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Potential absorption and economic carbon valuation of teak (*Tectona grandis*) at Hasanuddin University City Forest for supporting emission reduction in Makassar City

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Abstract. *The diversity of plants and vegetation in the UNHAS City Forest has a positive impact on the environment. One type of plant species in the UNHAS urban forest is Teak (*Tectona grandis *L.f.). The community views Teak as a plant that only has economic potential because of the quality of its wood, but it is also necessary to know that this plant is suspected to have potential as an environmental service provider. Therefore, it is necessary to understand the ability of teak plants to absorb carbon dioxide. In this study, carbon stored in teak stands (*Tectona grandis *L.f.) was measured using a case study in the City Forest at the Hasanuddin University Campus. The method of collecting Emission data were collected from the Aksara Bappenas website, which was used to collect data on the potential of biomass in this study using non-destructive methods. The data collected included the diameter, height, and specific gravity of teak trees. The teak plant diameter was determined by surveying each individual teak plant. The emissions produced by Makassar City in 2022 will be 6,944,242.74 tons of CO_2eq. Teak trees located in the urban forest of Hasanuddin University then succeeded in reducing 455.93–482.48 tons of CO_2eq according to carbon absorption calculations. The economic value of carbon reserves located in teak stands in the urban forest of Hasanuddin University ranged from USD 206.76/IDR 2,998,020 tons/ha to USD 218.8/IDR 3,172,600 tons/ha.*

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INTRODUCTION

Climate change poses a serious global challenge facing the world. People are currently experiencing erratic weather conditions, which is one of the signs of global warming. Global warming is still an important issue, which causes the Earth's temperature to increase. On the other hand, global warming is the impact of economic activities carried out without paying attention to environmental impacts, causing an increase in temperature on Earth (Prakoso et al. 2019). Global warming originates from various human activities, such as transportation, industry, and households derived from burning fossil fuels which cause carbon emissions and the greenhouse effect (Sukmawati et al. 2015). Climate change has become an important concern of the Paris Agreement. The Paris Agreement aims to reduce global temperature and direct a country to adapt to climate change and low-emission development (Masripatin et al. 2017)

Currently, the Indonesian government is focusing on research related to the benefits of forested areas in carbon absorption. Limited comprehensive data sources on carbon reserves in several types of forest ecosystems and other land uses, as well as the need for information on carbon potential to support Reducing Emission from Deforestation and Forest Degradation (REDD+) activities and reduce Greenhouse Gas (GHG) emissions (Arifanti et al. 2014). The more carbon is stored, the less carbon is released into the atmosphere, hence reducing climate change and global warming (Ayu et al. 2022). As a developing country, Indonesia, through ministries/institutions, local governments, academia, business and industrial sectors, non-governmental organisations, and the general public, is committed to efforts to reduce GHG emissions and low-emission development. Thus, the State of Indonesia has carried out efforts to mitigate climate change, namely GHG inventory activities, through the identification of carbon stocks. The emission calculation method currently accredited and internationally recognised is a method developed by the Intergovernmental Panel on Climate Change since 2006, covering the stages of measuring, monitoring, and reporting emission changes (Measurement, Reporting and Verification / MRV) (Arifanti et al. 2014). There have been several studies on carbon reserve calculations carried out in several types of forests in Indonesia (Mansur et al. 2016)

The existence of a city aims to meet the needs of its residents. Along with the development of an urban area, it is directly proportional to the increasing use of natural resources and the environment. An environmental problem experienced by urban communities is the decline in air quality due to the impact of increasing emissions from exhaust gases (Ismiyati et al. 2014). One alternative forest area in urban areas is the existence of green open spaces; therefore, the existence of green areas needs to be improved in urban areas. Green lines in urban areas can absorb exhaust gases and are effective in reducing CO gas pollutants (Hakim et al. 2017). One form of green area from green open spaces is the city forest, which has a CO_2 absorbing role (Untajana et al. 2019). One of the urban forest areas in Makassar City is on the campus of Hasanuddin University with an area of ± 20 ha according to the Decree of the Mayor of Makassar No:522.4/807/Kep/XI/2008 (Zainuddin and Tahnur 2018). The diversity of plants and vegetation in the UNHAS City Forest has a positive impact on the environment. One type of plant species in the UNHAS urban forest is Teak (*Tectona grandis* L.f.).

The community views Teak as a plant that only has economic potential because of the quality of its wood, but it is also necessary to know that this plant is suspected to have potential as an environmental service provider. Wahyuni et al. (2013) stated that teak leaves have a stomata number of 1,192–9,122 stomata/30 grams of leaf area, and the absorption power of carbon dioxide will depend on the number of stomata. Consequently, it is important to comprehend how well teak plants can absorb carbon dioxide. In this study, carbon stored in teak stands was estimated (Kumi et al. 2021). *Tectona grandis* L.f. was carried out using a case study in a City Forest at the Hasanuddin University Campus.

Our research was conducted in the City Forest of Hasanuddin University, a pilot urban forest in Makassar City. Several studies have been carried out on carbon absorption by Togi and Sahuri (2014), regarding the absorption of teak plants in rubber plantations in Sembawa, South Sumatra. Research conducted by Lukito and Romatio (2013) only discussed the estimated biomass of the teak stand and not the calculation of the carbon value of teak plants. Then the research conducted by Sasongko et al. (2023), only discussed the loss of carbon and oxygen of teak plants in the harvesting process. Therefore, the research we have conducted is something new and has never been done before.

METHOD

Research Location and Time

The study was conducted between October and November 2022. The research location was the urban forest area of Hasanuddin University, Makassar City, South Sulawesi Province. The total research area in the Hasanuddin University urban forest is 4.41 ha. Sampling data were collected from the two research plots (Figure 1).

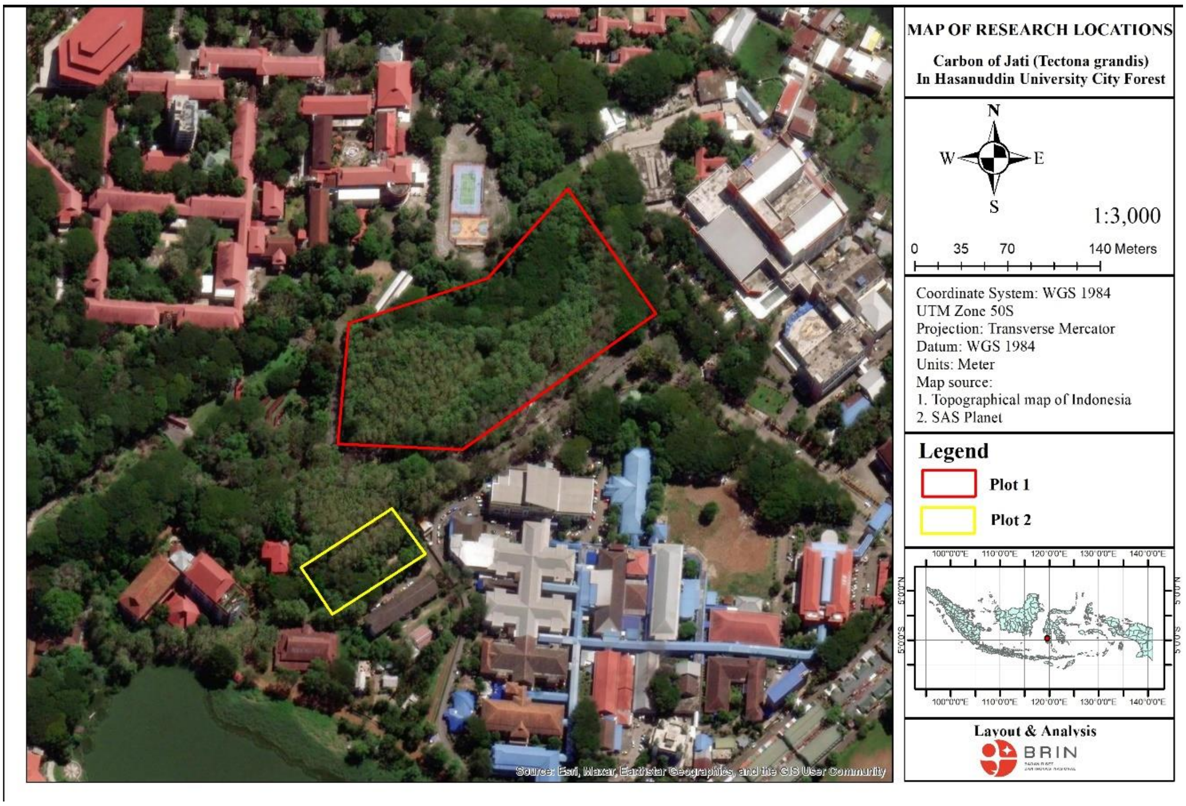

Figure 1 Map of research location

Research Tools and Materials

The instruments utilized in this study are a Global Positioning System (GPS) for location marking, a DSLR camera for documentation, meters, raffia ropes, office supplies for data entry (including field books and pencils to record measurement results), and color markers as gathered tree markers. The material used in this study was teak stands (*Tectona grandis* L.f.), with an average lifespan of approximately 23 years, in a plot measuring 625 m^2 with a total of 47 individuals. In addition, this study used specific gravity data collected from literature.

Data Collection Methods

Information about emissions was gathered from the Aksara Bappenas website. To collect data on biomass potential in this study, we used non-destructive methods. The diameter, height, and specific gravity of teak trees were among the information gathered. The teak plant diameter was determined by surveying each individual teak plant. Each teak plant's circumference was used as the unit of measurement. Each person's circumference was measured at a height of 1.3 meters, and its diameter was then calculated (Hairiah et al. 2011). Specific gravity data were obtained from a study by Pasaribu and Sicily (2019), who stated that the specific gravity value of teak was 0.67 gr/cm^3. The diameter and specific gravity values obtained were then used in the allometric analysis to obtain the biomass potential of teak stands and the potential of carbon stocks.

Data Analysis Methods

Carbon Emissions of Makassar City

Emission data obtained from the Bappenas script website show the emission data for each province in Indonesia. The provincial emission data are then converted into an individual carbon footprint which is the output of each individual's carbon emissions, by dividing the value of provincial carbon emissions by the total population of the province. In simple terms, this can be explained by Equation:

$$Individual\ Carbon\ Footprint = \frac{\Sigma\text{Province emission}}{\Sigma\text{Province population}}$$

After the individual carbon footprint data were obtained, they were multiplied by the number of residents of Makassar City to obtain the total carbon emissions in Makassar City. The total carbon emissions of Makassar were calculated using the following equation:

$$\Sigma\ Makassar\ City\ Emission = Individual\ Carbon\ Footprint\ x\ \Sigma\ Population\ Makassar$$

Biomass Potential and Teak Stand Carbon Stock

In this study, biomass potential was determined using an allometric equation approach developed by those compared (Perez and Kanninen (2003), with allometrics developed by (Ketterings et al. 2001). The development of an examination of the potential biomass in species for which allometric equations have not yet been particularly established led to the invention of the allometric equation. The use of allometrics in this study also takes into account the equations' arrangement based on the diameter and specific gravity of wood, which are the most significant predictors in calculating biomass in a stand. The use of allometrics also considers the data factors needed in the analysis to be obtained through nondestructive methods, considering that the object of study is an urban forest whose stands are under the protection of the law. According to Hairiah et al. (2011), one method to lessen tree damage is to utilize allometrics to estimate biomass potential. Tree diameter, tree height, and teak specific gravity are the variables needed in this allometric equation (Perez and Kanninen 2003; Ketterings et al. 2001). List of Allometric calculations of teak stands for carbon can be seen in Table 1.

Table 1 List of Allometric calculations of teak stands for carbon

Tree Biomass Estimation (kg/tree)	Source
$Y = 0.11 \times BJ \times D^{2.62}$	(Ketterings et al. 2001)
$Y = 0.153*D^{2.382}$	(Perez and Kanninen 2003)

Description: BJ = specific gravity, D = tree diameter, Y = dry weight

The investigation was then carried out by calculating the carbon stocks using the IPCC (2009) biomass content technique:

$$C = 0.5\ x\ W$$

C : Carbon stock (tC)
0.5 : Coefficient of carbon content in plants
W : Biomass (Kg)

Economic Valuation of Potential Carbon Reserves of Teak Stands

The economic value of the prospective carbon reserves in each teak stand was calculated after the amount of carbon stocks in each teak stand was determined. The selling value of carbon in the international market is obtained from the data released by the World Bank Group (2021) by the economic assessment of each potential carbon stock of teak stands using the following equation:

$$Carbon\ Economy\ Valuation\ =\ \Sigma C\ (ton)\ teak\ stands\ x\ Selling\ Value\ of\ Carbon$$

RESULT AND DISCUSSION

Carbon Emissions of Makassar City

The results of the analysis of individual carbon footprint values from the people of South Sulawesi are presented in Table 2. Based on data obtained from the Aksara Bappenas website, the total emissions produced by the Province of South Sulawesi are 39,860,234.46 tons of CO_2eq. To obtain an individual carbon footprint from the community in the South Sulawesi Province, it is necessary to know the number of residents. Based on data from the website of the Central Statistics Agency of South Sulawesi, the total population of South Sulawesi is 9,022,276. The individual carbon footprint value obtained based on the above data shows that the people of South Sulawesi produce 4.42 tons of CO_2eq/year. The individual value of the carbon footprint was then used to determine the amount of emissions in Makassar City by diverting it to the total population in Makassar City. The analysis of the total emissions of Makassar City is presented in Table 3.

Table 2 Analysis of individual carbon footprint values of South Sulawesi Province

Variable	Value
Provincial Emissions (tons of CO_2eq)*	39,860,234.46
Total Population of the Province (soul)**	9,022,276
Individual Carbon Footprint (tons of CO_2eq/person)	4.42

Source: (*) Aksara-Bappenas 2021; (**) Central Statistics Agency 2022

Table 3 Analysis of total carbon emissions in Makassar City

Variable	Value
Citizen (Soul) *	1,571,814.00
Individual Carbon Footprint (tons of CO_2eq/person)	4.42
Total city emissions (tons of CO_2eq)	6,944,242.74

Source: (*) Central Statistics Agency 2022

Data from the Central Statistics Agency of South Sulawesi show that the total population of Makassar City is 1,571,814. As a result, the people of Makassar City produce at least 6,944,242.74 tons of CO_2eq/year. In other words, Makassar City contributed 17.42% of the total emissions of South Sulawesi Province. This is because the number of people living and doing activities in Makassar City is much higher than other cities/regencies in South Sulawesi. The high total carbon emissions in Makassar City are also affected by human activities, all of which produce emissions such as energy generation, transportation provision, factories providing food, paper, entertainment, and waste production to meet human needs (Mawardi et al. 2022).

Biomass Potential and Teak Stand Carbon Stock

The potential carbon absorption of teak plants is inseparable from the calculation of the biomass from teak plants. The volume of organic material a tree has in its biomass. The quantity of photosynthesis that the plant has stored is shown by the biomass distribution in each part of the tree. Biomass describes the amount of carbon released into the atmosphere as carbon dioxide when forests are damaged. On the other hand, through estimation, carbon dioxide can be estimated which can be taken from the atmosphere by greening and reforestation. The teak stand biomass can be calculated using a non-destructive sampling method. Analysis of biomass on teak stands in the urban forest of Hasanuddin University showed that the estimate of potential biomass based on the calculation of Ketterings et al. (2001) was 13.67 tons/625 m^2 while based on Perez and Kanninen (2003) it was obtained as much as 12.92 tons/625 m^2. For potential biomass, teak stands based on Ketterings et al. (2001) calculations were obtained as much as 218.81 tons/ha while based on Perez and Kanninen (2003) as much as 206.77 tons/ha. The carbon content in plants can be determined by calculating the biomass (Prakoso et al. 2017). The age, diameter, and height of the tree have a big impact on the amount of biomass it produces (Chayaporn et al. 2021; Rifandi 2021; Santosa et al. 2020). The increase in the diameter of the rod determines how much carbon is absorbed in a stand, which is the result of photosynthesis (Afriansyah et al. 2019; Maruapey and Irnawati 2019; Ruslim et al. 2021). The biomass of stands increases with increasing stand density, and affects the amount of carbon (Bernal et al. 2018; Drupadi et al. 2021; Istomo and Farida 2017; Santosa et al. 2020). The biomass analysis of the teak stands is shown in Table 4.

Table 4 Teak stand biomass analysis

Species	Specific gravity (gr/cm^3)	Biomass potential estimation ($ton/625\ m^2$)		Biomass potential (ton/ha)	
		Ketterrings	**Perez and Kanninen**	**Ketterrings**	**Perez and Kanninen**
Tectona grandis	0.67	13.67	12.92	218.81	206.77

Teak Stand Carbon Absorption Analysis found that potential biomass estimates based on Ketterings calculations were obtained as much as 218.81 tons/ha while based on Perez and Kanninen as much as 206.77 tons/ha. The results of calculating the potential of stored carbon using the Ketterings method are 109.40 tons/ha while based on the Perez and Kanninen method as much as 103.38 tons/ha. Biomass has an impact on carbon uptake; the more biomass there is, the more CO_2 is absorbed by vegetation. Teak stands have long lifespans (Basuki et al. 2020; Natalia et al. 2014), and teak biomass accumulates to form solid teak stand wood (Pfutz et al. 2021; Ruslim et al. 2021). *Tectona grandis* L.f. has high carbon reserves and absorption, and teak biomass accumulates to form solid teak stand wood (Pfutz et al. 2021; Ruslim et al. 2021). *Tectona grandis* L.f. has high carbon reserves and uptake (135.87 ton/ha and 499.00 tonnes/ha) compared to other species used for energy, pulp and paper. Based on research Afriansyah et al. (2019) and Singh et al. (2020), in 23-year-old teak plantation forests in terms of carbon storage the highest above ground level (74%) followed by underground carbon (19%) and soil organic carbon (7%). Jati plants can be developed into greenery plants for climate change mitigation (Maruapey and Irnawati 2019; Pfutz et al. 2021). This is true because carbon dioxide absorption and storage are positively connected with biomass value. The amount of forest biomass affects carbon dioxide intake, and photosynthesis, one of the physiological functions of plants, is crucial for storing carbon. The magnitude of the rate of photosynthesis of stands is related to the chlorophyll content, the number of stomata in the leaf area, and the age of the stand. The larger the leaf area of the stands of land union, the greater the amount of CO_2 absorbed by the stand. Leaf area increases with stand age (Tambaru 2017; Ura′ et al. 2018). The teak had fairly good carbon dioxide absorption ability. Carbon dioxide used from free air enters through the leaf stomata and is converted into organic matter which is later assimilated in the plant body in the form of biomass through photosynthesis. Some of these organic materials then become carbon sources (Lukito and Rohmatiah 2013). The analysis of teak stand carbon uptake is shown in Table 5.

Table 5 Teak stand carbon absorption analysis

Species	Biomass potential estimation (ton/ha)		Carbon stock potential (ton/ha)	
	Ketterrings	**Perez and Kanninen**	**Ketterrings**	**Perez and Kanninen**
Tectona grandis	218.81	206.77	109.40	103.38

Contribution of Teak Carbon Absorption in UNHAS City Forest to Reduce Emissions in Makassar City

Climate change is already a new disaster for humanity. Global warming is a form of climate change that occurs due to an increase in GHG emissions such as CO_2 in the atmosphere. One strategy for lowering GHG concentrations (emissions) in the atmosphere is to cut back on CO_2 emissions. To reduce the amount of CO_2 released into the atmosphere, it is therefore important to maximize plant CO_2 absorption while minimizing emission release. Forests have an important function, one of which is to absorb CO_2 in the atmosphere. The absorption of CO_2 by the forest is carried out through the process of photosynthesis carried out by plants in the forest. South Sulawesi is one of the provinces that implements the National/Regional Action Plan (RAN/RAD) policy for greenhouse gases as part of The National Medium-Term Development Plan/Regional Long-Term Development Plan.

One of the efforts made in order to reduce emissions in South Sulawesi by preserving forests because theoretically plants function as carbon storage sites (Pergub 2020; Putri and Wulandari 2015). Based on the calculation results, it was found that the total emissions produced by Makassar City in 2022 were 6,944,242.74 tons of CO_2eq. Teak trees located in the urban forest of Hasanuddin University then succeeded in reducing 455.93–482.48 tons of CO_2eq in accordance with the calculation of carbon absorption, CO_2 emissions can be reduced through various activities through sustainable forest management, conservation and increasing carbon reserves (Santosa et al. 2020). The absorption power of carbon dioxide depends on the number of stomata, the more stomata, the greater the absorption of carbon dioxide. Teak plants can survive for a long time, so the greater the opportunity for this plant to absorb carbon dioxide in the atmosphere, which will later be stored in the form of biomass by Teak (Tambaru 2017).

Valuation of The Economic Value of Potential Carbon Stocks

The evaluation of the economic worth of carbon reserves is anticipated to give a general overview of the financial gains that connected parties will make if they maintain their forest stands as part of their efforts to lower the level of carbon emissions on earth. Additionally, it is anticipated that determining the economic worth of carbon reserves will make it easier to conduct transactions in carbon trading, which is currently anticipated to be a mechanism for reducing the level of carbon emissions. Several studies have been conducted to estimate the economic value of a stand's carbon stores, including research conducted by those who valuation the Betani et al. (2016) economic value of carbon reserves on pole stands and trees that exist in forest areas with special purposes of the Bukit Suligi Training Forest, Rokan Hulu Regency, where the total value of the estimated valuation the economic carbon reserves obtained ranged from USD 419,787.6, with a total carbon reserve of 83,957.52 tons. Another study that assessed the economic value of carbon reserves was conducted Damanik and Amru (2022) by ebony stands (*Dyospiros celebicca*) at the Kawanua Manado Arboretum, North Sulawesi, where estimates the economic valuation value of carbon reserves obtained from the *Dyospiros celebicca* plant is USD 135,536 with a potential carbon reserve of 67,768 tons/ha.

In valuation of the economic value of carbon reserves, determining the price of carbon used as an approach is important to know. Djaenudin (2014) states that there are variations in the value of carbon prices that have been set by REDD+, where the price of carbon commonly used by Indonesia ranges from 2 USD/ton C to USD 10/ton C. Furthermore, Djaenudin (2014) it states that the variation in carbon prices in trade is determined by several factors such as atmospheric crunch at the time, ecosystem type, type of forests and others. The World Bank (2021) also noted that local factors in each country, such as how the regulations contained in a country conduct climate control and also technical improvements, impact the rise and decrease of carbon costs.

The shortening of the carbon price issued is used in this study's estimation of the economic worth of carbon deposits by the World Bank (2021) which is 2 USD/ton C, this price was chosen based on the consideration that this price is a formulation of the average carbon price that exists around the world set by the World Bank (2021). The World Bank (2021) also stated that the price of carbon traded internationally still has the potential to increase, where the price of carbon can reach USD 50–100/ton C by 2030. This price is considered to be an effective price in an effort to reduce greenhouse gas emissions globally.

Based on these prices, the potential economic valuation value of carbon reserves in this study is shown in Table 6. The potential total valuation value of the economic value of carbon reserves using allometric keterings is USD 218.8/IDR 3,172,600 tons/ha, which is higher than the potential total valuation value of the economic value of carbon reserves using Perez and Keninen allometrics, which came to USD 206.76/IDR 2,998,020 tons/ha. When compared to the research conducted by the Damanik and Amru (2022), the value of the potential economic valuation of carbon reserves produced in this study is still greater. It is due to the reserves of the carbon produced by this object of study is also greater.

Table 6 Valuation of the economic value of carbon reserves

Species	**Carbon stocks potential (ton/ha)**		**Economic value valuation of carbon stocks (2 USD/ton)**		**Economic value valuation of carbon stocks (Rp 14,500/1USD)**	
	Keterings	**Perez and Keninen**	**Keterings**	**Perez and Keninen**	**Keterings**	**Perez and Keninen**
Tectona Grandis	109.4	103.38	218.8	206.76	3,172,600	2,998,020

For policymakers managing forest areas and their management by taking into account the environmental services supplied in terms of their capacity to absorb carbon to promote sustainable development, knowledge about the economic value of a forest area is intended to serve as a reference (Ulya et al. 2015). Ichwan (2021) stated that knowing the economic valuation value of a forest area can direct the behavior of individuals, communities, organizations in making decisions in managing and maintaining owned forest areas (Ichwan 2021).

CONCLUSION

The emissions produced by Makassar City in 2022 will be 6,944,242.74 tons of CO_2eq. Teak trees located in the urban forest of Hasanuddin University then succeeded in reducing 455.93–482.48 tons of CO_2eq according to carbon absorption calculations. The economic valuation of carbon reserves located in teak stands in the urban forest of Hasanuddin University ranges from USD 206.76/IDR 2,998,020 tons/ha to USD 218.8/IDR 3,172,600 tons/ha.

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