

## Article

# Study on Wood in Houses as Carbon Storage to Support Climate Stabilisation: Study in Four Residences around Jakarta Municipal City

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**Abstract:** Global agreements mandate the international community, including Indonesia, to commit to reducing the risks and impacts of climate change. Indonesia's Nationally Determined Contributions (NDCs) will contribute to the achievement of the Convention's goals by reducing greenhouse gas (GHG) emissions and increasing climate resilience. This commitment must be supported by a wide range of actions, including the use of timber. Despite the fact that wood contains carbon, limited information is currently available on the size of the wood utilisation subsector's contribution to reducing GHG emissions. More research is needed on the magnitude of wood products' contribution to climate change mitigation. This study assessed the amount of carbon stored in wood used as a building material. Purposive sampling was used to select the cities with rapid housing development surrounding Jakarta's capital city, i.e., the Bekasi District, East Jakarta City, Depok City, and Bogor District. The amount of carbon stored in wood was calculated according to EN 16449:2014-06 and energy dispersive X-ray spectroscopy (EDS/EDX) analysis. Results show that wood is currently only used in door frames, door leaves, window frames, shutters, and vents. The carbon stored on the components ranges from 450 to 680 kg (average of 554.50 kg) in each housing unit, according to the EN 16449:2014-06 calculation. The weight range is between 130 and 430 kg (average of 400.42 kg) according to EDX/S carbon analysis. With an increase in housing needs of 800,000 units per year, this amount has the potential to store 0.44 million tons of carbon over the lifespan of the products.

**Keywords:** wood utilisation; house buildings; carbon storage

## 1. Introduction

Humans have been using wood as a building material for the construction of houses for over 10,000 years [1]. Wood is still an important building material for homes all over the world today. As the human population grows, so does the demand for shelter, which means that the demand for wood is growing as well. However, the debate over the use of wood and other materials, such as metal and concrete or cement, continues, both in scientific and practical forums. This is consistent with the global rise of environmental movements attempting to maintain climate stability. Davis et al. [2] concluded that global CO<sub>2</sub> emissions from cement and steel manufacturing were approximately 1320 and 1740 Mt, respectively, in 2014. Unless properly addressed, the modern global building sector's

demand for construction materials will continue to be a major source of greenhouse gas (GHC) emissions. Buildings are a missed opportunity for long-term carbon storage because they are designed to be occupied for decades. To address this issue, the most commonly used building materials, such as steel and concrete, store almost no carbon [3].

The extraction of natural resources such as wood, iron ore, limestone, and aggregates usually start the cycle of use for structural building materials. Tracking energy use and emissions into air, water, and soil per unit of resource are where data collection begins. Fortunately, wood has a lower impact during this phase than concrete and steel, which are made of materials that must be mined and heated to extremely high temperatures [4].

According to wood scientists and technologists, wood products provide physical storage of carbon that was previously present in the atmosphere as a greenhouse gas. Significant climate benefits could be realized in the short to medium term by increasing the total carbon stock in wood products, using more wood products, or using longer-lived wood products. Long term, when product stocks stabilize at higher levels, wood products provide a stable carbon pool because new wood entering the pound is offset by old wood leaving the pound, allowing climate benefits from emissions substitution effects to be avoided [4]. Wood products used in construction, in fact, can act as a carbon sink. Churkina et al. [3] revealed that wooden buildings for new urban dwellers can save 0.01–0.68 GtC per year, depending on the scenario and the average floor area per capita.

Carbon captured from the atmosphere by trees and stored in wood is eventually released back into the atmosphere. As a result, the shifting demand for wood products may play an important role in the global carbon cycle and climate change mitigation [5].

According to Ministry of Public Works and Public Housing (PUPR) data, the number of houses needed (backlog) in Indonesia is 7.6 million units [6,7]; the annual demand rate is 800 thousand units [8]. If each standard house requires 4.85 m<sup>3</sup> of wood (3.5 m<sup>3</sup> for roof trusses and 0.35 m<sup>3</sup> for frames and doors), 36.86 million m<sup>3</sup> of processed wood will be used. If this volume of wood is converted to carbon at a 50 percent conversion factor, as suggested by Brown [9], Indonesia could store 18.43 million m<sup>3</sup> of carbon in housing. Indonesia, as one of the world's major wood producers, can play a significant role in promoting the use of renewable and environmentally friendly building materials for carbon storage. However, there are insufficient studies and data on this critical issue to accurately describe the potential and actual amounts of carbon stored in buildings across the country.

This article discusses the findings of a study on the use of wood in house construction to aid in climate stabilization. The ability of wood as a building material to store carbon indicates support for climate stabilisation. The amount of carbon stored in wood over the lifespan of the products used as a component in building houses can be determined by calculating the volume and the weight of wood used as components in houses.

## 2. Materials and Methods

### 2.1. Location of Sampling

This study was carried out in the field. Measurements and test samples were gathered from each of the target residences in and around the municipal cities of Jakarta, including Bogor District, Bekasi District, and Depok City (Table 1). The housing sample unit was defined by the material to be utilized, specifically whether wood is or will be employed as a building material. There was also quick access to data and information, and the capacity to take measurements and samples.

### 2.2. Materials and Equipment

The materials here mean the harvested wood products (HWP) used in house buildings that are being or will be built at the selected sites in house development areas. The equipment required for collecting wood samples were a saw, a digital moisture meter, plastic bags, a measuring tape, a tally sheet, a recorder, a camera, and a GPS unit. For carbon content measurement in wood, an EDS/X (Zeiss EVO50, Carl Zeiss Microscopy GmbH, Jena, Germany) was used.

**Table 1.** List of the housing complexes that served as the research sites.

| No | Sample of Housing Complexes | Wood Samples Taken | Loctions          | Coordinate Positions                        |
|----|-----------------------------|--------------------|-------------------|---------------------------------------------|
| 1  | Housing BA                  | BA1<br>BA2<br>BA3  | East Jakarta City | −6.326169534862831S,<br>106.89856809773443E |
| 2  | Housing B                   | B1<br>B2<br>B3     | Bekasi District   | −6.317569470103991S,<br>107.0381699693129E  |
| 3  | Housing BJ                  | BJ1<br>BJ2<br>BJ3  | Bogor District    | −6.497594177106979S,<br>106.78965554006263E |
| 4  | Housing D                   | D1<br>D2<br>D3     | Depok City        | −6.447205035445256S,<br>106.82625081221232E |

### 2.3. Work Procedures

- (i) From each city, one site of housing development representing low-middle class housing and one site with high-class housing were selected.
- (ii) Measurements were made of the dimensions (length, width, and thickness) of all wood parts of the house, to obtain partial and total volume of wood component of the house. The house components made from wood: columns and beams, doors, door and window frames, and roof structure. For the measurement, the SNI 7537.2-2010 Sawnwood—Part 2—Measurements and dimensions was referred to.
- (iii) The calculation of carbon dioxide based on the amount of biogenic carbon was carried out in accordance with DIN EN 16449:2014-06 EN 16449:2014 [10]. The calculation was based on the atomic weight of carbon (C = 12) and molecular weight of carbon dioxide (CO<sub>2</sub> = 44).

The following equation was employed, which takes into account the amount of biogenic carbon found in the product and the volume of wood, the bulk density, and the amount of moisture found in it:

$$PCO_2 = \frac{44}{12} \times cf \times \frac{\rho\omega \times V\omega}{1 + \frac{\omega}{100}} \quad (1)$$

where:

$PCO_2$  is the biogenic carbon oxidized as carbon dioxide emissions from the product system into the atmosphere (e.g., energy source at the end of life) (kg).

$cf$  is the carbon content of the wood biomass (kiln-dry mass), 0.5 being the standard value.

$\omega$  is the moisture content of the product (e.g., 12%).

$\rho$  is the gross density of the wood biomass of the product at  $\omega$  moisture content (kg/m<sup>3</sup>).

$V\omega$  is the volume of the solid wood product at  $\omega$  moisture content (m<sup>3</sup>). In the case of wood products, the wood volume content  $V\omega = VP \times$  percentage of wood.

$VP$  is the gross volume of the wood product.

In addition, energy dispersive X-ray spectroscopy (EDS/EDX) analysis was carried out to analyse the compositions of wood samples taken from the wood used in house construction.

## 3. Results and Discussion

### 3.1. Development of Residential Building Materials

According to the findings of discussions with the developers, very little wood is currently used as a building material for housing. Non-timber materials predominate over wood, except for the door leaf, which is made of solid and composite wood, such as particle board, thick block, or other types of wood panels. The main (front) door is made of solid wood, whereas the interior or inter-room doors are made of particle board. There

is still some housing that uses wood as the framing material. The use of structural and non-structural wood materials as housing building materials can be divided into three time periods, as shown in Table 2.

**Table 2.** The development of materials used for housing.

| Periods         | Materials Used for Structural                                 | Community's Perspective about Wood                                                                                                                                                                |
|-----------------|---------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Until the 1990s | Dominated by wood                                             | <ul style="list-style-type: none"> <li>Those who born until the 1970s still consider wood as an important building material for houses,</li> <li>Wood is still available in abundance.</li> </ul> |
| 2000–2010       | Wood + aluminum/mild steel                                    | <ul style="list-style-type: none"> <li>Wood is impractical, needs more maintenance, not durable.</li> <li>Timber production is starting to decrease.</li> </ul>                                   |
| After 2010      | Dominated by mild steel/aluminum and GRC, wood only for doors | <ul style="list-style-type: none"> <li>Wood is impractical, needs more maintenance, not durable.</li> <li>Wood availability is dwindling, and the price is rising.</li> </ul>                     |

There is still a desire on the part of a developer to use wood as the major material for both the structural (roof structure, frames) and non-structural components of the building (doors, windows, ceilings). The developer has established a dedicated woodworking studio for the production of door frames, structures, and other door-related items. However, the supply of wood does not support the need; it is extremely difficult to obtain, and even if it is available, the price is extravagant. Both of these scenarios are problematic.

In Indonesia, the lower middle class still has a significant housing shortage. The declaration to build a thousand towers of flats/apartments has yet to be fulfilled. In stark contrast to residential buildings/housing in other countries, which use wood as the main building material nearly 80 percent of the time, the materials used are mostly concrete and steel. Meanwhile, multi-story wooden apartment buildings with up to ten floors already exist in Europe, including England and Sweden [11]. Even in Norway, there are 18-story buildings made of wood [12].

The use of wood as a building and construction material could be a solution to the worldwide problem of carbon emissions. The use of wood products in the construction sector has the potential to reduce the concentration of carbon dioxide (CO<sub>2</sub>) in the atmosphere in the future. The lower fossil fuel energy required to produce wood, the avoidance of emissions from industrial processes associated with the manufacture of non-timber products, the option to use wood waste for bioenergy, and the actual physical storage of carbon in wood products all contribute to the climate benefits of using wood in construction [13–16]. Consideration of wood products (HWP) as a carbon storage mechanism is relatively new [17].

### 3.2. The Species of Wood Used

The developer provides trade names of the wood species used in the housing construction. This information is typically received by the community of house buyers without further question, and its veracity is difficult to be determined. Frequently, the wood species information is incorrect. Since in this study we focused on the weight of the wood for carbon calculation, macroscopic identification was conducted to verify the trade names. In fact, the name of a species of wood is often confused with others, as shown in Table 3.

**Table 3.** The trade names and definitive wood species used in the housing sites.

| No | Name of Housing Complex and Location | Sample Codes | Wood Species |                                          |
|----|--------------------------------------|--------------|--------------|------------------------------------------|
|    |                                      |              | Trade Names  | Identification Results                   |
| 1  | BA Residence                         | BA1 *        | Keruing      | Kempas ( <i>Koompassia</i> sp.)          |
|    |                                      | BA2          | Meranti      | White Meranti ( <i>Shorea</i> sp.)       |
|    |                                      | BA3          | Meranti      | Kapur ( <i>Dryobalanops</i> sp.)         |
| 2  | B Residence                          | B1           | Keruing      | Kempas ( <i>Koompassia</i> sp.)          |
|    |                                      | B2 *         | Meranti-1    | White Meranti ( <i>Shorea</i> sp.)       |
|    |                                      | B3           | Kamper       | Kapur/Kamper ( <i>Dryobalanops</i> sp.)  |
| 3  | BJ Residence                         | BJ1 *        | Meranti      | Red Meranti ( <i>Shorea</i> sp.)         |
|    |                                      | BJ2          | Singkil      | Keruing ( <i>Dipterocarpus</i> sp.)      |
|    |                                      | BJ3          | Mahoni       | Mahogany ( <i>Swietenia</i> sp.)         |
| 4  | D Residence                          | D1 *         | Meranti-2    | Yellow Meranti ( <i>Shorea</i> sp.)      |
|    |                                      | D2           | Singkil      | Keruing ( <i>Dipterocarpus</i> sp.)      |
|    |                                      | D3           | Meranti-2    | Ki Tulang ( <i>Kurrimia paniculata</i> ) |

\* Wood samples taken from the house were under construction when data were collected.

The trade names of Keruing (*Dipterocarpus* spp.), Meranti (*Shorea* spp.), and Kamper/singkil (*Dryobalanops* spp.), in line with the classification of wood species as the basis for the imposition of forestry contributions (The Decree of the Minister of Forestry Number 163/Kpts-II/2003 Year 2003), all refer to the *Dipterocarpaceae* family. House developers recognize them as Borneo timber, which is assumed to be good quality timber for construction. However, the wood identification testing resulted different results. It was discovered that in Jakarta and Bekasi, the samples named Keruing (*Dipterocarpus* sp.) are in fact Kempas (*Koompassia* sp.), which belong to the Leguminosae family. Moreover, in Depok city, a sample with the trade name Meranti (*Shorea* sp.) turned out to be Ki Tulang (*Kurrimia paniculata*) belonging to the Escalloniaceae family. Different wood species have different characters, and this determines the effective and efficient use of their timber. Especially in housing, where the safety of the occupants is a priority, the use of the wrong wood species is very important. A deeper study is needed on the species of wood promised by housing developers in comparison with the real wood species used in construction.

### 3.3. Carbon Stored in Residential Buildings

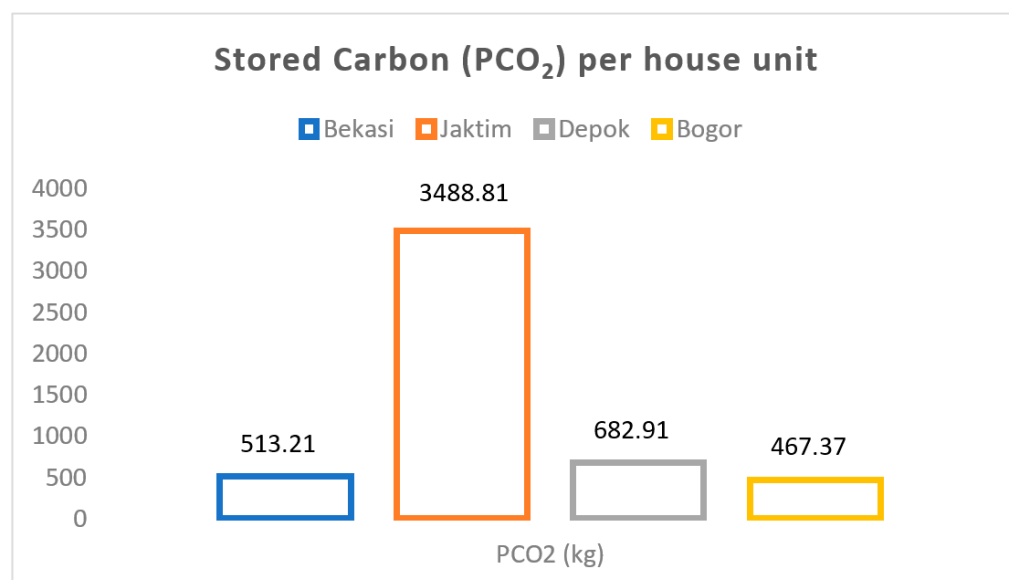
#### 3.3.1. Carbon Storage Based on Mass of Wood

The calculation results of stored carbon ( $PCO_2$ )—which was calculated based on Formula (1) of DIN EN 16449: 2014-06/EN 16449: 2014(D)—in housing measured in four cities/districts, are presented in Table 4 and Figure 1. Table 4 shows the total carbon stored in each house measured, and Figure 1 shows the average carbon stored in each housing unit. There is a striking difference between the carbon stored in the housing units in East Jakarta City and that stored in the other three cities/districts, due to the different types of houses: the type of house in East Jakarta is a two-story house with many doors and windows, and there are stairs with rails/railings and wooden handles. This is to show that in addition to the large volume ( $V$ ) of wood components used, wood species of higher density ( $\rho$ ) will also increase the amount of stored carbon.

The contribution of stored carbon to the National Determined Contribution (NDC) to reducing the emission rate must be calculated in aggregate. According to the 2015 Paris Agreement/COP21 of the United Nations Framework Convention on Climate Change (UNFCCC), the global community must commit to keeping the global average temperature rise below 2 °C and make efforts to keep the temperature rise below 1.5 °C above pre-industrial levels, recognizing that doing so will significantly reduce the risks and impacts of climate change [18]. For this reason, each country is urged to implement low greenhouse gas emission developments; in other words, countries must reduce emissions during their development. One year later, Indonesia made a commitment to reduce emissions by 29 percent independently and 41 percent with international support. As nationally determined contributions, these pledges were presented to the UNFCCC secretariat in 2016.

**Table 4.** Carbon stored in the housing based on standard calculations.

| Location               | House Component | Wood Trade Names | Moisture Content (%) | Density ( $\rho$ ), kg/m <sup>3</sup> | Stored Carbon (PCO <sub>2</sub> ), kg |
|------------------------|-----------------|------------------|----------------------|---------------------------------------|---------------------------------------|
| Bekasi District        | Door frame      | White Meranti    | 15.5                 | 578.29                                | 8146.82                               |
|                        | Leaf door       | White Meranti    | 15.5                 | 578.29                                | 2798.91                               |
|                        | Windows frames  | White Meranti    | 15.5                 | 578.29                                | 15,960.71                             |
|                        | Shutters        | White Meranti    | 15.5                 | 578.29                                | 3886.09                               |
|                        | Total           |                  |                      |                                       | 30,792.51                             |
| Average per house unit |                 |                  |                      |                                       | 513.21                                |
| East Jakarta City      | Door frame      | Kempas           | 15.3                 | 888.17                                | 126,612.66                            |
|                        | Leaf door       | Kempas           | 15.3                 | 888.17                                | 15,659.32                             |
|                        | Windows frames  | Kempas           | 15.3                 | 888.17                                | 18,280.58                             |
|                        | Shutters        | Kempas           | 15.3                 | 888.17                                | 33,939.90                             |
|                        | Stairs/ladder   | Kempas           | 15.3                 | 888.17                                | 13,887.95                             |
|                        | Total           |                  |                      |                                       | 174,440.50                            |
| Average per house unit |                 |                  |                      |                                       | 3488.81                               |
| Depok City             | Door frame      | Yellow Meranti   | 14.8                 | 769.97                                | 36,452.65                             |
|                        | Leaf door       | Yellow Meranti   | 14.8                 | 769.97                                | 118,956.77                            |
|                        | Windows frames  | Yellow Meranti   | 14.8                 | 769.97                                | 7881.84                               |
|                        | Shutters        | Yellow Meranti   | 14.8                 | 769.97                                | 2092.025                              |
|                        | Roster          | Yellow Meranti   | 14.8                 | 769.97                                | 9657.43                               |
|                        | Total           |                  |                      |                                       | 139,313.41                            |
| Average per house unit |                 |                  |                      |                                       | 682.91                                |
| Bogor District         | Door frame      | Red Meranti      | 14.8                 | 800.71                                | 31,462.22                             |
|                        | Leaf door       | Red Meranti      | 14.8                 | 800.71                                | 65,979.03                             |
|                        | Windows frames  | Red Meranti      | 14.8                 | 800.71                                | 11,313.42                             |
|                        | Shutters        | Red Meranti      | 14.8                 | 800.71                                | 3186.49                               |
|                        | Roster          | Red Meranti      | 14.8                 | 800.71                                | 6771.08                               |
|                        | Total           |                  |                      |                                       | 118,712.23                            |
| Average per house unit |                 |                  |                      |                                       | 467.37                                |

**Figure 1.** Total of stored carbon (PCO<sub>2</sub>, kg) in each house unit.

Indonesia's latest NDC document was submitted by the Ministry of Environment and Forestry on 21 July 2021. In the document it is stated that most of the emission reductions are expected to come from the forestry and land use sectors by 2030, amounting to 24.5 percent [19]. This produces about 692 metric tons (692,000 tons) of carbon dioxide equivalents [20]. Indonesia's NDC will contribute to achieving the Convention's objectives,

as stated in the Article 2, by reducing greenhouse gas emissions and increasing climate resilience, which will lead to long-term economic development. Climate change policies will be aligned with long-term economic development by reducing GHG emissions and increasing climate resilience. This policy then places forestry and other land uses as the leading sector, along with industrial processes and product use in the large-scale industrial sector (IPPU), by increasing the efficiency of raw material utilization and CO<sub>2</sub> recovery upstream. Furthermore, Indonesia has taken significant steps in the land use sector to reduce emissions, including a moratorium on clearing primary forests, reducing deforestation and forest degradation, restoring ecosystem functions, and implementing sustainable forest management [19].

If it is assumed that the houses we sampled were of average size in Indonesia, the potential carbon stored in each house, if currently built with wood only for door frames and doors, and window frames and frames, is 554.50 kg. This estimate is based on the assumption that we found the average house size for Indonesia. There will be storage of 4.2 million tons of carbon if the backlog of 7.6 million housing units are built [6,7] or the demand rate of 800 thousand housing units is met [8] with houses having the proportion of wood found in the three cities/districts that were analysed. This number suggests that there is the possibility of carbon emissions of this amount if the Indonesian backlog is constructed without the use of wood materials (4.2 million tons). If the housing requirements of 800 thousand units per year are met by building using door and window frame components made of wood, then there will be a stored carbon amount of 0.44 million tons per year from the home construction sector.

According to Kazulis et al. [21], carbon storage in bioproducts and recycling can create a bioeconomy loop because bioproducts at the end of their lives will be recycled and converted into new products. From a production environment perspective, the bioeconomic circle is the most desirable solution for managing CO<sub>2</sub> emissions, including using wood for end products and as building materials.

### 3.3.2. Stored Carbon Calculation Based on EDX Analysis

Energy dispersive X-ray spectroscopy—often abbreviated as EDX or EDS—is a standard method for identifying and measuring the elemental composition in very small samples of materials (even a few cubic micrometres). EDX/EDS is a form of scanning electron microscopy (SEM). In a well-equipped SEM, the atoms on the surface are excited by the electron beam, thereby emitting certain wavelengths of X-rays that are characteristic of the atomic structure of the element. Energy dispersion detectors (solid-state devices that distinguish between X-ray energies) can analyse these X-ray emissions. The corresponding element is given, providing in the atomic composition of the specimen's surface [22,23].

The results of the EDX analysis are shown in the table as the percentage of the weight of non-normalized carbon, the percentage of the weight of normalized carbon, the percentage of carbon atoms, and an error rate. According to the findings of this study, the percentage of weight of carbon consists of un-normalised (unn. C) and normalised (norm. C) carbon. Table 5 shows the results of the EDX/EDS analysis on the carbon content of wood samples taken from several housing estates in this study.

In Table 5 we can see the carbon content of wood species used as raw materials for house construction varies. In general, the carbon value that is used as the basis for further calculations is the unnormalized carbon value, because it is closer to the absolute value [24]. According to the results of this study's analysis, which are shown in Table 5, the proportion of carbon content that was not normalized was the same as the value of normalized carbon. However, these figures are lower on average than the theory, which states that the proportion of carbon in wood is around 50% [9,25]. The results of this study, which obtained a portion of carbon (C) of less than 50%, are similar, among others, to the findings of Silva et al. [26].

**Table 5.** Proportions of carbon in the wood used in housing.

| No | Location     | Code of WoodSample | Wood Species                             | Content of Carbon (C), % w/w |                      |
|----|--------------|--------------------|------------------------------------------|------------------------------|----------------------|
|    |              |                    |                                          | Unnormalised (unn. C)        | Normalised (norm. C) |
| 1  | Residence BA | BA1                | Kempas ( <i>Koompassia</i> spp.)         | 42.42                        | 42.42                |
|    |              | BA2                | Meranti putih ( <i>Shorea</i> spp.)      | 42.39                        | 42.39                |
|    |              | BA3                | Kapur ( <i>Dryobalanops</i> spp.)        | 46.96                        | 46.96                |
|    |              | Mean               |                                          | 43.92                        | 43.92                |
| 2  | B Residence  | B1                 | Kempas ( <i>Koompassia</i> spp.)         | 42.42                        | 42.42                |
|    |              | B2                 | Meranti putih ( <i>Shorea</i> spp.)      | 42.39                        | 42.39                |
|    |              | B3                 | Kapur ( <i>Dryobalanops</i> spp.)        | 46.96                        | 46.96                |
|    |              | Mean               |                                          | 43.92                        | 43.92                |
| 3  | Residence BJ | BJ1                | Meranti merah ( <i>Shorea</i> spp.)      | 45.37                        | 45.37                |
|    |              | BJ2                | Keruing ( <i>Dipterocarpus</i> spp.)     | 43.98                        | 43.98                |
|    |              | BJ3                | Mahogany ( <i>Swietenia</i> spp.)        | 44.26                        | 44.26                |
|    |              | Mean               |                                          | 44.54                        | 44.54                |
| 4  | Residence D  | D1                 | Meranti kuning ( <i>Shorea</i> spp.)     | 44.70                        | 44.70                |
|    |              | D2                 | Keruing ( <i>Dipterocarpus</i> spp.)     | 45.60                        | 45.60                |
|    |              | D3                 | Ki Tulang ( <i>Kurrimia paniculata</i> ) | 45.95                        | 45.95                |
|    |              | Mean               |                                          | 45.42                        | 45.42                |

The stored carbon value, as presented in Table 5, was calculated based on the carbon content of the EDX analysis for each wood species used in the sample housing, namely, 42.42% (Kempas), 42.39% (White Meranti), 45.37% (Red Meranti), and 44.70% (Yellow Meranti) (Table 5). The values of moisture content and density were obtained from measurements performed on the test samples from the wood taken. Based on the volume and density of the water content, the weight of the wood used in each sample house is known. From the weight and percentage of each type of wood used in the building of the house, one can calculate the weight of carbon stored from the wood used in the building of the house (Table 6, rightmost column).

In general, as shown in Table 1, the use of wood as a building material in modern house construction began to decline in the early 2000s. Aluminium or mild steel dominated structural parts, such as roof trusses, in houses built between 2000 and 2010. Wood is used in door frames, door leaves, window frames, shutters, vents (roster), and stairs (Table 6). As a result, the house serves as carbon storage in these areas.

The amount of carbon stored in each house built in the four cities/districts sampled varied. This was determined by the amount or volume of wood used in each unit of the house, and the type of wood used. The amount of carbon stored in each of the housing units sampled was as follows: Bekasi District (137.06 kg), East Jakarta City (1004.86 kg), Depok City (425.33 kg), and 323.64 kg (Bogor District). If the average house size is represented by three regencies/cities, namely, Bekasi District, Depok City, and Bogor District, one unit of a house built with some wood components can store between 130 and 430 kg of carbon, or an average of 400.42 kg. The house in East Jakarta City was a model of a large house. This variation in the amount of carbon stored can be explained by the fact that the volume of wood used in the field varies greatly. Furthermore, the wood species used differs. As different wood species have different densities or specific gravity values, the weight varies. This has implications for calculating the mass of carbon stored.

**Table 6.** Carbon storage of the housing based on EDX analysis.

| Location               | Housing Components | Wood Species   | Moisture Content (%) | Density ( $\rho$ ), kg/m <sup>3</sup> | Volume (m <sup>3</sup> ) | Weight (kg) | Stored Carbon (kg) |
|------------------------|--------------------|----------------|----------------------|---------------------------------------|--------------------------|-------------|--------------------|
| Bekasi District        | Door frame         | White Meranti  | 15.5                 | 578.29                                | 8.8754                   | 5132.56     | 2175.69            |
|                        | Leaf door          | White Meranti  | 15.5                 | 578.29                                | 17.3880                  | 10,055.31   | 4262.44            |
|                        | Windows frame      | White Meranti  | 15.5                 | 578.29                                | 3.0492                   | 1763.32     | 747.47             |
|                        | Shutters           | White Meranti  | 15.5                 | 578.29                                | 4.2336                   | 2448.25     | 1037.81            |
| Total                  |                    |                |                      |                                       |                          | 30,792.51   | 8223.42            |
| Average per house unit |                    |                |                      |                                       |                          | 513.21      | 137.06             |
| East Jakarta City      | Door frame         | Kempas         | 15.3                 | 888.17                                | 32.2317                  | 28,627.23   | 12,143.67          |
|                        | Leaf door          | Kempas         | 15.3                 | 888.17                                | 57.4223                  | 51,000.77   | 21,634.52          |
|                        | Windows frame      | Kempas         | 15.3                 | 888.17                                | 11.0883                  | 9848.30     | 4177.65            |
|                        | Shutters           | Kempas         | 15.3                 | 888.17                                | 12.9444                  | 11,496.83   | 4876.95            |
|                        | Stairs/ladder      | Kempas         | 15.3                 | 888.17                                | 19.6680                  | 17,468.53   | 7410.15            |
| Total                  |                    |                |                      |                                       |                          | 118,441.64  | 50,242.95          |
| Average per house unit |                    |                |                      |                                       |                          | 2368.83     | 1004.86            |
| Depok City             | Door frame         | Yellow Meranti | 14.8                 | 769.97                                | 29.6455                  | 23,737.45   | 10,769.68          |
|                        | Leaf door          | Yellow Meranti | 14.8                 | 769.97                                | 67.6872                  | 54,197.82   | 24,589.55          |
|                        | Windows frame      | Yellow Meranti | 14.8                 | 769.97                                | 4.5957                   | 36,798.23   | 16,695.37          |
|                        | Shutters           | Yellow Meranti | 14.8                 | 769.97                                | 1.7014                   | 13,623.28   | 6180.88            |
|                        | Roster             | Yellow Meranti | 14.8                 | 769.97                                | 7.8540                   | 62,887.76   | 28,532.18          |
| Total                  |                    |                |                      |                                       |                          | 191,244.54  | 86,767.65          |
| Average per house unit |                    |                |                      |                                       |                          | 937.47      | 425.33             |
| Bogor District         | Door frame         | Red Meranti    | 14.8                 | 800.71                                | 23.0226                  | 22,826.15   | 10,203.29          |
|                        | Leaf door          | Red Meranti    | 14.8                 | 800.71                                | 48.2803                  | 52,117.11   | 23,296.35          |
|                        | Windows frame      | Red Meranti    | 14.8                 | 800.71                                | 8.2786                   | 35,385.51   | 15,817.32          |
|                        | Shutters           | Red Meranti    | 14.8                 | 800.71                                | 2.3317                   | 13,100.27   | 5855.82            |
|                        | Roster             | Red Meranti    | 14.8                 | 800.71                                | 4.9548                   | 60,473.44   | 27,031.63          |
| Total                  |                    |                |                      |                                       |                          | 183,902.48  | 82,204.41          |
| Average per house unit |                    |                |                      |                                       |                          | 901.48      | 323.64             |

#### 4. Conclusions

- (i) Timber components in modern houses are currently decreasing in prevalence due to their scarcity, despite the developer's desire to use wood as the primary material for both structural and non-structural components.
- (ii) There is a discrepancy in the wood trade names cited by the developer and the seller of the wood, and the laboratory identification results. Accuracy in determining the wood species is required to calculate the carbon stored in wood. As a result, the laboratory results of wood species identification were used as the foundation for calculations.
- (iii) Carbon stored ( $PCO_2$ , kg) in each housing unit ranged from 450 to 680 kg (average 554.50 kg) based on the standard formula and from 130 to 430 kg (average 400.42 kg) based on EDX/S carbon analysis.
- (iv) The variation in the amount of carbon stored is understandable, given the wide range of volumes of wood used per housing unit and the fact that different wood species have different densities or specific gravity values. This has implications for calculating the mass of carbon stored.
- (v) Carbon emissions can be reduced by using wood as a building material, particularly in residential buildings. As a result, a downstream sector, construction, can contribute to the climate stabilisation.

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