$Cav = Boav \times \%C$$

Where, Boav: Total root biomass (kg); NAP: Root ratio value; Boap: Total biomass above the surface (kg); Cav: Carbon stock of root (kg), Boav: Total biomass of roots (kg); %C: Percentage of carbon content (0.47).

Carbon of dead trees:

$$Vpm = \frac{1}{4}\pi \left(\frac{dbh}{100}\right)\left(\frac{dbh}{100}\right) x\ t\ x\ f$$

$$Bopm = Vpm \times BJpm$$

$$Cpm = Bopm \times \%C$$

Where, Vpm: Dead tree volume (m^3); dbh: Diameter at breast height at 1.3 m of dead tree (cm); t: total height of dead tree (m); f: Form factor; Bopm: Total biomass of dead tree (kg); Vpm: Volume of dead trees (m^3); BJpm: Specific gravity of dead tree wood (kg m^3); Cpm: Carbon content of dead tree (kg); Bopm: Total biomass of dead tree (kg); %C: Percentage of carbon content (0.47).

Carbon of dead woods:

$$Vkm = 0{,}25\pi \left(\frac{dp+du}{2\ x\ 100}\right)^2 x\ p\ )$$

$$Ckm = Bokm \times \%C$$

Where, Vkm: Volume of dead wood (m^3); dp: Diameter of dead wood base (cm); du: Diameter of dead wood end (cm); p: Length of dead wood (m); π: 22/7 atau 3,14; Ckm: Carbon content of dead wood (kg); Bokm: Total biomass of dead wood (kg); %C: Percentage of carbon content (0.47).

Carbon of symbiomass:

$$Bos = (Bkt+Bbt)/Bbs$$

$$Cs = Bos \times \%C$$

Where, Boss: Litter biomass weight (kg); Bks: Sample dry weight (kg); Bbt: Total wet weight (kg); Bbs: Sample wet weight (kg); Cs: Carbon content of litter (kg); Boss: Total biomass of litter (kg); %C: Percentage of carbon content (0.47).

Soil carbon:

$$Ctm = Kd \times \rho \times \%C$$

Where, Ctm: Carbon content of dry mineral soil(g/cm^2); Kd: Sample depth of dry mineral soil (cm); ρ: Bulk density in (g/cm^3); %C: Soil carbon percentage value from laboratory analysis; Total carbon was calculated as the sum of all pools and presented as ton per hectare (tons ha^{-1}).

Statistical analysis

Pearson correlation test was used to investigate the relationship between dependent and independent variables. The dependent variables were carbon stock, carbon dioxide absorption and the independent variable is species diversity, growth, density of vegetation. Statistical analyses used Microsoft Excel.

RESULTS AND DISCUSSION

Vegetation diversity

Gold mining causes CO_2 emissions and other environmental impacts including water pollution and land degradation, so gold producers are seeking to adopt clean production solutions including through post-mining reclamation (Liang et al. 2019; Trench et al. 2023). The stages of reclamation process are land preparation, contour reorganization, topsoil spread, and ground cover planting, pioneer species planting and native species planting and maintenance (Sudarmadji and Hartati 2016; Setiawan et al. 2021).

Reclamation is one of the important processes in mining that can be evaluated from its carbon stock (Fauziah et al. 2021; Hutayanon and Somprasong 2021; Setiawan et al. 2021). In this study, the structure and composition of vegetation in the reclaimed area were analyzed at all levels of vegetation, including trees, poles, saplings, seedlings and understorey. The density (number individuals per hectare) of trees, poles, saplings and undergrowth in the reclamation area can be seen in Table 1.

Based on Table 1, the number of individuals in the reclamation area per planting location from 2014 to 2023 varied. The number of individuals at tree level vegetation is smaller compared to the level of poles, saplings and undergrowth. The number of species, frequencies and Shannon-Wiener diversity index at trees, poles, poles and understory levels at each reclamation area are presented in Table 2.

Revegetation activities in reclaimed land of former mines can maintain biodiversity through planting local tree species (Vachova et al. 2022). In this study, the succession was progressing which was marked by the previously barren land becoming covered with vegetation, so that the energy and food cycles occurred again and there will be ecosystem stability towards new forest reconstruction. The vertical strata formed with high biodiversity indicates that reforestation in mining areas has been successful, leading to the return of tropical rainforest ecosystems (Dendang and Handayani 2015; Setyaningsih 2023). Based on Table 2, the level of vegetation diversity index (H') at the tree, pole, sapling and undergrowth levels is greatly influenced by the number of species and the frequency of occurrences each species.

Table 1. Number of individuals at each vegetation level in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Year	Reclamation area	Trees (Individual ha^{-1})	Poles (Individual ha^{-1})	Saplings (Individual ha^{-1})	Understory plant (Individual ha^{-1})
1	2014	Ciladu	550	1,400	2,400	370,000
2	2014	Bantar Karet	675	1,300	2,400	370,000
3	2014	Cepak Puspa	475	2,900	3,200	310,000
4	2014	Cepak Puspa 2	450	1,100	2,800	160,000
5	2015	Quarry Bantar Karet	625	1,700	3,200	140,000
6	2015	Dam 1 Puspa	325	275	3,600	70,000
7	2016	Quarry Gunung Dahu 1	175	1,600	2,400	90,000
8	2016	Jalan Quarry Bantar Karet	225	2,000	3,200	160,000
9	2017	Gunung Dahu-Ciladu	200	1,600	3,200	100,000
10	2017	Top Soil Area Cepak Puspa	175	1,600	2,800	130,000
11	2018	Legok Geomin	350	2,500	2,800	130,000
12	2018	Eks Landfill Cepak Puspa	-	2,200	2,800	110,000
13	2019	Cepak Puspa Komp.1	-	-	2,800	50,000
14	2019	Bantarkaret Sidempok	-	1,200	2,800	110,000
15	2020	Double Track Pongkor	-	700	3,600	80,000
16	2020	Lamping Budin	-	200	3,200	110,000
17	2020	Belakang Pabrik	-	200	2,800	130,000
18	2021	Level .600 Ciurug	-	1,800	2,400	140,000
19	2021	Semen Silo	-	900	3,200	260,000
20	2021	Area Bukaan Pondok Batu	-	-	3,200	100,000
21	2022	Cikabayan Timur	-	-	2,800	110,000
22	2022	Batching Plant	-	-	3,200	120,000
23	2023	Cikabayan Timur 3	-	-	2,800	130,000

Table 2. Number of species, frequencies (F) and Shannon-Wiener diversity index (H') at all levels of vegetation in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Year	Reclamation area	Trees			Poles			Saplings			Understory		
			Species number	F	H'	Species number	F	H'	Species number	F	H'	Species number	F	H'
1	2014	Ciladu	7	22	1.83	5	14	1.51	2	6	0.64	6	37	1.50
2	2014	Bantar Karet	8	27	1.86	5	13	1.52	4	6	1.24	9	37	2.16
3	2014	Cepak Puspa	9	19	2.11	8	29	2.01	3	8	1.04	4	31	1.34
4	2014	Cepak Puspa 2	6	18	1.75	4	11	1.37	5	7	1.37	4	16	1.37
5	2015	Quarry Bantar Karet	6	25	1.70	4	17	1.32	6	8	1.32	8	14	1.97
6	2015	Dam 1 Puspa	4	13	1.22	3	11	1.22	5	9	1.22	3	7	1.08
7	2016	Quarry Gunung Dahu 1	3	7	1.08	4	16	1.07	5	6	1.07	5	9	1.52
8	2016	Jalan Quarry Bantar Karet	3	9	1.00	3	20	0.73	5	8	0.73	5	16	1.58
9	2017	Gunung Dahu-Ciladu	2	8	0.66	4	16	1.15	4	8	1.16	6	10	1.61
10	2017	Top Soil Area Cepak Puspa	2	7	0.60	4	16	1.14	3	7	1.15	8	13	2.03
11	2018	Legok Geomin	2	14	0.60	5	25	1.60	5	7	1.55	8	13	2.03
12	2018	Eks Landfill Cepak Puspa	-	-	-	2	22	0.62	5	7	1.48	5	11	1.47
13	2019	Cepak Puspa Komp.1	-	-	-	-	-	-	5	7	1.55	3	5	1.05
14	2019	Bantarkaret Sidempok	-	-	-	1	12	-	3	7	0.96	7	11	1.89
15	2020	Double Track Pongkor	-	-	-	1	7	-	5	9	1.43	6	8	1.73
16	2020	Lamping Budin	-	-	-	1	2	-	6	8	1.39	7	11	1.85
17	2020	Belakang Pabrik	-	-	-	1	2	-	3	7	0.96	7	13	1.84
18	2021	Level .600 Ciurug	-	-	-	1	18	-	2	6	0.64	8	14	1.82
19	2021	Semen Silo	-	-	-	2	9	0.62	3	8	0.90	4	26	1.18
20	2021	Area Bukaan Pondok Batu	-	-	-	-	-	-	5	8	1.49	7	10	1.49
21	2022	Cikabayan Timur	-	-	-	-	-	-	3	7	1.00	6	11	1.67
22	2022	Batching Plant	-	-	-	-	-	-	5	8	1.56	7	12	1.86
23	2023	Cikabayan Timur 3	-	-	-	-	-	-	4	7	1.28	6	13	1.41

Tree-level vegetation was only found in plots 1 to 11, where in plots 1 to 8, the species number of trees ranged from 2 to 9 with a frequency between 7 to 25 with a vegetation diversity index of 0.6 to 2.11 (low-medium category). There were 8 plots that fall into the H' medium category, namely plot 1 to plot 8 with the number of trees between 3 to 9 with a frequency between 7 to 27 per tree species. There are 3 plots that had low H', namely plots 9 to 11 with the number of trees only 2 and a frequency ranging from 7 to 14, resulted in an H' value of 0.6-0.66 (low).

Pole level vegetation was found in plots 1 to 12 and plots 14 to 19 (totaling 18 plots). For the poles in plots 1 to 12, the number of species ranged from 2 to 8 species with frequencies between 11 to 29 and diversity index of 0.62 to 2.01 (low-medium category). There were 5 plots that did not have a vegetation diversity index because only 1 species of pole was found (plots 14 to 18). Sapling-level vegetation was found in 23 plots with number of species ranged from 2 to 6 species and frequency ranging from 6 to 9 per species with diversity index of 0.64 to 1.56 (low-moderate). Undergrowth-level vegetation was found in 23 plots with number of species ranged from 3 to 9 and frequency of each species ranging from 7 to 37 and diversity index of 1.05 to 2.03 (moderate).

The Important Value Index (IVI) in tree-level vegetation was obtained from the sum of Relative Density (RD), Relative Frequency (RF), Relative Dominance (RD). The Important Value Index (IVI) of each species at tree, pole, sapling and undergrowth levels in the reclamation area from 2014 to 2023 are presented in Table 3.

Table 3. Important Value Index (IVI) of species at each vegetation level in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Species name	**Important Value Index (IVI) (%)**			
	Tree	**Pole**	**Sapling**	**Understorey**
Ganitri (*Elaeocarpus angustifolius* Blume)	102.40	154.50	70.14	-
Huru (*Litsea* sp.)	46.90	22.43	39.85	-
Jati putih (*Gmelina arborea* Roxb.)	71.50	67.00	44.06	-
Angsana (*Pterocarpus indicus*)	30.70	-	-	-
Mahoni (*Swietenia mahagoni* L. Jacq.)	32.30	54.43	57.77	-
Manglid (*Manglietia glauca* Blume)	40.50	59.64	83.30	-
Suren (*Toona sureni* Blume. Merr.)	35.60	27.73	34.06	-
Sengon (*Paraserianthes falcatria* L. Nielsen)	74.50	50.81	-	-
Puspa (*Schima walichii* DC. Korth.)	51.60	61.56	44.27	-
Rasamala (*Altingia excelsa* Noronha)	54.40	94.09	46.73	-
Ki kaya (*Khaya anthotheca* Welw. C.DC)	-	35.24	43.52	-
Huru bodas (*Litsea umbellata* Lour. Merr.)	-	79.74	-	-
Ki Sireum (*Syzygium lineatum* D.C. Merr & L.M Perry.)	-	67.30	38.40	-
Pulai (*Alstonia scholaris* L. R. Br)	-	10.11	34.29	-
Durian (*Durio zibethinus* Linn.)	-	31.69	-	-
Rambutan (*Nephelium lappaceum* L.)	-	-	35.42	-
Pasang (*Quercus argentata* Korth.)	-	-	34.29	-
Huru hiris (*Actinodaphne sphaerocarpa* Blume Ness)	-	-	37.69	-
Sengon Butho (*Enterolobium cyclocarpum* Jacq. Griseb)	-	-	34.29	-
Kayu Afrika (*Maesopsis eminii* Engl.)	-	-	29.80	-
Salam (*Syzygium polyanthum* Wight. Walp.)	-	-	62.93	-
Randu (*Ceiba pentandra* L. Gaertn.)	-	-	32.50	-
Jampang (*Eleusine indica* L. Gaertn.)	-	-	-	39.00
Anting-anting (*Acalypha indica* L.)	-	-	-	32.88
Belimbing tanah (*Oxalis barrelierli* L)	-	-	-	19.37
Selasih mekah (*Ocimum gratisimun* L. Linnaeus)	-	-	-	27.48
Jampang pait (*Digitaria sanguinalis* L. Scop.)	-	-	-	39.00
Putri malu (*Mimosa pudica* L.)	-	-	-	41.00
Jukut bau (*Hyptis suaveolens* L. Poit)	-	-	-	31.00
Babandotan (*Ageratum conyzoides* L.)	-	-	-	31.00
Pakis (*Diplazium esculentum* Retz. Sw.)	-	-	-	26.00
Areuy (*Trichosanthes tricuspidata* Lour.)	-	-	-	23.00
Ceker ayam (*Selaginella doederleinii* Hieron)	-	-	-	30.00
Talas hutan (*Colocasia esculenta* L. Scot.)	-	-	-	19.00
Jampang gewor (*Commelina benghalensis* L.)	-	-	-	39.00
Rumput gajah (*Pennisetum purpureum* Schumach.)	-	-	-	37.00
Harendong (*Melastoma malabathricum* L.)	-	-	-	39.00
Widelia (*Widelia trilobata* L. Pruski.)	-	-	-	44.00
Cacabean (*Ludwigia hyssopifolia* G. Don Exell)	-	-	-	29.09
Jotang kuda (*Synedrella nodiflora* L. Gaertn.)	-	-	-	63.46
Sanagori (*Codariocalyx gyroides* Roxb. Ex Link.)	-	-	-	24.36

At tree level, species with the highest important value index was Ganitri (*Elaeocarpus angustifolius*) with 102.4% and the lowest was Angsana (*Pterocarpus indicus*) with 30.70%. At pole level, the highest important value was found in Ganitri (*E. angustifolius*) with an IVI of 154.5% and the lowest was found in Pulai (*Alstonia scholaris*) with 10.11%. The highest IVI at sapling level was found in Manglid (*Manglietia glauca*) with 83.3% and the lowest was in Randu (*Ceiba pentandra*) with 32.5%. At understory level, species with the highest IVI was Jotang Kuda (*Synedrella nodiflora*) with 63.46% and the lowest was Starfruit (*Begonia hirsela*) and forest taro (*Colocasia esculenta*) with 19.37% and 19% each.

Human activities that utilize nature without care and do not practice sustainable principles in Indonesia are very high, causing natural destruction characterized by a decline in the quality of biodiversity of flora and fauna. One of the efforts to maintain the quality of biodiversity in Indonesia so that it does not become extinct and further deteriorates its quality is by carrying out conservation in situ (in its natural habitat). An example of in situ conservation is by replanting native species in former mining land areas through reclamation (Setyaningsih 2022). This study shows that tree level was only found in reclaimed areas from 2014 to 2018 (5 to 10 years age). The longer the reclamation, the more frequency and number of tree types found. Poles were found in the reclamation area from 2014 to 2021, but only one species was found in the site reclaimed in 2019, 2020 and 2021. Saplings and understory were found in all reclamation areas from 2014 to 2023.

Carbon dioxide absorption

Natural forests in the tropics are the world's largest carbon sink and contain rich biodiversity that provides a wide range of ecosystem services. Measuring the carbon stock of these ecosystems is critical to understanding the global carbon cycle. Soil organic carbon is a very important variable for soil quality and function, global food security, and climate change mitigation (Yan et al. 2020; Biney et al. 2021; Khaplea et al. 2021). Post-mining land reclamation and revegetation activities play an important role in restoring vegetation and degraded land, and mitigating climate change due to the loss of CO_2 from the atmosphere caused by mining activities (Bandyopadhyay and Maiti, 2022; Farosandi et al. 2024). Soils are effective carbon storage and immobilization sites through biomass production and increased Soil Organic Carbon (SOC). The soil's organic carbon storage capacity depends on land use and management. Degraded land loses a significant amount of carbon through soil organic decomposition, erosion, and leaching. The restoration of disturbed and degraded mining land can increase biomass productivity, improve soil quality, and increase soil carbon (Lal 2020; Han et al. 2022). Before obtaining the value of carbon storage in each carbon pool, it is necessary to obtain the value of biomass. The biomass values of upper plants (trees, poles, saplings), understorey plant, vegetation roots, dead trees, dead wood, litter and soil per hectare can be seen Table 4.

Table 4. Biomass of each carbon pool in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Biomass (ton ha^{-1})										Area reclaimed (Ha)	Biomass total (ton)
	Tree	Pole	Sapling	Understorey	Root	Dead tree	Dead wood	Litter	Soil	Total (ton ha^{-1})		
1	384.5	15.9	0.4	1.1	108.5	0.1	0.1	1.7	121.7	633.9	0.3	209.2
2	289.7	28.2	1.9	0.9	86.6	0.2	0.3	1.6	6.1	415.4	0.2	95.5
3	138.5	12.0	1.4	0.5	38.9	0.0	0.0	1.5	33.7	226.5	1.8	402.1
4	138.1	16.1	0.8	0.5	42.0	0.0	0.0	1.6	33.7	232.8	1.8	413.2
5	250.9	27.7	2.7	1.2	76.3	0.0	0.0	1.6	6.1	366.4	0.3	109.9
6	48.7	23.9	1.3	0.3	20.1	0.0	0.0	1.7	33.7	129.7	0.4	53.2
7	39.4	17.1	0.3	1.1	15.5	0.0	0.0	1.8	26.2	101.5	0.4	36.5
8	53.9	23.7	4.1	1.1	22.3	0.0	0.0	1.9	6.1	113.0	0.0	2.3
9	37.3	22.4	3.3	1.1	17.3	0.0	0.0	1.5	26.2	109.1	1.0	107.1
10	33.2	40.9	1.7	0.7	23.2	0.0	0.0	1.5	65.5	166.7	1.8	296.8
11	83.5	161.8	27.0	0.7	51.2	0.0	0.0	1.5	65.5	391.2	1.6	625.9
12	0.0	7.1	50.2	0.5	15.6	0.0	0.0	0.9	33.7	108.0	2.4	259.2
13	0.0	0.0	16.6	0.3	4.6	0.0	0.0	0.6	33.7	55.7	1.3	74.7
14	0.0	6.9	12.1	0.6	5.3	0.0	0.0	1.5	6.1	32.3	0.2	7.4
15	0.0	19.8	18.9	0.6	10.6	0.0	0.0	1.4	16.4	67.7	1.1	74.6
16	0.0	10.2	14.8	0.7	6.9	0.0	0.0	1.5	37.4	71.6	0.6	43.0
17	0.0	29.2	24.1	0.7	14.6	0.0	0.0	1.5	74.4	144.4	0.2	25.7
18	0.0	33.0	14.6	0.8	13.1	0.0	0.0	1.5	34.2	97.1	0.8	81.6
19	0.0	22.1	38.2	0.8	16.5	0.0	0.0	1.4	82.3	161.3	0.4	64.5
20	0.0	0.0	12.0	0.8	3.4	0.0	0.0	1.4	30.7	48.3	3.5	167.1
21	0.0	0.0	5.2	0.8	1.6	0.0	0.0	1.5	7.1	16.2	0.5	7.7
22	0.0	0.0	5.0	0.7	1.5	0.0	0.0	1.3	37.3	45.9	0.8	35.6
23	0.0	0.0	3.6	0.7	1.2	0.0	0.0	1.4	7.1	14.1	0.2	2.7
												3,195.5

Based on Table 4, biomass at each plot of the reclamation area highly varied. Biomass in the Plot 1, which was reclaimed in 2014 (10 years old) had the highest biomass value with 633.9 tons ha^{-1}. Conversely, biomass in the Plot 23, which was reclaimed in 2023 (1 year old), only had biomass of 14.1 ton ha^{-1}. The value of biomass is influenced by several factors such as the age of vegetation, the density of vegetation, the growth rate (diameter and height of vegetation), the specific gravity of each vegetation and the growth nature of the vegetation type (fast and slow growing) as well as the land management. The total biomass produced in the reclamation area with extent of 21.6 ha was 3,195.4 tons. The highest total biomass was obtained in Plot 11 with a value of 625.9 tons and reclamation area of 1.6 ha and the lowest biomass was in the reclamation area in 2016 (plot 8) with 2.3 tons.

The total value and percentage of biomass derived from 10 biomass sources can be seen in Table 5. Based on Table 5, the total biomass produced from the reclamation area of 21.6 ha is 3,195.5 tons. The largest biomass was obtained from trees with 1,024.2 tons or 32.05%, while the lowest biomass was obtained from dead trees with 0.1 tons or 0.0024%.

The biomass values are used to analyze carbon stocks in the reclamation area from 2014 to 2023. Carbon storage from vegetation root is influenced by the value of the Root Shoot Ratio (RSR) which is the comparison between root biomass and aboveground biomass. The RSR constant value used in this study was tropical mountain forest (highland forest) and referred to SNI 7724:2019 it has RSR of 0.37-0.38. Carbon storage in soil is influenced by the organic C value (%) in each soil, which was obtained from primary data through laboratory analysis of soil quality in the reclamation area with the values shown in Table 6.

The results of the analysis of carbon stocks from all carbon pools in each reclamation area are presented in Table 7. Carbon storage in the Pongkor reclamation area was concentrated in tree-stage vegetation, poles, saplings, undergrowth, plant roots, litter, and soil, due to the very limited carbon contribution of seedlings, dead trees, or dead woods. The total carbon stock across the entire 21.6 Ha reclamation area is 1,502 tons, equivalent to 69.5 tons of carbon per hectare. The highest carbon storage per hectare was found in Plot 1/Ciladu (10 years old) with 297.9 tons per hectare, and the lowest carbon storage per hectare was found in Plot 23/East Kabayan 3 (1-year-old) with 6.6 tons per hectare.

Table 5. Biomass value and percentage of each source in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Biomass source	Biomass (ton)	Percentage (%)
Trees	1,024.2	32.051%
Pole	528.3	16.533%
Sapling	311.0	9.732%
Seedling	0.0	0.000%
Understorey	14.1	0.441%
Roots	471.4	14.752%
Dead trees	0.1	0.003%
Dead woods	0.1	0.003%
Litter	29.9	0.936%
Soil	816.4	25.548%
Total	**3,195.5**	**100**

Table 6. Organic C value (%) in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Reclaimed area	Initial state before reclamation	C organic (%)
1	Ciladu (Sidempok Ranca)	Former excavation of soil material (cut and fill)	2.60
2	Bantar Karet	Former excavation of soil material (cut and fill)	0.13
3	Cepak Puspa	Former stockpile of hazardous waste (tailings)	0.72
4	Cepak Puspa 2	Former stockpile of hazardous waste (tailings)	0.72
5	Quarry Bantar Karet	Former excavation of soil material (cut and fill)	0.13
6	Dam 1 Puspa	Formerly stockpiled hazardous waste (tailings)	0.72
7	Quarry Gunung Dahu	Former excavation of soil material (cut and fill)	0.56
8	Jalan Quarry Bantar Karet	Former non-mining road	0.13
9	Gunung Dahu-Ciladu	Former excavation of soil material (cut and fill)	0.56
10	Cepak Puspa	Former top soil and sub soil stockpile	1.40
11	Legok Geomin	Former non-ore stockpile (disposal waste)	1.40
12	Landfill Cepak Puspa	Former hazardous waste stockpile (Tailings)	0.72
13	Landfill Cepak Puspa 1	Former stockpile of hazardous waste (Tailings)	0.72
14	Bantarkaret Sidempok	Former excavation of soil material (cut and fill)	0.13
15	Double Track Pongkor	Former non-mining road	0.35
16	Lamping Budin	Natural landslide area	0.80
17	Belakang Pabrik	Former excavation of soil material (cut and fill)	1.51
18	L.600 Ciurug	Former soil material excavation (cut and fill)	0.73
19	Semen Silo	Former soil material excavation (cut and fill)	1.83
20	Bukaan Pondok Batu	Former non-ore dump (disposal waste)	0.66
21	Cikabayan Timur	Former soil material excavation (cut and fill)	0.16
22	Batching Plant	Former non-ore stockpile (disposal waste)	0.83
23	Cikabayan Timur 3	Former excavation of soil material (cut and fill)	0.16

Table 7. Carbon stock in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Reclaimed year	Area (Ha)	Total Carbon Stock-C (Ton C)								Carbon stocks per Ha (ton C Ha^{-1})
			Tree	Pole	Stake	Understorey plant	Root vegetation	Litter	Soil	Total carbon stock (Ton)	
1	2014	0.3	59.6	2.5	0.1	0.2	16.8	0.3	18.9	98.3	297.9
2	2014	0.2	31.3	3	0.2	0.1	9.4	0.2	0.7	44.9	195.2
3	2014	1.8	115.6	10	1.1	0.4	32.4	1.2	28.1	189	106.5
4	2014	1.8	115.2	13.5	0.7	0.4	35	1.4	28.1	194.2	109.4
5	2015	0.3	35.4	3.9	0.4	0.2	10.8	0.2	0.9	51.7	172.2
6	2015	0.4	9.4	4.6	0.2	0.1	3.9	0.3	6.5	25	61
7	2016	0.4	6.7	2.9	0.1	0.2	2.6	0.3	4.4	17.2	47.7
8	2016	0.0	0.5	0.2	0	0	0.2	0	0.1	1.1	53.1
9	2017	1.0	17.2	10.3	1.5	0.5	8	0.7	12.1	50.3	51.3
10	2017	1.8	27.7	34.2	1.4	0.6	19.4	1.3	54.8	139.5	78.4
11	2018	1.6	62.8	121.7	20.3	0.5	38.5	1.2	49.3	294.2	183.9
12	2018	2.4	0	8	56.6	0.6	17.6	1	38	121.8	50.8
13	2019	1.3	0	0	10.5	0.2	2.9	0.4	21.2	35.1	26.2
14	2019	0.2	0	0.7	1.3	0.1	0.6	0.2	0.7	3.5	15.2
15	2020	1.1	0	10.2	9.8	0.3	5.5	0.7	8.5	35.1	31.8
16	2020	0.6	0	2.9	4.2	0.2	2	0.4	10.6	20.2	33.7
17	2020	0.2	0	2.4	2	0.1	1.2	0.1	6.2	12.1	67.9
18	2021	0.8	0	13	5.8	0.3	5.2	0.6	13.5	38.3	45.7
19	2021	0.4	0	4.2	7.2	0.1	3.1	0.3	15.5	30.3	75.8
20	2021	3.5	0	0	19.5	1.2	5.6	2.3	50	78.6	22.7
21	2022	0.5	0	0	1.2	0.2	0.4	0.3	1.6	3.6	7.6
22	2022	0.8	0	0	1.8	0.3	0.6	0.5	13.6	16.7	21.6
23	2023	0.2	0	0	0.3	0.1	0.1	0.1	0.6	1.3	6.6
Total		**21.6**	**481.4**	**248.2**	**146.2**	**6.9**	**221.8**	**14**	**383.9**	**1,502**	
Average											**69.5**

Carbon storage per hectare in the reclamation area from 2014 to 2023 is influenced by the biomass produced from each carbon pool. In the 4.1 Ha reclamation area at year 2014 (Plot 1, 2, 3 and 4 or Ciladu, Bantar Karet, Cepak Puspa and Cepak Puspa 2) with 10 years old have been contributed 526.4 tons of total carbon storage, or almost 36% of the total reclamation area (1,502 tons in 21.6 ha). Total carbon storage is influenced by the area of land reclamation, vegetation age, vegetation density, and biomass value as well as the structure of vegetation in the reclaimed area (Syaufina and Ikhsan 2013; Setyaningsih et al. 2022; 2023). The total value and percentage of carbon storage derived from each carbon pool are presented in Table 9. Based on Table 8 the largest carbon store was obtained from trees with 494.37 tons or 32.91%, while the lowest was obtained from dead trees and dead woods with 0.04 tons or 0.0025%.

The average increment of diameter and height, and carbon sequestration of each plant species per year are presented in Table 9. Based on Table 9, mahagony has the highest carbon absorption capacity with 0.929 tons of C/plant/year followed by Ganitri with 0.854 tons of C/plant/year. The lowest carbon absorption was found *Quercus argentata* with 0.005 tons C/plant/year. The carbon absorption capacity of each plant is affected by the annual average growth of diameter and height as well as the specific gravity of each vegetation. Reclamation using native species is the best engineering technique to improve the environmental conditions of former mines (Buta et al. 2019).

The results of the analysis of the potential value of carbon storage in the reclamation area from 2014 to 2023 were used to analyze the potential for carbon dioxide (CO_2) sequestration. The potential absorption of carbon dioxide (CO_2) was obtained from vegetation at the level of trees, poles, saplings, seedlings and undergrowth with results are presented in Table 10. Reclamation plays a role in increasing CO_2 absorption by utilizing sunlight and water from the soil, chlorophyll vegetation to absorb CO_2 from the atmosphere through photosynthesis. The results of photosynthesis are stored in the form of biomass, which makes vegetation grow larger or taller (Noor et al. 2020). Based on Table 11, the total CO_2 absorption in the reclamation area of 21.6 ha is 3,238.6 tons. The highest CO_2 absorption was obtained in the reclamation area of 2014 (10 years old) at 297.9 tons Ha^{-1}.

Table 8. Total carbon stock and percentage of each carbon pool in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Carbon pool	Total carbon stock (tons)	Percentage (%)
Trees	494.37	32.91%
Pole	241.06	16.05%
Sapling	140.39	9.34%
Seedling	-	0.00%
Understorey	6.65	0.44%
Roots	221.56	14.75%
Dead trees	0.04	0.0025%
Dead woods	0.04	0.0025%
Litter	14.03	0.93%
Soil	383.72	25.54%
Total	**1,501.9**	**100.00%**

Table 9. Annual increment of diameter and height, and carbon sequestration of each trees species in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Tree name	Average annual diameter growth (cm/year)	Average annual height growth (cm/year)	Carbon sequestration (C ton/plant/year)
Angsana (*Pterocorpus inidicus* Willd.)	2.19	1.86	0.406
Ganitri (*Elaeocarpus angustifolius* Blume.)	2.75	2.63	0.854
Huru (*Litsea* sp.)	2.13	1.07	0.171
Jati putih (*Gmelina arborea* Roxb.)	2.61	3.15	0.849
Mahoni (*Swietenia mahagoni* L. Jacq.)	2.86	2.44	0.929
Manglid (*Manglietia glauca* Blume)	2.18	1.41	0.242
Puspa (*Schima wallichii* DC. Korth.)	2.21	1.43	0.422
Rasamala (*Altingia excelsa* Noronha)	2.26	1.57	0.574
Sengon (*Paraserianthes falcatria* L. Nielsen.)	3.42	1.23	0.656
Suren (*Toona sureni* Blume. Merr.)	2.17	2.72	0.416
Huru bodas (*Litsea umbellata* Lour. Merr.)	1.07	1.30	0.014
Kayu Afrika (*Maesopsis eminii* Engl.)	0.95	1.05	0.010
Ki kaya (*Khaya anthotheca* Welw. C.DC)	1.27	1.03	0.022
Ki Sireum (*Syzygium lineatum* D.C. Merr & L.M Perry.)	0.91	0.87	0.007
Pasang (*Quercus argentata* Korth.)	0.53	0.70	0.005
Pulai (*Alstonia scholaris* L. R. Br)	1.77	1.90	0.057
Randu (*Ceiba pentandra* L. Gaertn.)	0.73	2.07	0.011
Salam (*Syzygium polyanthum* Wight. Walp.)	1.20	1.37	0.047
Sengon buto (*Enterolobium cyclocarpum* Jacq. Griseb)	2.10	2.40	0.116

Table 10. Total CO_2 absorption in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Plot	Year	Area (ha)	CO_2 absorption (Tons)					Total CO_2 absorption (tons)
			Tree	Pole	Sapling	Seedling	Understorey	
1	2014	0.3	218.9	9.0	0.2	0.0	0.6	228.7
2	2014	0.2	114.9	11.2	0.8	0.0	0.3	127.2
3	2014	1.8	424.1	36.8	4.2	0.0	1.6	466.7
4	2014	1.8	422.7	49.4	2.5	0.0	1.4	476.0
5	2015	0.3	129.8	14.3	1.4	0.0	0.6	146.2
6	2015	0.4	34.5	16.9	0.9	0.0	0.2	52.5
7	2016	0.4	24.4	10.6	0.2	0.0	0.7	36.0
8	2016	0.04	1.9	0.8	0.1	0.0	0.0	2.9
9	2017	1.0	63.1	38.0	5.6	0.0	1.9	108.5
10	2017	1.8	101.8	125.6	5.2	0.0	2.0	234.7
11	2018	1.6	230.4	446.5	74.6	0.0	1.8	753.3
12	2018	2.4	0.0	29.3	207.8	0.0	2.1	239.2
13	2019	1.3	0.0	0.0	38.4	0.0	0.6	39.1
14	2019	0.2	0.0	2.7	4.8	0.0	0.2	7.7
15	2020	1.1	0.0	37.5	35.9	0.0	1.2	74.6
16	2020	0.6	0.0	10.6	15.3	0.0	0.7	26.6
17	2020	0.2	0.0	9.0	7.4	0.0	0.2	16.6
18	2021	0.8	0.0	47.8	21.2	0.0	1.1	70.1
19	2021	0.4	0.0	15.3	26.3	0.0	0.5	42.1
20	2021	3.5	0.0	0.0	71.4	0.0	4.5	75.9
21	2022	0.5	0.0	0.0	4.3	0.0	0.6	4.9
22	2022	0.8	0.0	0.0	6.7	0.0	1.0	7.7
23	2023	0.2	0.0	0.0	1.2	0.0	0.2	1.4
Total		**21.6**	**1,766.6**	**911.3**	**536.4**	**0.0**	**24.4**	**3,238.6**

The percentage of CO_2 emissions and absorption from areas reclaimed during 2014-2023 can be seen in Table 14. The total value and percentage of CO_2 uptake from each carbon pool are presented in Table 11. Carbon storage can be obtained above the soil surface, which includes tree biomass, understory biomass, necromass, and litter biomass. The largest proportion of carbon stored on land is found in trees, namely in the trunk (Pradipta and Sutrisno 2022). Based on Table 11, the total CO_2 absorption produced from the reclamation area of 21.6 ha is 3,238.6 tons. The largest carbon absorption was obtained from trees with 1,766.6 tons or 54.55%, while the lowest was from undergrowth with 24.4 tons or 0.75%.

Each reclamation site has different carbon dioxide absorption capacity depending on initial state before reclamation as presented in Table 12. The largest percentage of CO_2 absorption was in the reclamation area with the initial state of the former area of soil material excavation (cut and fill) with 2,276.19 tons of CO_2 ha^{-1} or 57.64%, followed by the former hazardous and toxic materials waste (tailing) landfill area with 783.46 tons of CO_2 ha^{-1} or 19.84%. The lowest absorption was in the area of the former natural avalanche with 44.32 tons of CO_2 ha^{-1} or 1.12%. Direct carbon dioxide emissions resulting from mining activities from 2014 to 2023 averaged 5,493.4 tons of CO_2 $year^{-1}$.

Based on Table 13, until the year 2023, the cumulative carbon dioxide emissions produced for 10 years (2014-2023) was amount 54,934.03 tons. The reclamation area of 21.6 Ha is able to absorb carbon dioxide of 3,238.6 tons or 5.89% of total emission. The value of carbon dioxide absorption is relatively small compared to the emissions produced because the reclamation area is very small due to the mining method carried out is underground mines that are not much to clear land and forests. Other CO_2 emissions have the potential to be absorbed by vegetation from primary forests such as conservation forests and protected forests around the reclaimed areas.

The percentage of CO_2 emissions and absorption from areas reclaimed during 2014-2023 can be seen in Table 13. Based on Table 14, the estimated carbon dioxide absorption in 2041 for 10-year-old reclamation was 1,196.62 tons ha^{-1}, was the biggest than the all year reclamation. The carbon dioxide absorption of 6 years reclamation age, 1,093.44 tons Ha^{-1}, was the second biggest and even bigger compared to the older reclamation age of 7 to 9 years. This is due to the individual density of trees, poles and saplings in the reclamation area of age 6 years.

To determine the correlation between vegetation diversity and carbon dioxide absorption in each plot in the reclamation area, a Pearson correlation test was carried out with the results described in Table 16. Through the analysis of the Pearson correlation coefficient, carbon sequestration shows a very significant positive correlation with vegetation diversity in reclaimed areas (Qiu 2022). Based on the results of the Pearson correlation test in Table 15 (at the level of 5% or p value<0.05), the variables that were significantly correlated with CO_2 sequestration were the vegetation diversity index (H') of the pole level (R=0.6853) and tree level (R= 0.5075). Meanwhile, the correlation of CO_2 sequestration to the total vegetation diversity index (overall H') (R= 0.4691) was un-significant.

Table 11. Value and percentage of CO_2 absorption from each carbon pool in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Carbon pool	Total CO_2 absorption (tons)	Percentage (%)
Tree	1,766.5	54.55%
Pole	911.3	28.14%
Sapling	536.4	16.56%
Seedling	-	0.00%
Understorey	24.4	0.75%
Total	**3,238.6**	**100.00%**

Table 12. Percentage of CO_2 absorption in each initial state of site in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Initial state of reclamation	Total reclamation area (Ha)	Percentage of reclamation area (%)	Biomass (ton Ha^{-1})	Carbon sequestration (ton C Ha^{-1})	CO_2 absorbtion/ Ha	Percentage of sequestration (%)
Natural avalanche marks	0.60	2.78	71.6	33.7	44.32	1.12%
Former excavation of soil material (cut and fill)	4.52	20.96	2,091.7	983.1	2,276.19	57.64%
Former waste landfill hazardous and toxic materials (tailing)	7.7	35.71	752.7	353.8	783.46	19.84%
Former stockpile non ore (disposal waste)	5.84	27.09	485.4	228.1	502.65	12.73%
Former stockpile top soil and sub soil	1.78	8.26	166.7	78.3	131.64	3.33%
Former non-mining roads	1.12	5.19	180.8	85.0	210.50	5.33%
Total	**21.6**	**100**				

Table 13. Percentage of CO_2 emissions and absorption from 2014 to 2023 in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Year	Reclamation area (ha)	CO_2 emissions (ton)	Cumulative CO_2 emissions (ton)	CO_2 absorption (ton/year)	Cumulative CO_2 absorption (ton)	Percentage of CO_2 absorption (%)
2014	4.11	6,391.64	6,391.64	1,298.00	1,298.00	20.31%
2015	0.71	5,663.88	12,055.51	198.70	1,496.70	12.42%
2016	0.38	5,084.02	17,139.53	38.80	1,535.50	8.96%
2017	2.76	5,093.00	22,232.53	343.20	1,878.70	8.45%
2018	4.00	4,569.00	26,801.53	992.50	2,871.20	10.71%
2019	1.57	5,253.00	32,054.53	46.80	2,918.00	9.10%
2020	1.88	6,004.72	38,059.25	117.80	3,035.80	7.98%
2021	4.70	5,891.30	43,950.55	188.10	3,223.90	7.34%
2022	1.25	5,545.44	49,495.99	12.65	3,236.55	6.54%
2023	0.19	5,438.04	54,934.03	1.43	3,237.98	5.89%

Table 14. Estimated carbon dioxide absorption in 2041 in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Reclamation age (Years)	Average CO_2 uptake (ton ha^{-1}) in 2024	Average CO_2 absorption (ton Ha^{-1} $year^{-1}$)	Estimated CO2 absorption in 2041 (ton Ha^{-1} $year^{-1}$)	Total estimated CO2 absorption in 2041 (ton Ha^{-1} $year^{-1}$)
10	443.19	44.32	753.43	1,196.62
9	307.67	34.19	581.15	888.81
8	121.35	15.17	257.87	379.22
7	121.18	17.31	294.30	415.48
6	285.24	47.54	808.19	1,093.44
5	31.40	6.28	106.75	138.15
4	68.40	17.10	290.71	359.12
3	70.22	23.41	397.91	468.13
2	10.10	5.05	85.88	95.98
1	7.53	7.53	127.93	135.45

Table 15. Correlation (R) between vegetation diversity and CO_2 absorption in the reclamation areas of gold mining in Pongkor, West Java, Indonesia

Variables	H' trees	H' pole	H' sapling	H' understorey	H' overall	Reclamation age (years)
CO_2 sequestration (ton CO_2 ha^{-1})	0.5075*	0.6853**	-0.1497	0.2717	0.4691*	0.7004**
H' tree		0.5717	-0.1904	-0.2366	0.6964*	0.9534**
H' pole			0.1532	-0.1648	0.8512**	0.8431**
H' sapling				0.0168	0.4989*	-0.1466
H' understorey					0.1156	-0.0359
H' overall						0.3152
Reclamation age (years)						

Note: **: Significant correlation at the level of 1% (p-value<0.01); *: Significant correlation at the level of 5% (p-value<0.05)

There was positive and significant correlation (R=0.7004) of CO_2 sequestration to reclamation age. Each of these variables has a positive correlation with CO_2 uptake, meaning that the higher the vegetation diversity index, the higher the CO_2 uptake. Likewise with the reclamation age, the higher the reclamation age, the higher CO_2 absorption will be.

In conclusion, reclamation in gold mining area is able to restore vegetation diversity and absorb carbon dioxide emissions generated from mining activities. Nevertheless, it took approximately 10 years to make the carbon stock contributable to offset the carbon emissions. The results of the study showed that the Shanon-Wiener diversity Index (H') of the tree, pole, sapling and lower-level plant was in the moderate category (1<H'<3). The reclamation area of 21.6 Ha was able to absorb carbon dioxide cumulatively of 3,237.98 tons or contributed to absorb the 5.89% of CO_2 emissions in 10 years (2014-2023). Reclamation in the gold mining area is able to restore the ecology of vegetation and absorb carbon dioxide emissions generated from mining activities.

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