Potential of Carbon Stocks and Its Economic Values in Tropical Karst Landscape (Case Study in Biduk-Biduk Karst, East Kalimantan, Indonesia)

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Abstract. Karst especially tropical karst landscape has a potential value to store an amount of both organic and inorganic carbon. Tropical karst landscape can store organic carbon derived from forest ecosystem biomass that covers this karst landscape. While inorganic carbon stocks in tropical karst landscape are stored on carbonate rock (CaCO₃). This potential can be calculated to identify the economic carbon value to support carbon trade program in East Kalimantan, Indonesia. This research aims to (1) identify carbon stocks value from organic and inorganic carbon in the study area; (2) calculate economic carbon value in the study area. Organic carbon stocks were measured using field measurement to calculate aboveground, belowground, and litter biomass. Calculation of aboveground, belowground, and litter biomass was measured based on the standard method in SNI 7724: 2011. X-Ray Fluorescence (XRF) method was used to identify the CaO concentration in carbonate rock. This CaO concentration was measured to calculate carbon (C) concentration in carbonate rock formation namely inorganic carbon stocks. Economic carbon value was calculated using cost-benefit transfer method. Biduk-Biduk Karst Region has a big value of organic carbon stocks of 0.007 Pg-C and inorganic carbon stocks of 9.02 Pg-C. Therefore, the total carbon stock in Biduk-Biduk Karst Region is 9.037 Pg-C. Based on the total value of carbon stocks, Biduk-Biduk Karst has a total economic value of US$ 45,171,544,296.

1. Introduction

The potential of global carbon storage has become one of the interesting topics in a few decades ago. The impact of global climate change that is increasingly felt in the last few decades makes efforts to reduce factors causing this phenomenon need to be done. One of the biggest factors that occur global climate change is greenhouse gases accumulation in the atmosphere. One of greenhouse gas constituents is carbon dioxide which has a significantly increased. An effort to reduce the amount of
carbon in the atmosphere is initiated to inventory the potential of carbon stocks in various ecosystems [1], [2], [3]. The inventory of carbon stocks potential is intended to protect ecosystems that have ability to store carbon. The preservation of these ecosystems can reduce the number of carbon emissions into the atmosphere. Therefore, research to find and calculate the potential of carbon stocks in various ecosystems become one of the interesting topics for climatic researchers.

Until now, research on carbon stocks that have developed in Indonesia is focused in vegetation (green carbon), soil, and ocean (blue carbon) stocks [4], [5], [6]. Even though, there are still a lot of carbon stocks potential that have not been widely studied, such as the carbon stocks potential in rock formations. According to previous research, the potential value of carbon stocks in rock formations is greater than the potential of carbon storage in vegetation and soil. Estimation of carbon storage in rocks is 10,000 Pg C. This value is just lower than the potential of carbon stocks in the ocean of 38,000 Pg-C [7], [8], [9].

One of the rock formations that have the ability to store the number of carbon is carbonate rocks or limestones [10]. Carbon is stored inside the limestone body which has the chemical formula of CaCO3. Carbon storage in the limestone body is known as inorganic carbon stocks. Carbon in limestone will be stored forever unless there is a limestone extraction or processing process. The processing of limestone for various purposes such as a mixture of cement, building materials, fertilizer materials, and the pest is carried out to produce pure carbonate elements. The limestone purification process is carried out by releasing carbon elements in the limestone body into the atmosphere. Therefore, if limestone is still preserved, the potential of the karst region in storing this amount of carbon can help in reducing global carbon emissions.

In addition, some karst regions also have the potential to store organic carbon [11], [12]. Karst regions which have a double potential to store carbon both organic and inorganic are karst regions with forest ecosystems cover. Karst regions with forest ecosystems cover are often found in the karst region with a tropical climate called tropical karst [12], [13]. In tropical karst regions, there are still many karst landscapes that are covered by tropical rainforest ecosystems. Tropical rainforest ecosystems are one of ecosystems that has big potential to store organic carbon. In addition, carbon storage in this ecosystem is used as an indicator of achieving efforts to reduce carbon emissions. In previous research, potential value of organic carbon stocks in tropical rainforest ecosystems ranges from 190-221 Pg-C [14] or 40% of all terrestrial carbon stocks above the surface [15], [16], [17]. The ability of tropical karst region to store organic and inorganic carbon can help to achieve carbon emissions reduction targets at the regional, national and global scale.

Tropical karst regions are spread in the country which has tropical climate such as Brazil, South Africa, Malaysia, Indonesia, etc. Karst in Indonesia is spread in all of islands such as Pidie, Baturaja, Sarolangun Karst Region in Sumatera Island; Citatah-Rajamandala, Gombong, Gunungsewu, Kendeng, South Malang Karst Region in Java Island; Sangkulirang-Mangkalihat Karst Region in Kalimantan Island; etc. The total area of karst landscapes that cover Indonesia is 140,000 km2 [18]. One of the tropical karst region in Indonesia which is still dominated by forest ecosystems is Biduk-Biduk Karst Region [19]. The Biduk-Biduk Karst Region is part of the Sangkulirang-Mangkalihat Karst Region. The Biduk-Biduk Karst Region is located at the eastern of Berau Regency, East Kalimantan Province. This area was developed on carbonate rocks in the Lebak, Karangan, and Domaring Formation. The Biduk-Biduk Karst Region is relatively close to the coastal area. The dominant land cover in this karst region is primary and secondary forest ecosystems. Primary forest ecosystems that develop in the Biduk-Biduk Karst Region are included in the Dipterocarp forest with
dense of vegetation canopy. Meanwhile, secondary forest ecosystems are developed in forestry concessions that have been abandoned for a long time.

Carbon in the Biduk-Biduk Karst Region is stored in the forest ecosystems and carbonate rock formation. Forest ecosystems as a land cover in the study area can store a number of organic carbon. Organic carbon is stored in aboveground in forest vegetation, belowground in the root zone, and forest litter. Meanwhile, karst ecosystem plays a role in storing a number of inorganic carbon. Inorganic carbon is stored in the carbonate rock as a constituent of the Biduk-Biduk Karst Region. The double potential of Biduk-Biduk Karst Region in storing carbon can help to achieve reducing carbon emissions targets in East Kalimantan and Indonesia by 26% (Presidential Regulation No. 61: 2011) through efforts to increase carbon stocks. Therefore, this area can be used as a supporting area in the REDD + program in Berau District, East Kalimantan Province, Indonesia.

The benefit value produced by the Biduk-Biduk Karst Region in terms of carbon storage needs to be quantified. The direct use value of the Biduk-Biduk Karst Region can be determined by calculating an economic value that can be generated from the region's ability to store carbon. This value can be included in the global carbon trade scheme. The global carbon trade is an incentive or compensation scheme for carbon storage countries from carbon-producing countries because it has safeguarded and preserved these carbon reservoirs. The provision of incentives or compensation is calculated based on the value of carbon stocks that can be produced using standard carbon prices in the global market. The greater potential of carbon storage can be generated the greater an amount of incentives or compensation given. The double potential of the Biduk-Biduk Karst Region to store carbon storage can increase the economic value generated in carbon trade schemes. Therefore, it is necessary to quantify organic and inorganic carbon stocks as well as the economic carbon value that can be generated in the Biduk-Biduk Karst Region. Based on this background, this study aims to (1) identify the potential of carbon stocks value from organic and inorganic in the study area; (2) calculate economic carbon value in the study area.

2. Study Area

This research was conducted in the Biduk-Biduk Karst Region. Biduk-Biduk Karst Region is a part of Sangkulirang-Mangkalihat Karst Region which is located in Berau District, East Kalimantan Province, Indonesia. Biduk-Biduk Karst Region is nearly close to the equator line, so this area has a tropical climate zone. Annual rainfall in the Biduk-Biduk Karst Region is 2521 mm/year with the absence of a dry month for a year (rainfall under 100 mm/month). The average air temperature in the study area is 26.4–27.4°C. Based on the Koppen climate classification, the study area is included in the Af climate with the absence of dry months for a year and relatively warm air temperatures each year.

Biduk-Biduk Karst Region was developed in the area with lithology of coral limestones and crystalline limestones in the Domaring Formation (Tmpd); bioclastic limestones with an interlude of breccia in the Lebak Formation (Toml); and bioclastic limestones with coral limestone inserts in the Karangan Formation (Teok) [20]. Three lithologies were deposited in a shallow-neritic environment in Tertiary times. Each lithology in the Biduk-Biduk Karst Region will form different geomorphological units.

Geomorphological units in the study area were controlled by three main processes, namely solutional, marine, and structural. These processes form three geomorphological units in the Biduk-Biduk Karst Region. Geomorphological units that can be identified are karst plain, terrace marine
solutional 1, and terrace marine solutional 2. The Karst Plain has a wavy morphology with a slope ranging from 0–13%. Lithology in the Karst Plain is coral limestones and crystalline limestones in the Domaring Formation (Tmpd). Terrace Marine Solutional 1 has a hilly morphology with a slope ranging from 8–80%. Lithology in the Terrace Marine Solutional 1 is bioclastic limestone with an interlude of coral limestone in the Karangan Formation (Teok). Karst features that can be found in this geomorphological unit are “ceruk”, ponors, and limestone pavement. Terrace Marine Solutional 2 was exposed after Terrace Marine Solutional 1. Terrace Marine Solutional 2 has hilly morphology with a slope of 8–55%. Lithology of Terrace Marine Solutional 2 is the intersection of bioclastic limestone with breccia in the Lebak Formation (Toml). Karst features that can be found in this geomorphological unit are clustered conical hills and cockpits.

Biduk–Biduk Karst Region has nine terrestrial ecosystems as a result of interactions among the three components of the abiotic, the biotic, and cultural environments. These ecosystems are spreading with the dominance of tropical forest ecosystems belonging to the Dipterocarpaceae forest type, both primary and secondary. Other ecosystems formed by human activities both crop cultivation and built land area are scattered throughout the Biduk–Biduk coastal area. The distribution and types of terrestrial ecosystems in the Biduk - Biduk Karst Region can be seen in Figure 1.

![Figure 1. Distribution of Ecosystem in Study Area](image)

3. Method

3.1. Data Collecting
Data collected in this study were organic carbon stocks, NDVI data, limestone volume, CaO content in limestones, and price of carbon. Organic carbon stocks that were measured in this study consists of aboveground carbon in vegetation, belowground carbon in root zone, and litter carbon storage. All of organic carbon stocks data were obtained by making a plot sample measuring 12x12 meters. Organic carbon stocks were measured based on the standard for measuring forest carbon stocks of SNI 7724: 2011. Organic carbon stocks were measured in nine ecosystems at December 2016. NDVI data in each ecosystem were obtained from SPOT 7 image processing in November 2016.

Limestone volume was measured using the cut and fill method. Data used to calculate limestone volume was DEMNAS imagery issued by the Geospatial Information Agency. Limestone volume that was measured in this study was only limestone above the surface ground because the extraction of limestone is only done on limestones above the ground. Limestone volume was calculated in each difference of lithology or rock formations.

CaO content in limestones was obtained from laboratory analysis using X-Ray Fluorescence (XRF) methods. Limestone samples analyzed in the laboratory were limestones in Lebak, Domaring, and Karangan Formation. The difference of depositional environment in each lithological formation can cause differences in the purity of the limestone. Therefore, the inorganic carbon stocks will also vary in each lithological formation.

Price of carbon was obtained by a literature review on previous research and data from government agencies, namely REDD+ Working Group in Berau District. The price of carbon used in this study was $5USD. This value was taken from the lowest compensation value in the carbon trading scheme that has been applied in Indonesia Country.

3.2. Data Analysis

Total organic carbon storage from vegetation, subsurface layer, and litter was analyzed with regression method. Regression was done to create a model of organic carbon stocks determination in vegetation layer based on the NDVI value. NDVI was calculated using the formula number 1. Total organic carbon stocks in the study area can be calculated by summing the value of organic carbon stocks in the nine ecosystems.

\[ \text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})} \]  
(1)

Where NIR is reflectance value of Near-Infrared Band; and Red is reflectance value of Red Band.

Inorganic carbon stocks in the limestone bodies were calculated using the formula number 2.

\[ M\ C = \left( \frac{\text{Ar C}}{\text{Mr CaCO}_3} \right) \times \left( \frac{\text{Mr CaCO}_3}{\text{Mr CaO}} \right) \times \%\text{CaO} \times \text{BJ CaCO}_3 \times \text{V CaCO}_3 \]  
(2)

Where M C is the mass of carbon in limestone (g); Ar C is the relative atomic mass of carbon (12 g/mol); Mr CaCO$_3$ is the relative atomic mass of CaCO$_3$ (100 g/mol); Mr CaO is the relative atomic mass of CaO (56 g/mol); % CaO is the percentage of CaO content in limestone from laboratory analysis; BJ CaCO$_3$ is the specific weight of CaCO$_3$ (2.71 g/cm$^3$); and V CaCO$_3$ is the volume of limestone. The total value of carbon stocks potential can be calculated by summing the potential of organic carbon stocks and inorganic carbon stocks.
Economic carbon value was calculated using the cost-benefit method. The cost-benefit method is a method to calculate economic carbon value using price of carbon from previous studies or a carbon price standards that have been applied in Indonesia Country. The price of carbon used in this study was $5USD per tonne of carbon. The economic value of carbon in the study area can be calculated using formula number 3.

\[
ECV = (OCS + ICS) \times CV
\]  

(3)

Where ECV is a total economic carbon value that can be generated; OCS is the total amount of organic carbon stocks (tons); ICS is the total amount of inorganic carbon stocks (tons); and CV is a standard price of carbon per tones.

4. Results

4.1. Organic Carbon Stocks

Organic carbon stocks are the number of carbon stored in vegetation, litter, and root zone. Organic carbon stocks in Biduk-Biduk Karst Region can be calculated by regression analysis between NDVI values and the organic carbon value in the field measurement. Regression analysis will produce a model that can be used to calculate organic carbon stocks using NDVI data. NDVI is assumed to describe vegetation density in the study area. The NDVI value was obtained by processing imagery that has a red band and near-infrared band.

Modeling results using SPOT 7 show that NDVI values in study area ranging from 0 – 0.904. NDVI with the value of 0 illustrates low vegetation density. This value is spread in residential areas and water bodies like rivers or lake. Whereas, NDVI with the value of 0.904 illustrates high vegetation density both primary and secondary forest ecosystems. The rate of NDVI in the study area has a big value of 0.703. This condition happens because land cover in the study area is still dominated by forest ecosystems, either primary or secondary, which have big NDVI values. The distribution of NDVI values in the study area can be seen in Figure 2.
Based on NDVI values, the value of carbon stocks in aboveground (vegetation), belowground (root zone), and litter can be calculated. This value can be approached using the result of a regression formula between NDVI values and organic carbon stocks in each carbon sink. The regression used in the study area is exponential regression. The regression result is $y = 0.0098e^{13.598x}$. This regression was chosen because it has a greater coefficient of determination and smaller RMSE value than the other regression. RMSE value from this exponential regression is much lower than the standard deviation of aboveground carbon stocks. Spatial distribution of aboveground carbon in the study area has a similar pattern with NDVI value (see Figure 3). The biggest value of aboveground carbon is found in the area with big NDVI values in primary and secondary tropical forest ecosystems.

Based on the spatial distribution of each organic carbon stocks in Figure 3, potential of organic carbon stocks in nine ecosystems can be calculated. The results of organic carbon stocks calculation in nine ecosystems in the study area can be seen in Table 1.
Figure 3. Distribution of Aboveground and Belowground Carbon in Biduk-Biduk Karst Region

Table 1. Organic Carbon Stocks in Biduk-Biduk Karst Region

| Ecosystem                          | Aboveground Carbon Stocks (ton/ha) | Underground Carbon Stocks (ton/ha) | Litter Carbon Stocks (ton/ha) | Total Carbon Stocks (ton/ha) | Area (ha) | Organic Carbon Stocks (ton) |
|------------------------------------|-----------------------------------|----------------------------------|------------------------------|------------------------------|-----------|----------------------------|
| Primary Tropical Forest with Medium Density | 132.001                           | 103.916                          | 6.441                        | 242.358                      | 11721.20  | 2,840,728                  |
| Secondary Tropical Forest with High Density | 136.997                           | 107.848                          | 6.141                        | 250.986                      | 13868.72  | 3,480,851                  |
| Secondary Tropical Forest with Medium Density | 131.976                           | 103.896                          | 2.539                        | 238.412                      | 2701.49   | 644,068                    |
| Teak Forest Plantation             | 110.438                           | 86.941                           | 4.114                        | 201.492                      | 43.04     | 8,673                      |
| Sengon Forest Plantation           | 114.393                           | 90.054                           | 4.429                        | 208.877                      | 68.98     | 14,408                     |
| Rubber Estate                      | 111.780                           | 87.997                           | 3.249                        | 203.026                      | 271.16    | 55,052                     |
| Palm Oil Estate                   | 125.573                           | 98.855                           | 1.362                        | 225.790                      | 298.84    | 67,475                     |
| Coconut Estate                    | 93.672                            | 73.742                           | 4.821                        | 172.234                      | 657.93    | 113,319                    |
| Shrubs                             | 82.482                            | 64.932                           | 6.811                        | 154.225                      | 3736.65   | 576,284                    |
| **Total**                          |                                   |                                  |                              | **7,773,358**                |           |                            |
The biggest density value of organic carbon stocks is found in high-density secondary forest ecosystems of 250.9 tons/ha. Meanwhile, the lowest value is in the shrubs ecosystem of 82.4 tons/ha. The average value of organic carbon stocks density in the study area is relatively high of 210.8 tons/ha. This condition happens because forest ecosystems with high organic carbon stocks are spread evenly across all study areas. Secondary tropical forest ecosystem with high vegetation density is dominated in the study area. This secondary forest formed in abandoned forest concessions since the early of the 1990s. The total value of organic carbon stocks in the Biduk-Biduk Karst Region is 0.007 Pg-C.

4.2. Inorganic Carbon Stocks

Inorganic carbon stocks were calculated by considering volume and carbon content inside limestone bodies (CaCO$_3$). Limestone volume to calculate inorganic carbon stocks was carried out in each difference rock lithology. Each rock lithology is assumed having different values of carbonate purity so the carbon content will also varied. Calculation results of limestone volume in each lithology or rock formation are presented in Table 2. Based on this calculation, the total volume of the Biduk-Biduk Karst Region is 31,822,183.653 m$^3$ in four lithological formations.

| Lithology        | Volume (m$^3$) |
|------------------|----------------|
| Domaring Formation | 1,455,389,811  |
| Golok Formation   | 719,749,357    |
| Karangan Formation| 9,377,983,970  |
| Lebak Formation   | 20,329,060,515 |

Inorganic carbon stocks can be calculated by considering the volume and purity of carbonate content in the limestone. The purity of limestone was analyzed using rock samples in the four lithological formations to obtain CaO values. CaO values was measured using XRF method. The result of CaO calculation in three lithological formation using XRF method can be seen in Table 3.

| Lithology        | CaO (%) |
|------------------|---------|
| Domaring Formation | 47.6    |
| Golok Formation   | 40.7    |
| Karangan Formation| 46.2    |
| Lebak Formation   | 50.3    |
Rock samples with the highest CaO values are found in the Lebak Formation of 50.3%. While the lowest CaO value is found in the Golok Formation. The difference value of CaO happens due to differences in the purity of limestone. Lebak Formation has a high value of CaO because this lithological formation contains of coral limestone. Whereas Golok Formation has lithology of clastic limestone. Depositional environment of coral limestone in shallow sea causing limestone impurity is not much compared than clastic limestone which has depositional environment in the neritic zone of the sea.

A number of inorganic carbon stocks in the study area can be seen in Table 4. The biggest value of inorganic carbon stocks is found in the area with Lebak Formation of 5.93 Pg-C. Inorganic carbon stocks in the Lebak Formation have a big value due to the high volume of limestone with higher purity compared than other rock formations. Based on the calculation results, the total value of inorganic carbon stocks in the Biduk-Biduk Karst Region is 9.03 Pg-C.

### Table 4. Inorganic Carbon Stocks in Study Area

| Lithology            | Volume (m³) | Limestone Density (ton/m³) | CaO (%) | CaCO₃ (%) | CaCO₃ (ton) | Inorganic Carbon Stocks (ton) |
|----------------------|-------------|---------------------------|---------|-----------|------------|-----------------------------|
| Domaring Formation   | 1,455,389,811 | 2.71                      | 47.6    | 85.00     | 3,352,490,430 | 402,298,852                |
| Golok Formation      | 719,749,357  | 2.71                      | 40.7    | 72.68     | 1,417,610,622 | 170,113,275                |
| Karangan Formation   | 9,377,983,970 | 2.71                      | 46.2    | 82.50     | 20,966,827,661 | 2,516,019,319              |
| Lebak Formation      | 20,329,060,515 | 2.71                      | 50.3    | 89.82     | 49,484,200,464 | 5,938,104,056              |
| **Total**            | **9,026,535,502** | **2.71**                  | **50.3** | **89.82** | **5,938,104,056** |                            |

4.3. Economic Carbon Value

The important value of the Biduk-Biduk Karst Region as carbon storage can provide economic benefits. The economic value of potential carbon storage can be calculated and included in global carbon trade schemes. The ability to store an amount of carbon can provide benefits in the form of incentive or compensation money from carbon-producing countries. A distinctive feature of the Biduk-Biduk Karst Region in the tropical zone makes the potential of organic carbon stocks in this area similar to other tropical rainforest ecosystems. In addition, the ability of the study area to store some of inorganic carbon in the limestone body can increase the economic carbon value.

The economic carbon value in tropical karst areas, especially in the Biduk-Biduk Karst Region, was calculated from two potential of carbon storage both organic and inorganic carbon stocks. Based on the calculation, the total economic carbon value that can be generated in the study area is $45,181 billion USD. The economic value of inorganic carbon stocks can be produced $45,132 billion USD or 98% of total economic carbon value in the Biduk-Biduk Karst Region. Meanwhile, the economic value of organic carbon stocks can be produced $38,866 million USD or 2% total economic carbon value in the study area. The result of economic carbon calculation in the Biduk-Biduk Karst Region is presented in Table 5.
Table 5. Economic Carbon Value in Biduk-Biduk Karst Region

|                  | Total Stocks (ton) | Economic Value per ton (USD) | Economic Carbon Value (USD) |
|------------------|--------------------|------------------------------|----------------------------|
| Organic Carbon Stocks | 7,773,358          | 5                            | 38,866,790                 |
| Inorganic Carbon Stocks | 9,026,535,501     | 5                            | 45,132,677,506             |
| Total            | 9,037,339,666      |                              | 45,171,544,296             |

5. Discussion

Tropical karst region especially Biduk-Biduk Karst Region has a great potential to store an amount of carbon. The carbon stored in the tropical karst region is from organic and inorganic. This condition can be seen in the Biduk-Biduk Karst Region which has potential to store organic carbon in the forest ecosystem cover and inorganic carbon in the carbonate rocks. A double potential of carbon stocks in the tropical karst region, especially the Biduk-Biduk Karst Region, make this region has a high carbon stock value.

Based on the measurement results, the value of organic carbon stocks in tropical karst region has a high value as well as other regions in the tropical climate zone. The density of organic carbon stocks in the Biduk-Biduk Karst Region has an average value of 210.8 tons/ha. This value is similar with the value of organic carbon stocks in other tropical climate regions such as Malua Forest, Malaysia [2], Bukit Timah Nature Reserve, Singapore [16], Houzhai Watershed, China [12], and South China Karst [21]. A high density of vegetation cover is the factor which can affect highly organic carbon stocks in tropical karst regions such as Biduk-Biduk Karst Region [16], [3]. The dominance of primary and secondary forest ecosystems in the study area makes carbon stocks in the aboveground (vegetation) have a high value. Vegetation with a large diameter that is still found in many forest ecosystems in the study area can store big amounts of biomass. In addition, the absence of logging activities by forest companies that carried out in the study area in the past of 20 years has made vegetation growth optimally.

The similarity of organic carbon stocks in the study area with forest ecosystems in non-karst regions is contrary with a few previous studies. In previous study, forest ecosystems in the karst region have lower organic carbon stocks compared than forest ecosystems in non-karst regions [22], [11], [12]. This condition is mainly due to that ecosystem productivity in the karst region is limited by the availability of water in the near surface, the thinness of the soil layer, and the limited nutrient content of the soil [23], [13]. This difference finding can be due to the measurement of above-ground carbon in the study area using one allometric formula for various species of vegetation. Therefore, it is very possible that aboveground carbon calculation is overestimated. The measurement of potential carbon stock per vegetation species using different allometric formula needs to be done to improve the validity of organic carbon stocks measurement results.

Organic carbon stocks in the Biduk-Biduk Karst Region are stored in three carbon sinks in the vegetation, root zone, and litter. The highest percentage of organic carbon stocks is contributed by above-ground vegetation of 55%. Vegetation has the highest value because it has potential to store biomass in all parts of the plant such as leaf, root, stem, and branch. Meanwhile, other carbon stocks are only stored in one part such as belowground carbon only stored in plant roots. Several studies
conducted in other forest areas such as Malua Forest, Malaysia [2], Bukit Timah Nature Reserve, Singapore [16], Houzhai Watershed, China [12], Kinsangani, Kongo [17], Guizhou Karst, China [11] showed that vegetation carbon stocks have a higher value than belowground and litter carbon stocks.

Besides being able to store organic carbon, tropical karst regions also have potential to store some of carbon in carbonate rocks. Potential of carbon storage in carbonate rocks in the study area has a value of 9.03 Pg-C. This value is greater than organic carbon stocks potential from vegetation of 0.007 Pg-C. The percentage of inorganic carbon stock is 98% from total carbon stocks in the study area. Therefore, it can be concluded that the potential of inorganic stocks is greater than organic carbon stocks. This condition is similar with previous studies explained that potential of carbon storage in rock formations is one of highest carbon stocks on earth below ocean carbon stocks [24]. Previous studies stated that the potential of carbon stocks in rock formations is 10,000 Pg-C, while the potential of carbon stocks in vegetation is only 560 Pg-C [8], [9].

On the other side, inorganic carbon stocks in tropical karst regions are rarely studied. Research on carbon stocks which has been developed is organic carbon storage in vegetation and forest ecosystems [4], [5], [6]. At the global scope, efforts to reduce carbon contained in REDD+ program are still focusing on efforts to conserve organic carbon stocks in forest ecosystems. Various efforts to conserve forest ecosystems have been carried out in various ways to maintain the presence of organic carbon stocks. Whereas inorganic carbon stocks that have greater value are also very vulnerable to exploitation by mining activities. Limestone is to be one of raw materials for making building materials, cement, cosmetics, and other uses. If this is allowed, an amount of carbon released into the atmosphere due to the limestone extraction is higher and higher.

Potential of inorganic carbon stocks in tropical karst region can help increase carbon storage at the global level. The presence of inorganic carbon stocks can increase the economic carbon value in the carbon trade scheme. This condition can be seen in the study area where economic carbon value is $45 billion USD. This total value is greater than the economic value of organic carbon ($38 million USD). Therefore, inorganic carbon storage is very important to be taken into carbon trade schemes and carbon reduction efforts through REDD+ schemes. Efforts to conserve karst ecosystems as a sink of inorganic carbon also need to be considered, as well as forest ecosystems.

6. Conclusion

Tropical karst areas have a great potential to support efforts in reducing carbon emissions in the atmosphere. The ability of the tropical karst region to store an amount of carbon both organic and inorganic can help to reach the target of reducing global carbon emissions. Organic carbon stocks are stored in forest ecosystems that dominantly cover tropical karst areas. These organic carbon stocks consist of aboveground carbon in vegetation, belowground carbon in the root zone, and litter carbon. The rate of organic carbon density in the study area is 210.8 ton/ha. This potential value of organic carbon storage in tropical karst areas, especially in Biduk-Biduk Karst Region, has a similar value with organic carbon storage in non-karst forest areas. Calculation of organic carbon stocks in the study area is still carried out with an allometric approach assuming a homogeneous forest ecosystem condition. Meanwhile, forest ecosystems in the karst region have a heterogeneous vegetation species. Therefore, calculation of organic carbon stocks using allometric formulas in each vegetation species needs to be done so the calculation results are not overestimated.
The others potential carbon stocks owned by tropical karst areas is inorganic carbon stocks. Inorganic carbon is stored in limestone bodies. The total potential value of inorganic carbon stocks in the study area is 9.03 Pg-C. This value is 98% greater than the potential of organic carbon stocks. This calculation still uses a medium scale of elevation data. Therefore, a more detailed calculation of inorganic carbon stocks needs to be done using a detailed scale of elevation data.

The ability of tropical karst areas to store organic and inorganic carbon can provide higher economic benefits. The tropical karst area, especially the Biduk-Biduk Karst Region has the potential to generate an economic value of $45,171,544,290USD. The biggest contribution to total economic value in the study area came from inorganic carbon stocks of $45,132,677,506USD or 98% of total economic carbon value. Both organic and inorganic carbon stocks in tropical karst areas can be included on carbon trading schemes to provide additional income for Indonesia Country.

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