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Research Article

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Ecological footprint mitigation through corporate environmental management: Measuring carbon sequestration in PT Organon Pharma Indonesia's conservation and industrial areas

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ABSTRACT

Climate change mitigation in the pharmaceutical industry is necessary for corporate conservation. This study aims to measure the carbon sequestration potential in the conservation area and the Seroto Block plantation area, evaluate the company's environmental management strategy, and analyze the success factors of the conservation program at PT Organon Pharma Indonesia. This study uses a mixed-methods approach with a sequential explanatory design. The research instruments include GPS, tree measuring tools, environmental sensors, and biomass assessment tools. Data analysis techniques include estimating biomass per tree, determining carbon stocks, calculating CO_2 equivalents, and evaluating the effectiveness of conservation strategies. The results show that the conservation area stores the most carbon (a total of 40.39 tons C/ha, equivalent to 462.56 tons CO_2), followed by the industrial area (a total of 10.77 tons C/ha, equivalent to 95.55 tons CO_2), and the plantation area shows minimal carbon storage (60.95 kg). *Pinus merkusii* dominated the conservation area (85.6% of carbon storage), while *Mangifera indica*, *Pterocarpus indicus*, and *Filicium decipiens* contributed 91.5% of carbon storage in the industrial area. Environmental conditions, which were optimal in the conservation area (24.3°C, 73% humidity, pH 6.3) and harsher in the industrial area (33.3°C, 56% humidity), had a significant impact on carbon sequestration. This study concluded that conservation areas have the highest carbon storage capacity compared to industrial and plantation areas.

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INTRODUCTION

Global climate change is now one of the most important challenges of the 21st century, where carbon dioxide levels in the atmosphere have reached the highest level in human history, namely 419 ppm in 2023 (IPCC, 2023). This condition requires collective action from various sectors, including industries that contribute greatly to global carbon emissions. Indonesia, a country with exceptionally high biodiversity, has significant potential to mitigate the impact of climate change through carbon sequestration by its forest ecosystems. Basuki et al. (2022) stated that Indonesia's forest ecosystems are capable of sequestering up to 2.4 Gt CO_2 of carbon each year, but this potential is decreasing due to the high rate of deforestation.

PT Organon Pharma Indonesia is a multinational pharmaceutical company operating in Indonesia with a commitment to environmental sustainability. The company manages two different sites that serve as conservation areas and green open areas: the Seroto Block conservation area with an area of 2.5 Ha located in Jatiarjo Village, Prigen District, and the green open area in the industrial area (factory). Both locations have different characteristics but are managed with an integrated conservation approach as an implementation of the company's environmental policy. The existing body of research lacks specific studies that thoroughly evaluate the effectiveness and unique challenges of implementing integrated conservation approaches within a pharmaceutical corporate setting in Indonesia, particularly across geographically disparate and characteristically different sites like those managed by PT Organon Pharma Indonesia. Pharmaceutical industry activities are known to contribute to the global carbon footprint through production processes, transportation, and energy use. Hartini et al. (2023) showed that the pharmaceutical sector generates higher emissions intensity than the automotive industry, with an average of 55% TCO_2e per million dollars of revenue. This condition creates an urgency for pharmaceutical companies to implement effective mitigation strategies through measurable conservation approaches.

While many companies have made environmental commitments, a significant gap between these pledges and actual implementation in carbon footprint mitigation, particularly within the pharmaceutical sector, remains a major concern. Based on research from Hawkins et al. (2025) only 79% of Multinational companies identified have made conservation pledges, and only 13% have strong commitments that enable accountability. The lack of comprehensive studies on the effectiveness of conservation efforts made by the private sector, especially pharmaceutical companies in Indonesia, is one of the problems that needs to be addressed.

The concept of *ecological footprint* has evolved as an indicator of sustainability and environmental impact. Ding (2023) mentions that the ecological footprint approach enables a comprehensive evaluation of the impact of human activities on the biosphere. Meanwhile, the theory of *corporate environmental stewardship* proposed by González-Ordóñez (2024) emphasizes the importance of integrating environmental values in business practices to achieve long-term sustainability. Carbon storage mechanisms in different plant species and ecosystems have been the subject of much research attention in recent years. Igu et al. (2023) and Liu et al. (2015) found that carbon sequestration capacity varies significantly depending on ecosystem type, with tropical forests showing the highest potential at 7-10 tons of carbon/hectare/year. However, altered ecosystems such as industrial areas with afforestation initiatives also have potential contributions that should not be ignored.

Various previous studies have addressed aspects of carbon sequestration in diverse contexts. Warner et al. (2023) found that above-ground carbon stocks in mixed plantation forests are, on average, 70% higher than monocultures, and 77% higher than commercial monocultures. These findings suggest that mixed-species forests, especially young stands, are more effective at carbon sequestration than

monocultures. Meanwhile, Seeberg-Elverfeldt (2008) examined carbon sequestration in Indonesian conservation areas managed through public-private partnerships and payment for environmental services (PES) schemes, emphasizing the potential for increased carbon sequestration through sustainable agroforestry systems and the need for improved participation and monitoring structures in existing natural resource management schemes. Research by Karuru et al. (2021) and Noor'an et al. (2016) presents estimates of carbon stocks in various vegetation types in East Java, with an average mean of 267.42 ± 119.25 tons C/ha for secondary forests in the lowlands. While previous research has extensively explored carbon sequestration in various contexts, a critical gap remains. None of these studies have explicitly integrated corporate environmental management within the framework of conservation efforts, particularly in the Indonesian context.

However, this study has not incorporated elements of corporate environmental management in the context of conservation. Leijten et al. (2020) discusses the effectiveness of conservation initiatives launched by multinational corporations in Southeast Asia, but has not specifically measured and compared carbon sequestration between conservation areas and industrial areas managed by a single institution. This study uniquely addresses these by investigating the direct role of corporate environmental management in facilitating carbon sequestration within integrated conservation and industrial areas, specifically within the Indonesian pharmaceutical sector. By quantitatively measuring and comparing carbon stocks in both the industrially managed area and its associated conservation area, this research provides novel insights into the actual outcomes of corporate environmental commitments and aims to offer a more nuanced understanding of effective mitigation strategies in this critical sector.

The limitations of previous studies have specifically evaluated and compared carbon sequestration in conservation sites and industrial areas managed by a single company, which is an essential opportunity for this study. In addition, the lack of studies assessing the effectiveness of conservation programs by pharmaceutical companies in Indonesia and the absence of a comprehensive model linking corporate environmental commitments to quantitative outcomes in terms of carbon sequestration are reasons for the importance of this research. The importance of this research is also driven by Indonesia's commitment to reduce greenhouse gas emissions by 29% by its efforts and up to 41% with international assistance by 2030, as stated in the Nationally Determined Contribution (Tacconi, 2018). The role of the private sector through conservation efforts is a crucial element in achieving this national goal. The need for an evidence-based evaluation of corporate conservation initiatives to achieve carbon emission reduction targets and the importance of developing replicable corporate environmental management models are fundamental reasons for this research.

According to Long (2021) emphasizes that conservation programs that are linked to business strategies show better levels of sustainability than initiatives that are merely philanthropic. Carefully conducted comprehensive economic and ecological analyses of corporate environmental responsibility programs reveal that the strategic integration of conservation principles and values into the overarching business model has the potential to generate multiple benefits. Specifically, these benefits include not only the achievement of environmental sustainability goals but also a significant improvement of a company's competitive position and market position within its respective industry. This research aims to measure and analyze the total potential carbon sequestration in the Seroto Block conservation area and planting areas in the Seroto Block conservation area, as well as within the industrial area of PT Organon Pharma Indonesia, an area of 2.4 hectares. Furthermore, to evaluate the effectiveness of environmental management strategies implemented by the company in terms of their effectiveness in mitigating the

ecological footprint generated from industrial activities, and to analyze the factors that influence the success of conservation programs.

RESEARCH METHODS

This study used a mixed-methods approach with a sequential explanatory design, combining quantitative and qualitative methods. Quantitative methods were applied to measure biomass, carbon stocks, and CO_2-equivalents in the Seroto Block conservation area and the industrial area of PT Organon Pharma in Pasuruan, while a qualitative approach was used to analyze the effectiveness of environmental management strategies and identify factors that influence the success of conservation programs. This research was conducted over three months, from December 2024 to February 2025, encompassing the survey, data collection, and data analysis phases. The study sites included two areas managed by PT Organon Pharma Indonesia: first, the Seroto Block conservation area in Jatiarjo Village, Prigen District, spanning 2.5 Ha, alongside an 8320 m² Conservation Planting Area; and second, PT Organon Pharma's industrial area (factory) in Pasuruan, covering 2.4 Ha. The map of the conservation area sampling location can be seen in Figure 1. The factory area sampling location map can be seen in Figure 2.

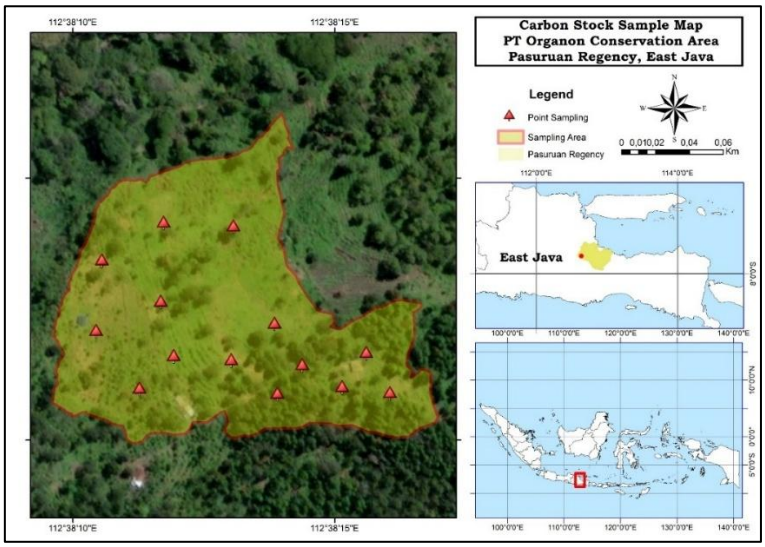

Figure 1. Map of Conservation Area Sampling Location

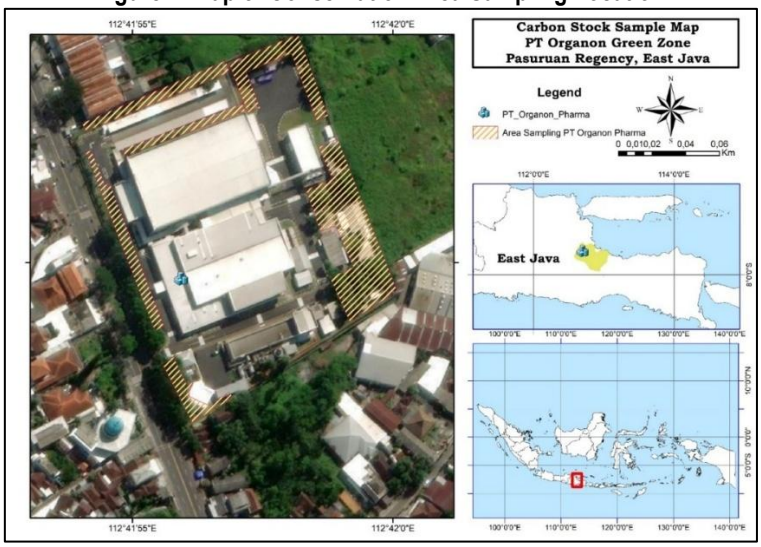

Figure 2. Factory Area Sampling Location Map

Tools and materials used for vegetation and environmental data collection included: coordinate positioning devices (GPS & Alpine Quest application), a tree diameter measuring device (phi band), a measuring tape (meter), a clinometer for slope measurement, a laser rangefinder for tree height, a soil tester for soil parameters, a thermohygrometer for air conditions, a lux meter for light intensity, an anemometer for wind speed, a digital weighing scale with 0.1 g accuracy, a compass, a work map (Avenza Maps application), cutting shears, an oven and stove/heater, an oven thermometer, tally sheets, 5 kg plastic sample containers, label paper, and square plots made of raffia measuring 2x2m, 5x5m, 10x10m, and 20x20m. Vegetation sampling employed a systematic sampling method with a nested plot approach. At each location (conservation area and industrial area), 14 observation plots were established for each vegetation level: 20 m × 20 m for the tree level, 10 m × 10 m for the pole level, 5 m × 5 m for the sapling level, and 2 m × 2 m for the seedling and understory levels. Determining the number of plots refers to the species-area curve to achieve adequate representation. The sampling plot in the research place can be seen in Figure 3.

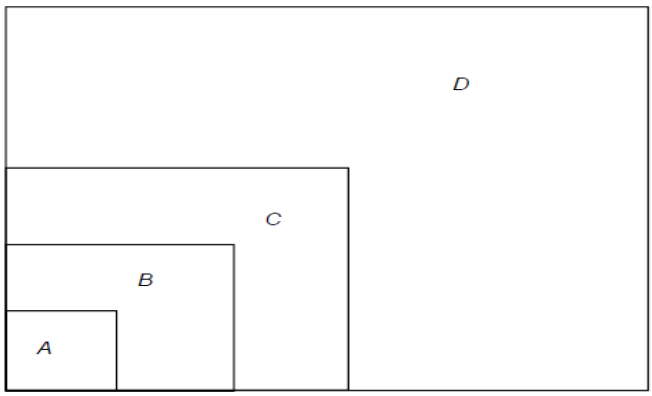

Figure 3. The Sampling Plot

For qualitative data, purposive sampling is applied in the selection of key informants which include: 2 people from the management of PT Organon Pharma Indonesia; 2 conservation area management staff; and 1 person from the local farmer group. Data collection includes both quantitative and qualitative data. Quantitative data includes tree biomass measurement, undergrowth and biomass assessment, and calculation of carbon reserves and CO_2-equivalent. Tree biomass measurement: 1) Measurement of diameter at breast height (DBH) using a diameter tape on all trees with DBH ≥ 5 cm; 2) Tree height measurement using a clinometer; 3) Determination of wood specific gravity using local and global databases; 4) Estimation of aboveground biomass (AGB) using allometric equations developed by Chave et al. (2014).

$$AGB = 0.0673 \times (\rho D^2 H) \text{ ^ } 0.976 \quad (1)$$

Where ρ is the specific gravity of wood (g/cm³), D is the DBH (cm), and H is the height of the tree (m). Undergrowth and litter biomass measurement involved collecting all understory plants and litter within subplots, measuring their wet weight in the field, taking subsamples for oven-drying at 80°C for 48 hours, and then determining dry weight for biomass. Carbon reserves and CO_2-equivalent were calculated by converting biomass to carbon using a factor of 0.47, according to (SNI, 2019); converting the carbon value to CO_2-equivalent by multiplying it by a factor of 3.67, and finally calculating the total carbon storage per

component (trees, understory, litter) and per site. Qualitative data includes in-depth interviews and field observations. In-depth interview: 1) semi-structured interviews with key informants using an interview guide; 2) documentation of interviews through audio recordings and transcriptions; 3) exploration of environmental management strategies, implementation challenges, and success factors. field observation: 1) direct observation of conservation program implementation; 2) visual documentation (photos and videos) of environmental management practices; 3) recording vegetation conditions and management interventions at both sites.

Data analysis in this study includes both quantitative and qualitative approaches. The quantitative analysis focuses on biomass and carbon reserve estimation, where biomass is calculated per individual tree using an allometric equation, aggregated to the plot level, and extrapolated to a hectare scale. Carbon stocks are determined for different ecosystem components, including trees, litter, and understory, and converted into CO_2-equivalents. The qualitative analysis evaluates the effectiveness of environmental management strategies based on predefined criteria and identifies key success factors, including supporting and inhibiting elements that influence the implementation of conservation programs.

FINDING AND DISCUSSION

Based on research conducted in the Seroto Block conservation area of Jatiarjo Village, Prigen District, with an area of about 2,506 hectares, the results of the estimation of biomass, carbon stocks, and CO_2-equivalents are presented in Table 1.

Table 1. Total Estimated Plant Biomass, Carbon Stocks, and CO_2-equivalents of Seroto Block Conservation Area

No.	Category	Biomass (tons/ha)	Carbon (tons/ha)	CO_2-equivalent (tons/ha)
1	Trees	85,94	40,39	148,10
2	Litter	19,6	9,21	33,77
3	Undergrowth	1,57	0,74	2,71
Total (tons/ha)	210 individuals; 16 species	107,11	50,34	184,58
Total Estimation (L area = 2,506 ha)		268,42	126,15	462,56

Based on the results of the vegetation inventory in the Seroto Block conservation area of Jatiarjo Village, Prigen District, there are 16 plant species with a total of 210 individuals. The analysis showed that the total biomass of vegetation in the area reached 85.94 tons/ha, with carbon storage of 40.39 tons/ha, and the CO2-equivalent value reached 148.10 tons/ha. The main plant that plays a role in carbon sequestration in this conservation area is *Pinus merkusii,* with 89 individuals that produce 41,178.87 kg of biomass, or about 85.6% of the total tree biomass. *Pinus merkusii* also stores the highest carbon at 19,354.07 kg (85.6%). The dominance of *Pinus merkusii* is supported by its morphological characteristics, which recorded an average trunk diameter of 21.26 cm and an average tree height of 18.29 m.

The second dominant species was *Acacia decurrens* with 19 individuals, which contributed 5,897.72 kg (12.3%) of biomass and 2,771.93 kg (12.3%) of carbon. In addition to trees, litter and understory vegetation components also contributed to the total carbon stock, amounting to 9.21 tons/ha and 0.74 tons/ha, respectively. In general, the 2,506 ha Seroto Block conservation area is estimated to have a total biomass of 268.42 tons, a carbon stock of 126.15 tons, and a CO_2-equivalent of 462.56 tons. This statement is in line with research Polosakan & Alhamd (2014) which states that pine forests can store carbon ranging from 30-50 tons/ha, depending on the density and age of the plants.

Abiotic environmental conditions in the Seroto Block conservation area showed an average air temperature of 24.3°C and an average air humidity of 73%. The average light intensity reached 4,564.1

lux with a very low wind speed of 0.2 m/s. Soil conditions show an average pH of 6.3 and soil moisture of 5.1 at an average altitude of 1,231 meters above sea level. This situation is very favorable for the development of vegetation, especially coniferous species such as *Pinus merkusii,* which grow best at an altitude of 1,000-1,500 masl and soil pH of 5.5-6.5 (Tang, 2006).

The high quality of carbon sequestration in the Seroto Block conservation area is in line with the findings of Mildrexler et al. (2020), which states that native forest ecosystems dominated by large trees have better carbon sequestration capabilities than converted ecosystems. The study showed that natural forests in Indonesia can store carbon between 36-57 tons/ha. The carbon sequestration potential of the Seroto Block conservation area ranges from 40.39 tons C/ha to 50-60 tons C/ha within 10-15 years. This increase will contribute significantly to climate change mitigation and support the achievement of Indonesia's target to reduce greenhouse gas emissions by 29-41% by 2030. Based on research conducted on the planting area in the Seroto Block conservation area of Jatiarjo Village, Prigen District, with an area of about 8320 m^2 (Figure 4), the results of the estimation of biomass, carbon stocks, and CO_2-equivalents are presented in Table 2.

Based on Figure 4 and Table 2, the planting area in the Seroto Block conservation area, with an area of 8,320 m^2, has a different vegetation composition from the conservation area as a whole. In this area, the type of plant that grows is dominated by *Persea americana* (avocado) as much as 21.90% of the total individuals. This species contributes to carbon sequestration of 48.62 kg with a CO_2-equivalent value of 178.27 kg. Other plant species growing in this planting area are *Psidium guajava* (guava) as much as 3.81% with carbon contribution of 12.14 kg and CO_2-equivalent of 44.51 kg, and *Pometia pinnata* (matoa) as much as 0.48% with carbon contribution of only 0.19 kg and CO_2-equivalent of 0.70 kg. The total plant biomass in this planting area reached 129.68 kg with a carbon stock of 60.95 kg and a CO_2-equivalent value of 223.48 kg.

The low carbon stock in this planting area is due to the dominance of small-sized plants with an average stem diameter only ranging from 1.9-3.64 cm and tree height between 2-3.35 m. According to Chave et al. (2014), Jo & Ahn (2012), Marnaek et al. (2024), and Tahmazov (2023), the size of the stem diameter is an important factor that determines tree biomass and is directly proportional to the amount of carbon stored. The larger the trunk diameter, the greater the biomass and carbon stored. It is worth noting that this planting program has been running for 5 years, but the plants have not yet reached the ideal size desired. This suggests that there are several growth-inhibiting factors that need to be identified and resolved. According to Poorter et al. (2016), fruit crops such as avocados are expected to attain a stem diameter of 8-10 cm and a height of 4-5 m after 5 years of planting under ideal growing conditions.

When compared to the overall conservation area, the planting area contributes very little to the total carbon stock. This indicates the importance of evaluating and improving planting zone management strategies to optimize vegetation growth and increase carbon sequestration. Proper selection of tree and crop species, along with sustainable land management practices, can significantly enhance the carbon absorption potential of the planting area. According to Sharma et al. (2021), fruits such as avocado and guava have significant carbon sequestration ability in the mature phase, which is about 2-3 tons C/ha/year. Integrating these species into planting zones and ensuring optimal growing conditions can help maximize carbon storage while supporting biodiversity.

Based on the vegetation inventory data and environmental conditions in the Seroto Block conservation area, the following are some Solutions to maintain and improve carbon sequestration potential: 1) evaluation and improvement of soil conditions abiotic factor data shows variations in soil pH between 5.0-6.8 with relatively low soil moisture (3.5-7.5). According to Natale et al. (2012) and Sharma

et al., 2018). Fruit crops such as avocado grow optimally at soil pH 5.5-7.0 with sufficient soil moisture. Organic fertilization and ameliorants (agricultural lime) are recommended to improve soil conditions, especially in plots with low soil pH. Providing organic matter can also improve the soil's ability to store water and nutrients. 2) Intensive Maintenance Management Implementation of an intensive maintenance system needs to be done, including: Scheduled irrigation, especially during the dry season, to maintain optimal soil moisture. A drip irrigation system can be an efficient option to save water. And Balanced fertilization with NPK and organic fertilizers every 3-4 months to increase the availability of nutrients for plants (Lal, 2015).

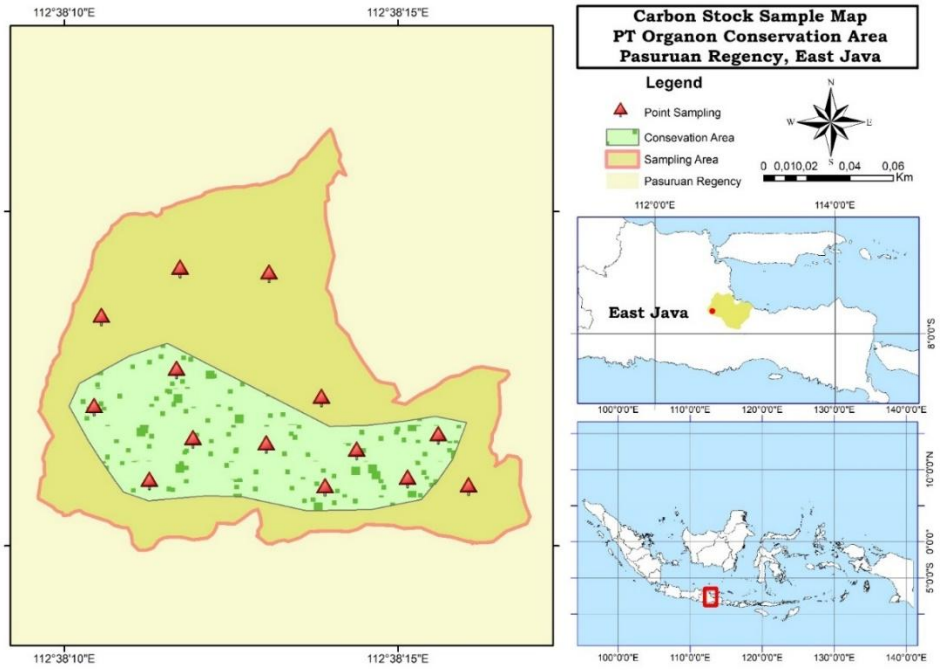

Figure 4. Planting Area in Seroto Block Conservation Area Based on Sampling Points

Table 2. Estimated Plant biomass, Carbon Stock and CO2-equivalent Planting Area

No.	Local Name	Scientific Name	Sample	Plot	Mean D (cm)	Height (m)	Biomass (kg)	Carbon (kg)	CO_2-equivalent (kg)
1	Avocado	*Persea americana* Mill.	21,90%	1, 2, 3, 4, 5, 6, 9, 12	3,33	2,34	103,44	48,62	178,27
2	Cloves	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	0,00%	-	0	0	0	0	0,00
3	Guava	*Psidium guajava* L.	3,81%	4, 5, 13	3,64	3,35	25,82	12,14	44,51
4	Oranges	*Citrus* L.	0,00%	-	0	0	0	0	0,00
5	Mangium	*Acacia mangium* Willd.	0,00%	-	0	0	0	0	0,00
6	Matoa	*Pometia pinnata* J.R.Forst. & G.Forst.	0,48%	13	1,9	2	0,41	0,19	0,70
			Total				129,68	60,95	223,48

The next suggestion is 3) Plant Enrichment and Diversification Plant diversification by adding high-biomass and fast-growing species is necessary to increase carbon stocks, Some recommended species: *Altingia excelsa* (rasamala), *Castanopsis argentea* (saninten), and *Schima wallichii* (puspa) in naturally formed gaps or areas with low density, as well as fruiting plants that also function as animal feed, such as *Bischofia javanica* (gadog), *Ficus* spp. (banyan), and *Dysoxylum* spp. (kedoya), which have high biomass and support biodiversity. 4) Implementation of Silvopastur Systems, combining tree crops with grass and/or livestock (silvopastur), can increase land productivity and carbon stocks (Yadav et al., 2019). These systems can also provide additional economic benefits to local communities through the production of fodder and livestock products such as *Calliandra calothyrsus* (calliandra), *Flemingia macrophylla*, and some small shade-adapted bamboo species.

Continued 5) Increased carbon stocks in soil, an important component of the forest ecosystem carbon cycle that is often overlooked. Research Shi et al. (2020) and Wang et al. (2012; 2018) shows that soil carbon can account for 50-81% of the total carbon stock in forest ecosystems. With the implementation of soil and water conservation techniques such as making rorak, gulu, and contour, and retaining dams on areas with steep slopes to reduce erosion and soil organic carbon loss. 6) Institutional Strengthening and Community Participation Sustainability of conservation area management for carbon sequestration optimization requires strong institutional support and active community participation. Nam & Thanh (2024) showed that community involvement can increase the effectiveness of conservation programs as cultural heritage. Development of performance-based incentive schemes for communities involved in conservation activities and carbon stock enhancement, such as *payment for ecosystem* services.

The plant area of PT Organon Pharma Indonesia, with an area of about 2.42 ha, has 15 types of plants with various contributions to carbon sequestration. The total plant biomass in the plant area reached 55,428.93 kg with a carbon stock of 26,058.38 kg and a CO_2-equivalent value of 95,547.39 kg. If converted per hectare, the plant area has a biomass of 22.9 tons/ha with a carbon stock of 10.77 tons/ha and a CO_2-equivalent of 39.49 tons/ha (Table 3). The dominant plant species contributing to carbon sequestration in the plant area is *Mangifera indica* (mango), as much as 16.22% of the total individuals with a biomass contribution of 20,909.35 kg (37.7%) and carbon of 9,827.39 kg (37.7%). The second dominant species was *Pterocarpus indicus* (sono kembang) as much as 8.11% with a biomass contribution of 17,625.50 kg (31.8%) and carbon of 8,283.98 kg (31.8%). The third species is *Filicium decipiens* (kiara umbrella), as much as 12.16% with a biomass contribution of 12,209.75 kg (22%) and carbon of 5,738.58 kg (22%).

Table 3. Estimation of Plant Biomass, Carbon Reserve, and CO_2-equivalent of PT Organon Pharma Indonesia

No.	Scientific name	Local Name	∑ Individual (%)	Average D Stem (cm)	Average Tree Height (m)	Biomass (kg)	Carbon (kg)	CO_2-equivalent (kg)
1	*Adonidia merrillii* (Becc.) Becc.	Princess palm	10.81%	14.36	5.35	495.76	233.01	854.37
2	*Aquilaria malaccensis* Lam.	Aloes	5.41%	11.98	8.63	219.12	102.98	377.59
3	*Araucaria heterophylla*	Norfolk fir	10.81%	15.71	11.84	972.13	456.9	1,675.30

No.	Scientific name	Local Name	∑ Individual (%)	Average D Stem (cm)	Average Tree Height (m)	Biomass (kg)	Carbon (kg)	CO_2-equivalent (kg)
4	(Salisb.) Franco *Cerbera manghas* L.	Bintaro	1.35%	9	5.9	24.36	11.45	41.98
5	*Chrysophyllum cainito* L.	Kenit	1.35%	21.5	10.2	238.5	112.09	411.00
6	*Dimocarpus longan* Lour.	Longan	1.35%	6.7	7.9	11.24	5.28	19.36
7	*Elaeis guineensis* Jacq.	Oil palm	1.35%	55	8.7	84.98	46.74	171.38
8	*Ficus benjamina* L.	Banya	1.35%	14.5	4	84.97	39.94	146.45
9	*Filicium decipiens* (Wight & Arn.) Thwaites	Kiara Payung	12.16%	34.77	13.3	12,209.75	5,738.58	21,041.46
10	*Mangifera indica* L.	Mango	16.22%	44.3	15.53	20,909.35	9,827.39	36,033.76
11	*Mimusops elengi* L.	Cape	2.70%	20.05	9.45	513.32	241.26	884.62
12	*Pterocarpus indicus* Willd.	Sono kembang	8.11%	39.7	16.2	17,625.50	8,283.98	30,374.59
13	*Syzygium aqueum* (Burm.f.) Alston	Water guava	2.70%	27.25	13.95	900.37	423.17	1,551.62
14	*Terminalia catappa* L.	Ketapang	9.46%	15.24	11.6	991.48	466	1,708.67
15	*Terminalia mantaly* H.Perrier	Ketapang kencana	14.86%	6.42	6.38	148.1	69.61	255.24
		Total (kg)				55,428.93	26,058.38	95,547.39
		Factory Area = ± 2.42 ha Total (tons/ha)				22.9	10.77	39.49

The large contribution of the three plant species to carbon stocks is due to their large stem diameters, which averaged 44.3 cm for *Mangifera indica*, 39.7 cm for *Pterocarpus indicus*, and 34.77 cm for *Filicium decipiens*. In addition, the three species also have significant tree heights, averaging 15.53 m for *Mangifera indica*, 16.2 m for *Pterocarpus indicus*, and 13.3 m for *Filicium decipiens*. The abiotic environment in the PT Organon Pharma Indonesia factory area shows an average air temperature of 33.3°C and an average air humidity of 56%. The average light intensity reached 40,559 lux while the average wind speed was 0.5 m/s. Soil conditions show an average pH of 6.0 and soil moisture of 7.9 at an average altitude of 190 meters above sea level. The high air temperature and low humidity create microclimatic conditions that are not ideal for the maximum growth of various plant species.

When compared to the Seroto Block conservation area, the PT Organon Pharma Indonesia factory area has much less carbon storage (10.77 tons/ha compared to 40.39 tons/ha). This can be explained by several factors, namely: (1) lower vegetation density, (2) prevalence of plant species with different carbon sequestration properties, and (3) less favorable environmental conditions for vegetation development. However, the PT Organon Pharma Indonesia factory area has shown a good effort in providing green open space that supports carbon sequestration. Based on a study by Zubair et al. (2022), trees in urban

or industrial areas can sequester carbon around 7.6s-12.7 tons/ha, depending on the species, size, and density of vegetation. Therefore, the carbon stock at the PT Organon Pharma Indonesia factory site (10.77 tons/ha) is still within the normal range for industrial areas.

Based on the analysis of vegetation data and environmental conditions in the PT Organon Pharma Indonesia factory area, the following are some solutions and suggestions for increasing carbon sequestration potential. 1) Optimization of Vegetation Stratification, the implementation of the multi-layer vegetation stratification concept can improve the efficiency of vertical space utilization and increase biomass per unit area (Lugo, 2015) . Recommended stratification: Upper canopy layer: Tall trees such as *Pterocarpus indicus* and *Terminalia catappa*, Middle canopy layer: Medium trees such as *Mangifera indica* and *Filicium decipiens*, Lower layer: Shrubs and bushes such as *Coffea arabica* and ornamental plants, Ground layer: Ground cover such as *Arachis pintoi* or *Desmodium spp*.

Continued 2) Development of Green Belt Systems and Ecological Corridors, the establishment of a green belt with a minimum width of 10-15 meters around the factory area with a combination of trees, shrubs, and ground cover can function as a pollution sink, noise reducer, and carbon sink (Endreny, 2018). Types of plants recommended for green belts: Broad-leaved and dense plants such as *Ficus benjamina* and *Mimusops elengi*, waxy-leaved plants such as *Swietenia macrophylla* and *Terminalia mantaly*, and coniferous trees such as *Araucaria heterophylla*. 3) Increasing Vegetation Density in Open Areas; based on vegetation composition data, plant density in factory areas can still be increased. Research by Jumiati et al. (2022) shows that emphasizes the importance of increasing vegetation as Green Open Space (GOS) to increase carbon sequestration and reduce greenhouse gas emissions. Areas that can be optimized include: Parking areas (with *tree pit* and *silva cell* systems), internal factory roadsides, buffer and transition areas between buildings, areas that have not been optimally utilized.

Continued 4) Continuous Monitoring and Evaluation Program; the development of a regular monitoring system of vegetation growth and health is important for evaluating program success and adjusting strategies (Calfapietra et al., 2015) . Recommended monitoring components: a) Annual growth (diameter and height) measurements, b) Periodic plant health assessments, c) Measurement of soil and microclimate parameters, d) Estimation of biomass and stored carbon every 2-3 years, e) Documentation of flora and fauna biodiversity. 5) Integration with Corporate Social Responsibility (CSR) Programs, the development of greening programs in the factory area can be integrated with the company's CSR through: a) Tree adoption program by employees, b) Training on green space management for surrounding communities, c) Plant nurseries to support greening outside the factory area, d) Development of a mini arboretum for environmental education, e) Collaboration with educational and research institutions for the development of industrial greening innovations.

Based on vegetation inventory data conducted in three different locations (Seroto Block conservation area, planting area, and PT Organon factory area), there are significant differences in carbon sequestration capacity. The Seroto Block conservation area has the highest carbon storage at 40.39 tons/ha, followed by the PT Organon factory area with 10.77 tons/ha, while the planting area has the lowest carbon storage. This difference reflects variations in vegetation arrangement, composition type, plant size, and environmental conditions at each site. The Seroto Block conservation area, dominated by *Pinus merkusii* (85.6% of the total carbon stored), shows that large natural vegetation makes an important contribution to carbon sequestration. This finding is in line with research conducted by Pregitzer & Euskirchen (2004) which shows that mature coniferous forests can store 3-4 times more carbon than young secondary forests. The multi-layered vegetation structure consisting of large trees, ground

vegetation, and litter layers forms a comprehensive carbon storage system, with the non-tree part contributing about 19.8% of the total biomass.

In the PT Organon factory area, although the carbon stock is lower than the conservation area, the figure of 10.77 tons/ha is still within the normal range for industrial areas. Based on research Davies et al. (2011), green areas in industrial areas usually store carbon between 7-15 tons/ha, depending on the type and density of vegetation. Planting strategies in factory areas that prioritize large trees such as *Mangifera indica, Pterocarpus indicus*, and *Filicium decipiens* have proven successful in optimizing carbon sequestration in limited spaces. The planting area in Seroto Block shows minimal carbon storage potential after 5 years of the reforestation program. Plants dominated by *Persea americana* with an average stem diameter of 3.33 cm and a height of 2.34 m have not yet reached the ideal size to make a significant contribution to carbon sequestration. In comparison, D´Asaro (2017) states that *Persea americana* is expected to reach 8-10 cm in diameter and 4-5 m in height after 5 years of planting under optimal growing conditions. This suggests that there are growth-limiting factors that must be addressed to optimize the carbon sequestration capability of the planting area.

PT Organon's environmental management program includes conservation of the Seroto Block area, tree planting in the conservation zone, and reforestation in the factory area, demonstrating a holistic approach in reducing the ecological footprint. The total carbon stock of the three sites reached 126.15 tons in the conservation area (2,506 ha), 60.95 kg in the planting area (8,320 m²), and 26,058.38 kg in the factory area (2.42 ha). When calculated in CO_2-equivalent, the program can reduce emissions by 462.56 tons in the conservation area, 223.48 kg in the planting zone, and 95,547.39 kg in the factory site.

The success of a company's environmental management strategy can be analysed from two main aspects: (1) contribution to climate change mitigation and (2) improvement of local environmental quality. In terms of climate change mitigation, the Seroto Block area preservation program made the largest contribution with a total carbon stock of 126.15 tons, or equivalent to 462.56 tons CO_2-equivalent. This total is equivalent to the annual emissions of approximately 100 passenger vehicles based on an average emission standard of 4.6 tons of CO_2/year per vehicle (Greene et al., 2011).

In terms of improving the quality of the local environment, the greening program in the factory area plays a role in improving the microclimate, which is evident from the abiotic factor data showing an average temperature of 33.3°C in the factory area. While this temperature is still considered high, research by Endreny (2018) indicates that without vegetation, surface temperatures in industrial areas can reach 40-45°C under similar conditions. Plants with large canopies, such as *Mangifera indica* and *Filicium decipiens* function as temperature regulators through evapotranspiration and shade provision.

The different environmental conditions in the three sites require different optimization strategies. In the conservation area with an ideal environment (air temperature 24.3°C, humidity 73%, soil pH 6.3), the main concern is to maintain and increase carbon storage through sustainable management of *Pinus merkusii* forests and species diversification to strengthen ecosystem resilience. In plant sites that have non-ideal environmental conditions (temperature 33.3°C, humidity 56%, very bright light), greening strategies should focus on increasing vegetation density and selecting plant species that are able to adapt to environmental stress conditions. Lin et al. (2017) suggested increasing the complexity of vegetation structure with multi-layer stratification to generate a better microclimate and increase carbon sequestration in urban and industrial areas.

In planting sites where plant growth is not maximized after 5 years, a thorough assessment and improvement of planting and maintenance methods should be conducted. The low-moisture soil (3.5-7.5) indicates the need for irrigation systems and the application of organic matter to improve soil water

retention capacity. In addition, species variation by adding fast-growing plants and nitrogen fixers can accelerate canopy cover establishment and improve soil conditions (Wong et al., 2022). Vegetation composition and arrangement are important factors that influence the success of conservation programs related to carbon sequestration. Vegetation inventory data showed significant differences in the number of species, density, and size of plants across the three sites. The Seroto Block conservation area consists of 16 plant species with 210 individuals, dominated by large trees (average diameter of *Pinus merkusii* 21.26 cm). The mill area contained 15 plant species, dominated by shade trees with wide canopies, while the planting area was dominated by small fruit trees.

The dominance of *Pinus merkusii* in conservation areas makes an important contribution to the effectiveness of carbon sequestration, but also creates vulnerability to certain threats such as fire and pest attacks. According to Cavanaugh et al. (2014), the dominance of certain plant species can reduce ecosystem resilience to environmental change and disturbance, although in the short term, it can optimize carbon sequestration. Diversifying species while maintaining the main composition of *Pinus merkusii* and adding other native species can increase ecosystem stability in the long term. In the factory area, the selection of tree species such as *Mangifera indica, Pterocarpus indicus*, and *Filicium decipiens* with large trunk diameters (34.77-44.3 cm) proved effective in increasing carbon sequestration in confined spaces. The large trunk diameters directly facilitate substantial woody biomass accumulation, their effectiveness in limited settings is also attributable to other inherent characteristics. These species often exhibit efficient growth patterns that prioritize vertical development and dense wood formation, allowing for significant carbon storage even where lateral expansion is restricted. Furthermore, their robustness and adaptability to semi-urban or industrial environments ensure their viability and continuous carbon uptake.

These three species accounted for about 91.5% of the total carbon stored in the plant area. The abiotic conditions in the factory area, with an average temperature of 33.3 °C, air humidity of 56%, light intensity of 40,559 lux, and soil pH of 6, optimally support the growth and vitality of these three species, thereby reinforcing their carbon sequestration capacity. This study is in line with the findings of Yang et al. (2015) which indicated that the selection of tree species according to growth traits and carbon storage ability can increase the effectiveness of industrial area greening programs by 30-40%.

In the planting zone, the dominance of small, slow-growing fruit trees is a constraint to the success of the program. According to Pantera et al. (2021) , agroforestry or mixed planting programs that combine fast-growing species with crops of economic value can maximize ecological as well as socio-economic benefits simultaneously. The introduction of species such as Sengon (*Albizia chinensis*), which grows quickly and has the ability to fix nitrogen, can accelerate the development of canopy cover and improve soil quality to support fruit crop growth.

Abiotic factors significantly influence the success of conservation programs through their effects on plant growth and ecosystem dynamics. Differences in environmental conditions across the three sites reflect variations in carbon sequestration potential. The Seroto Block conservation area with an average elevation of 1,231m above sea level, an air temperature of 24.3°C, and 73% humidity, creates an ideal situation for *Pinus merkusii* growth and biomass accumulation. This corresponds to the ideal ecological range for conifer species (22-26°C and 70-80% humidity) as expressed by (Castro et al., 2020). In contrast, the plant area with a temperature of 33.3°C and humidity of 56% produces environmental stresses that reduce photosynthesis rates and plant growth.

The difference in soil pH (5.0-6.8 in the conservation zone compared to 5.1-6.6 at the mill site) also affects nutrient availability and microbial activity in the soil. Malik et al. (2018) revealed that soil pH influences carbon dynamics through its impact on the speed of organic matter decomposition and carbon

stabilization in the soil. Slightly acidic soil pH levels (5.5-6.5) are usually most ideal for macronutrient availability and the growth of various forest plants. The much higher brightness at the mill site (mean 40,559 lux) compared to the conservation area (mean 4,564.1 lux) suggests differences in canopy closure and possible light stress in plants. Under high-light conditions, plants often experience photoinhibition and increased respiration processes that can reduce carbon sequestration efficiency (Wasilewska-Dębowska et al., 2022). Adjustment strategies by selecting high-light-tolerant plant species and developing vegetation stratification systems can overcome these constraints in plant areas.

The lower soil moisture levels in the conservation area (average 5.1) when compared to the mill area (average 7.9) suggest differences in soil water holding capacity and the possibility of water stress during the dry season. Studies by Kannenberg et al. (2020), reveal that soil moisture is a strong indicator of vegetation productivity and carbon sequestration, particularly in ecosystems with marked seasonal variation. The application of water conservation methods and rainwater collection can serve as adaptive strategies to maximize soil moisture in dry periods. Human involvement through management and maintenance is a key element for the long-term success of conservation programs. The difference in plant growth at the planting site after 5 years, when compared to their growth potential, shows the limitations of management methods. Maintenance activities such as fertilizer application, watering, weed control, and branch cutting can significantly increase growth rates and biomass accumulation. Alan (2020) reported that the application of intensive silviculture can increase the productivity of plantation forests up to 2-3 times higher than natural growth. At the Seroto Block planting site, the application of intensive care systems can accelerate plant growth and optimize carbon sequestration ability.

In conservation areas, little intervention with an emphasis on protecting ecosystems from disturbances such as fire, logging, and over-mining has proven effective in maintaining large carbon stocks. According to Duncanson et al. (2023), forests with effective protection experience 20-25% less carbon loss than unprotected forests. Improving the monitoring system and protection of the Seroto Block conservation area can ensure the sustainability of the carbon sequestration function in the long term.

At the plant site, landscape planning that maximizes the use of limited space is a major factor in the success of the greening program. The selection of tree species with specific growth characteristics and strategic placement according to ecological and aesthetic functions creates green spaces that are efficient in sequestering carbon and improving environmental quality. This result follows the "right tree, right location" principle advocated by Grant (2016) to maximize the ecosystem benefits of urban and industrial vegetation.

The long-term success of conservation programs is highly dependent on integrating socio-economic aspects and stakeholder participation. Although socio-economic data is not included in the appendix, an analysis of the selected crops, especially in the planting sites, shows that economic benefits are considered in conservation programs. The selection of fruit trees such as *Persea americana* (avocado), *Psidium guajava* (guava), and *Pometia pinnata* (matoa) within the planting areas reflects a strategy that combines ecological objectives (carbon sequestration) with economic benefits for local communities. This approach is in line with the idea of "multifunctional landscaping", which emphasizes the optimization of multiple ecosystem functions simultaneously (Rodríguez-Gallego et al., 2019).

In conservation areas, the dominance of *Pinus merkusii*, which has economic value from its resin and timber, has the potential to create a conflict of interest between conservation and extraction objectives. Rakatama and Pandit (2020) revealed that conservation programs that ignore the economic needs of local communities are likely to experience resistance and have low success rates in the long run. The development of performance-focused incentive schemes, such as payments for ecosystem

services, can link conservation interests with community economies. In factory settings, green initiatives that focus on improving the quality of the work environment provide indirect benefits to employee productivity and well-being. Wolf et al. (2020) reported that a workplace with good plant cover can increase employee efficiency by 8-12% and reduce work stress levels by 15-20%. This aspect provides an additional benefit to the greening program in the plant area, supporting its primary function of reducing the ecological footprint.

CONCLUSION

Research on ecological footprint mitigation at PT Organon Pharma Indonesia shows significant differences in carbon sequestration across the three sites managed by the company. The Seroto Block conservation area has the highest carbon stock (40.39 tons/ha) with a total CO_2-equivalent of 462.56 tons, far exceeding the mill area (10.77 tons carbon/ha) and the minimal planting area. The effectiveness of carbon sequestration is strongly influenced by vegetation composition and structure, with the dominance of *Pinus merkusii* in the conservation area and *Mangifera indica, Pterocarpus indicus*, and *Filicium decipiens* in the mill area contributing the most to carbon stocks.

PT Organon Pharma Indonesia's environmental management program has shown a positive contribution to climate change mitigation with a total CO_2-equivalent absorption of more than 558 tons, equivalent to the annual emissions of approximately 100 passenger vehicles. However, there are several development opportunities to improve the effectiveness of the program, including diversification of plant species in conservation areas, implementation of intensive care in planting areas, optimization of vegetation stratification in factory areas, and strengthening the integration of socio-economic aspects through the selection of economic value plants. The implementation of management strategies tailored to the environmental characteristics of each location has the potential to significantly increase carbon sequestration, supporting the achievement of Indonesia's national targets in reducing greenhouse gas emissions.

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