Economic valuation on carbon sequestration and carbon stocks at green open space based on cost of illness

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Abstract. Green open space is an open area to grow plants that functions as a balancer to urban ecosystems. Unfortunately, the condition of the green open space has declined and impact on human health at a certain level. This study aims to measure the value of ecosystem services for carbon sequestration and stock based on Cost of Illness (COI). The study was conducted at Tegalega, sub area of Bandung City, which is the most populous area in Bandung. Data collection was carried out in two activities. The tree data collection was done by sampling as much as 15%. On the other hand, the health problem data collection was done through interviews with COI method. The results showed that the potential of green open space in absorbing carbon was 126,321.96 kg CO₂.hectare⁻¹.year⁻¹ and carbon stocks in current green open space were 47,319 kg.hectare⁻¹. The value of COI from the availability of current green open space is IDR 288,777,324,987 per year. This value shows the high costs of health that caused by carbon pollution to human in a certain area. The average value of one tree with the service of absorbing and storing carbon is IDR 1,236,566,136.

1. Introduction

Green open space is an open area as a place to grow plants. In urban area, green open space has a proportion of at least 30% of the total area that expected to guarantee the balance of urban ecosystem[17]. However green open space is often converted into residence because of the increase of population is not balanced with the provision space. This is also accompanied by an increase of motorized vehicles pollution, especially CO₂. This condition effects on the decreasing of the environmental quality and impacts on human health at a certain level.

Bandung is a city with high population growth. According to the Bandung City Central Bureau of Statistic, the density of Bandung’s population reaches 14,986 people.km⁻², with the densest area is Tegalega, sub area of Bandung, with a density of 24,048 people.km⁻². In 2017, the number of motorized vehicles was 1,811,498 units [2]. On the other hand, the existence of green open space did not reach the proportion that it should have been. According to DPKP3’s data, the total of green open space in Bandung only reaches 12.15% with the green open space plan in Tegalega is 67.75 hectares.

Based on the problem found these matters, the valuation of green open space is needed to illustrate the importance of ecosystem services produced by trees. One of the possible solution known as economic valuation is needed to be done. This method is giving value to goods and services produced by natural resources both on market and non-market value. This valuation can be done using the Cost of Illness (COI) method of various diseases that emerge from air pollution. Thus this study aims to measure the potential and monetary value on carbon sequestration and stocks at green open space based on COI.
2. Materials and Methods

This study was conducted in Tegalega, sub-area of Bandung City (Figure 1). The methods in this study used tree and health problem data. The data collection is done by purposive sampling method, which is a sampling method that deliberately selecting samples to provide important information that cannot be obtained from other samples. In this study, the sampling area for tree data collection is 15%, based on field condition. Each tree is measured in diameter and identified by species.

![Figure 1. Research Sites](image)

Health problems data are divided into type of illness, number of sufferers, also procedures and medical expenses. The type of disease and treatment procedures are obtained from interview with doctors. The number of patients was obtained from Bandung City Health Office and 13 health centers in Tegalega. Medical expenses calculated based on National Health Insurance Program, stated in Minister of Health Regulation Number 52 of 2016 concerning Health Service Tariff Standards in the Implementation of Health Insurance Programs.

2.1. Tree data analysis

Tree data is used to calculate carbon sequestration and stocks at green open space. In addition, tree data were also analyzed for density and diversity that needed for this study. Theses analyzes used mathematical and allometric equations as follows:

- Tree density [14]

\[
D = \left( \frac{n_i}{he} \right) = \frac{n_i}{g} \cdot \frac{o}{s} \cdot \frac{t_i}{a}
\]
Shannon Wiener diversity index [12]

\[ H' = - \sum_{i} \frac{n_i}{N} \ln \frac{n_i}{N} \]

with:
- \( H' \): Shannon Wiener diversity index
- \( n_i \): Number of individuals to \( i \)
- \( N \): Total number of individuals

The Shannon-Wiener diversity index criteria are divided into three categories, which are:
- a. \( H' < 1 \), low diversity
- b. \( 1 < H' < 3 \), medium diversity
- c. \( H' > 3 \), high diversity

\[ \text{CO}_2 \text{ absorption rate } [16] = \times (3) \]

\[
N \text{ CO}_2 = \sum_{i} \frac{n_i}{N} \times V_i \times \text{ CO}_2 S_i
\]

\( N \text{ CO}_2 \): CO\text{2} absorption rate (kg.year\textsuperscript{-1})

The value of CO\text{2} Sequestration obtained from previous studies that have calculated the average value of the CO\text{2} uptake of each species each year.

\[ \text{Carbon stocks} \]

Estimating the value of carbon storage using an allometric model is one of the non-destructive calculation methods. Calculation of carbon storage using this method begins with measuring the DBH from a tree trunk which can then be calculated and produce biomass values and can be converted into carbon storage values and carbon sequestration. Biomass calculations are carried out using allometric formulas as follows:

| Species                  | Allometric model                                      |
|--------------------------|-------------------------------------------------------|
| Pterocarpus indicus [4]  | \( Y = e \times (-2,134 + 2,530 h_i \times L_i) \)   |
| Swietenia macrophylla [1] | \( Y = 0,048 \times D^{2.6} \)                       |
| General (branched tree) [5] | \( Y = \pi \times e \times (-1,499 + 2,148 h_i \times L_i + 0,207 (h_i \times L_i)^2 - 0,0281 (h_i \times L_i)^3) \) |

\( Y \): Tree biomass (kg)
\( D \): Diameter (cm)
\( \rho, \pi \): Wood density (g/cm\textsuperscript{3})

Carbon stocks are calculated using equations as follow [6]

\[ C_s = 0,46 \times Y \times t \]

Carbon absorption values are calculated using equations as follow [3]

\[ C \alpha v = c \times s \times 3,67 \]

2.2. Analisis Cost of Illness (COI)

COI analysis was carried out using a prevalence-based approach, which is estimating direct and indirect economic burden as a result of the total number of cases that occurred at a certain time in an area [9]. However, this study only calculated the direct costs. The cost for each disease is totaled to get the final
result. This value can be calculated through a modified mathematical approach from the Regulation of the Minister of Environment No 15/2012 as follows [18]:

\[ C = \sum_{i=1}^{n} x_i \times b_i \]

with:
\( x_i \): number of patients of case \( i \)
\( b_i \): cost incurred for \( i \) disease for one year

3. Result and Discussion

3.1. Tree compositions at green open space

The results of the vegetation analysis showed that there were 38 species of trees with a total of 2,691 individuals at green open space sampling area of 10.53 hectares. Green open space with the function and location as green belt has the highest number of trees (2,466 individuals), while those located in settlements are 255 individuals, consisting of playgrounds (77 individuals), sport fields (104 individuals), yards (36 individuals), and other functions (7 individuals). The number of trees in each green open space can be seen in Figure 2.

The difference in the number of individuals in green open space caused different tree densities. The yard has the highest tree density of 945 trees/hectare (Figure 3). This is because of the function of this area is usually used as living pharmacy and noise reducer. Plants are able to reduce noise with effectiveness determined by plant thickness and density, the closer the vegetation, the higher the effectiveness [15]. In addition, trees planted with irregular distance so the density becomes higher. Meanwhile the playground has another main function so the area is dominated by pavements that cause the distance between trees is not too close.
Figure 3. Tree density at each green open space functions

The diversity of tree species varies. However, all forms of green open space have a medium diversity index, which is between 1-3. The yard has the highest diversity index, while the lowest is the green belt (Table 2).

Table 2. Shannon Wiener Diversity Index

| No.  | Green Open Space Function | Diversity Index |
|------|---------------------------|-----------------|
| 1    | Yard                      | 2.4             |
| 2    | Playground                | 2.35            |
| 3    | Sport field               | 1.9             |
| 4    | Other functions           | 1.55            |
| 5    | Green belt                | 1.3             |

The low biodiversity in the green belt is influenced by aesthetic factors, where plants planted along the path are more uniform and neatly arranged, too much species diversity can cause chaos [8]. While the plants in the yard does not require neat arrangement. The yard can be planted with various types of plants that have benefits for community so that a yard will not be dominated by only one type of plant.

3.2. CO₂ sequestration

Based on Table 2, the total of CO₂ that can be absorbed by green open space is 1,330,114.94 kg CO₂.year⁻¹. Polyalthia longifolia has the highest absorption, which is 403,514.88 kg.year⁻¹. The high total absorption capacity of P. longifolia caused by the number of individuals and its high absorption capacity. P. longifolia can absorb 6,304.92 kg CO₂.year⁻¹ [18]. There are 64 individuals so that the amount of absorbance is huge. Although the amount of Swietenia macrophylla is abundant, the absorption of S. macrophylla much lower than P. longifolia and caused the absorption is not greater than P. longifolia. Likewise for Samanea saman, even though its absorption capacity is large (28,488.8 kg CO₂.year⁻¹), the amount of S. saman is only seven individuals, so it cannot absorb greater amount than P. longifolia. Based on the total area of studied, the absorption of CO₂ is 126,313.96 kg CO₂.year⁻¹.hecate⁻¹.

The ability of trees to absorbs CO₂ differently in each species. The amount of CO₂ absorption of each species can be seen in Table 3.
### Table 3. Absorption of CO₂ per Tree Type.

| No  | Species                      | Number of tree (individuals) | Total of CO₂ absorption (kg.year⁻¹) | No  | Species                      | Number of tree (individuals) | Total of CO₂ absorption (kg.year⁻¹) |
|-----|------------------------------|------------------------------|--------------------------------------|-----|------------------------------|------------------------------|--------------------------------------|
| 1   | *Acacia auriculiformis*      | 1                            | 48.68                                | 20  | *Mimusops elengi*            | 1                            | 34.29                                |
| 2   | *Annona muricata*            | 2                            | 157.24                               | 21  | *Morinda citrifolia*         | 8                            | 16,557.6                             |
| 3   | *Annona reticulata*          | 4                            | 314.48                               | 22  | *Muntingia calabura*         | 41                           | 215.66                               |
| 4   | *Artocarpus altilis*         | 31                           | 5,974.32                             | 23  | *Pithecellobium dulce*       | 1                            | 30.95                                |
| 5   | *Artocarpus heterophyllus*   | 44                           | 5,566.44                             | 24  | *Persea americana*           | 6                            | 50.88                                |
| 6   | *Averrhoa carambola*         | 1                            | 55.45                                | 25  | *Plumeria rubra*             | 34                           | 1,741.14                             |
|     |                              |                              |                                       |     | *Polalthia longifolia*       | 64                           | 403,514.88                           |
| 7   | *Bauhinia purpurea*          | 17                           | 198,269.13                           | 26  | *Pometia pinnata*            | 43                           | 14,179.68                            |
| 8   | *Cassia siamea*              | 19                           | 100,613.93                           | 27  | *Psidium guajava*            | 29                           | 11,327.69                            |
| 9   | *Cassarina equisetifolia*    | 5                            | 1,971                                | 28  | *Pterocarpus indicus*        | 55                           | 611.6                                |
| 10  | *Cerbera manghas*            | 20                           | 16,976.8                             | 29  | *Punica granatum*           | 2                            | 885.26                               |
| 11  | *Dalbergia latifolia*        | 10                           | 111.2                                | 30  | *Samanea saman*             | 7                            | 199,418.73                           |
| 12  | *Delonix regia*              | 79                           | 3,333.8                              | 31  | *Spathodea campanulata*      | 1                            | 211.64                               |
| 13  | *Erythrina cristagalli*      | 3                            | 13.65                                | 32  | *Swietenia macrophylla*      | 1,852                        | 211,183.56                           |
| 14  | *Ficus benjamina*            | 65                           | 36,535.85                            | 33  | *Swietenia mahagoni*        | 11                           | 3,253.03                             |
| 15  | *Ficus lyrata*               | 27                           | 15,176.43                            | 34  | *Syzygium aquum*            | 9                            | 14,428.8                             |
| 16  | *Filicium decipiens*         | 6                            | 2,428.98                             | 35  | *Syzygium malaccense*       | 2                            | 3,206.4                              |
| 17  | *Gmelina arborea*            | 2                            | 217.42                               | 36  | *Tabebuia argentea*         | 86                           | 19,737.86                            |
| 18  | *Mangifera indica*           | 85                           | 38,689.45                            | 37  | *Terminalia mantaly*        | 12                           | 2,539.68                             |
| 19  | *Michelia alba*              | 6                            | 531.36                               | 38  |                             |                              |                                      |
|     | Total individuals            | 2,691                        |                                       |     | Total of CO₂ absorption     | 1,330,114.94                  |                                      |
|     |                               |                              |                                       |     | (kg.year⁻¹)                 |                              |                                      |

### 3.3. Carbon stocks

Carbon stocks can be known by calculating biomass from trees. The result of the analysis of biomass, carbon stocks, and carbon absorption values can be seen in Figure 4.

![Figure 4. Total Biomass, Carbon Stocks, and Carbon Sequestration](image-url)
The calculation results show that until early 2019, the biomass in sampling area was 1,083,193.58 kg, carbon stocks were 498,269.05 kg, and carbon sequestration was 1,828,647.4 kg (Table 4). Thus biomass, carbon stocks, and carbon sequestration that exist were 102,876 kg/hectare, 47,319 kg/hectare, and 173,660.72 kg/hectare.  

Table 4. Biomass, carbon stocks, and carbon sequestration values

| No. | Green Open Space Function | Biomass (kg) | Carbon stocks (kg) | Carbon Sequestration (kg) |
|-----|---------------------------|--------------|--------------------|--------------------------|
| 1   | Playground                | 100,638.00   | 46,293.48          | 169,897.07               |
| 2   | Sport Field               | 29,188.53    | 13,426.72          | 49,276.08                |
| 3   | Green belt                | 923,986.86   | 425,033.96         | 1,559,874.62             |
| 4   | Yard                      | 20,618.38    | 9,484.46           | 34,807.95                |
| 5   | Other function            | 8,761.80     | 4,030.43           | 14,791.67                |
|     | **Total (kg)**            | **1,083,193.58** | **498,269.05**   | **1,828,647.4**        |

Biomass is influenced by several factors, such as diversity of tree species, soil type, litter production, and age of trees, the amount of carbon storage depends on plant diversity and density, soil fertility and how to manage it. Tree density affects on carbon stocks, the denser the stand, the higher biomass [7]. Diversity also affects carbon stocks which can be seen in the comparison of plantations and natural forests. In plantations, which tend to be monoculture, carbon deposits are lower [11]. Thus, the lower diversity, the lower carbon stocks. However, in this study, the highest biomass, carbon stocks, and carbon sequestration value is determined by green belt, not by yard which has the highest value of tree density and diversity. This happens because of the differences in number of individuals and large area between each function.

3.4. **Cost of Illness**

Air pollution has relation to human’s health problems. Based on the interviews done, there were 10 diseases that may emerge from carbon pollution with a total of 115,001 people, as shown in the Figure 5.

![Figure 5. Number of Patients with Health Problems](image)

From the data in Figure 5, there are costs that must be compensated to cure the diseases (Table 5). In this study there were three types of direct costs calculated; health cost at first level health facilities (FKTP), and advanced referral health facilities (FKRTL). FKTP has a capitation rate of IDR 3,000. The capitation rate is based on the condition of health facilities in the field. FKRTL fee covers all components of hospital resource, both medical and non-medical services. This is called INA-CBG. This study used the average rate of government and private hospital in first regional which cover Banten, DKI Jakarta, West Java, Central Java, DI Yogyakarta, and East Java.
In Table 5 can be seen that the total value from health problems that occurs due to carbon pollution is IDR 288,777,324,987. This shows that in one year, each person spends an average of IDR 2,511,085 for medical treatment. When it is compared to minimum wage of West Java Province in 2018, which is IDR 1,544,360 then 13.5% of the wages received by the community will be spent to treat the disease. This amount is equal to the costs that people spend for goods and services in one year.

The value will also affect the increase in the level of poverty and a decrease in welfare. People who are classified as poor have lower spend of goods and services, including health services. If carbon pollution causes an expenditure of 13.5% of the wages earned, the poor population will tend to avoid health services. Thus, poverty and health have inseparable reciprocal relationship, poor health causes poverty, and poverty leads to poor health.

Through this study we can see that although the value is relatively high, this value can be said to be undervalued. This is because the monetary value based on INA-CBG is far lower than the value that should be spent without JKN. JKN allows participants to get health services with lower out of pocket than the people who do not have health insurance. However, the value set for each treatment has a considerable different with the actual value. This is supported by previous research conducted by Lilissuriani et al. [10] that shows there were significant difference in value between the real value and INA-CBG.

Based on the total value, the price of CO$_2$ sequestration in this study was IDR 33,744.kg$^{-1}$.year$^{-1}$. In this study, one tree had a value ranging from IDR 153,536 to IDR 961,312,233. Thus the average value of one tree for absorbing CO$_2$ in one year is IDR 53,350,340. The price of tree’s carbon stocks in this study is IDR 90,008.kg$^{-1}$. The current value of the ability of one tree to store carbon ranges from IDR 831,721 to IDR 22,556,739,061 with an average of IDR 1,180,215,796. Thus the average value of one three in current green open space is IDR 1,236,566,136.

From these value, it can be seen that trees and green open space in urban area plays important role in maintaining urban ecosystems. Not only in terms of ecology, but also health and economy. By providing adequate green open space in urban area can minimize medical costs that may emerge due to air pollution.
4. Conclusion
Based on the results of this study, the potential of green open space in Tegalega for absorbing carbon at this time is 126,313.96 kg CO$_2$ year$^{-1}$hectare$^{-1}$ and the value of carbon stocks are 47,319 kg.hectare$^{-1}$. The value of Cost of Illness that emerges from carbon pollution is IDR 288,777,324,987.00.year$^{-1}$ so that the average value of one tree with services to absorb and store carbon is IDR 1,236,566,136.00.

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