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POTENTIAL FOR CARBON STORAGE IN SCHOOL INFRASTRUCTURE AS A SUSTAINABILITY STRATEGY: A CASE STUDY

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Resumo

Potencial de armazenamento de carbono na infraestrutura escolar como estratégia de sustentabilidade: estudo de caso. O presente estudo teve como objetivo estimar o estoque de carbono em produtos de madeira na Escola Secundária Eduardo Mondlane, localizada em Maputo, Moçambique. Foi utilizada amostragem aleatória simples em cinco salas de aula, nas quais se mensuraram as dimensões e a umidade do mobiliário escolar (carteiras, portas, janelas, quadros, mesas e cadeiras). A partir desses dados, calcularam-se os volumes, a densidade aparente e os estoques de CO_2, conforme a norma EN 16449:2014. Os resultados indicaram que as carteiras mistas (madeira e metal) armazenam, em média, 308,56 kg de CO_2 por unidade, enquanto as carteiras 100% de madeira maciça acumulam 511,08 kg. As portas apresentaram os maiores valores, com 1.834,68 kg de CO_2 por unidade, ao passo que os quadros armazenaram 23,54 kg. O estoque total de carbono na escola foi estimado em 244.091,0kg de CO_2, correspondente a 290,58 kg/m², considerando uma área média de 56 m² por sala de aula. Conclui-se que os produtos de madeira em escolas públicas constituem um importante reservatório de carbono, contribuindo significativamente para a mitigação das mudanças climáticas.
Palavras-chave: Produtos de madeira, CO_2 biogênico, Mudanças climáticas.

Abstract

Wood plays a fundamental role in mitigating climate change due to its ability to fix and store carbon dioxide (CO_2). This study estimated the carbon stored in wood products at Eduardo Mondlane Secondary School in Maputo, Mozambique. Simple random sampling was adopted in five classrooms, measuring the dimensions and humidity of furniture (desks, doors, windows, blackboards, tables, and chairs) to calculate volumes, apparent densities, and CO_2 stocks, according to the EN 16449:2014 standard. The results revealed that mixed desks (wood and metal, type 1) store an average of 308.56 kg of CO_2 each, while solid wood desks (type 2) accumulate 511.08 kg. Doors stand out with 1,834.68 kg of CO_2 per unit, compared to 23.54 kg in blackboards. In the real-world school setting, the total carbon stock reaches 244,091 kg of CO_2, equivalent to 290.58 kg/m² (considering 56 m² per classroom). It is concluded that wood products in public schools represent a significant carbon reservoir, contributing to climate mitigation.
Keywords: Wood products, Biogenic CO_2, Climate change.

INTRODUCTION

The atmospheric concentration of carbon dioxide (CO_2) has been continuously increasing, intensifying global climate change (PACHAURI *et al.*, 2014; HOUGHTON, 2015). These changes represent one of the greatest environmental challenges of our time, reflected in extreme events such as severe droughts, forest fires, melting glaciers, and intense climate variations (VAN DER WERF *et al.*, 2009). Anthropogenic greenhouse gas (GHG) emissions, mainly from the burning of fossil fuels and changes in land use, are the main contributors to this scenario (ANDERSON *et al.*, 2016).

Given this context, it becomes essential to adopt mitigation strategies that reduce emissions and promote carbon sequestration. Among these strategies, the use of renewable energy sources, reforestation, and the storage of biogenic carbon in wood-derived products stand out (NEGRO; BERGMAN, 2019). Wood, through photosynthesis, acts as a natural carbon reservoir, storing it in its biomass and in products manufactured from it until the end of its useful life (JÚNIOR *et al.*, 2015).

Approximately 45% of the dry mass of wood corresponds to carbon, and it is estimated that each cubic meter of wood incorporated into buildings or furniture fixes approximately 250 kg of carbon, equivalent to 1 ton of CO_2 retained (OLIVEIRA *et al.*, 2011). Furthermore, the production of wood products requires less energy and emits fewer GHGs than materials such as steel and concrete (LIPPKE; EDMONDS, 2009; HOWE; FERNHOLZ, 2015).

In Mozambique, according to the Ministry of Education and Human Development (MINEDH, 2021), school furniture in public institutions is predominantly made of solid wood from native species, such as *Afzelia quanzensis* Welw. (chanfuta) and *Pterocarpus angolensis* DC. (umbila). These items, namely desks, doors,

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windows, tables, and chairs, therefore represent potential reservoirs of biogenic carbon. In this context, this study hypothesizes that wood products used in the infrastructure and furniture of Eduardo Mondlane Secondary School constitute significant reservoirs of biogenic carbon, contributing meaningfully to carbon storage and representing a viable sustainability strategy for climate change mitigation.

Therefore, considering the relevance of wood as a sustainable material and its role in climate mitigation, this study aims to estimate the amount of carbon stored in wood products used at Eduardo Mondlane Secondary School in Maputo. This quantification seeks to contribute to knowledge about carbon stocks in school environments and to support public policies focused on sustainability and the reduction of CO_2 emissions.

MATERIALS AND METHODS

The study was conducted in the city of Maputo, southern Mozambique (25°58'S; 32°35'E), characterized by a tropical savanna climate, with an average annual rainfall of 781 mm and an average temperature between 25 °C and 31 °C (INE, 2020).

Data collection was carried out at Eduardo Mondlane Secondary School. The study population consisted of 15 classrooms (7 x 8 m) with standardized wooden furniture made of *Afzelia quanzensis* (chanfuta) specie. A probabilistic sampling approach was adopted, in which 5 classrooms (33.3% of the total) and 10 of the 26 desks per classroom (38.5%) were randomly selected for analysis. The sample size was determined based on finite population sampling principles to ensure statistical representativeness and operational feasibility. Considering the low variability of the furniture characteristics (dimensions, material composition, and wood species), the population was assumed to be homogeneous. The minimum sample size was estimated using the finite population correction model:

$$n = \frac{N.Z^2.p(1-p)}{e^2(N-1) + Z^2.p(1-p)}$$

where n is the required sample size, N is the population size, Z is the critical value associated with the confidence level, p is the estimated population proportion, and e is the admissible sampling error. assuming a 95% confidence level, 10% admissible error, and maximum variability (p=0.5). The adopted sampling intensity was considered sufficient to provide reliable estimates of carbon storage in the evaluated school furniture.

Two types of desks were identified: type 1, made of wood and metal; and type 2, produced entirely from solid wood. In addition to the desks, other wooden items present in the classrooms were evaluated, including doors, windows, blackboards, tables, and teacher's chairs. Table 1 shows the quantity of each item found in the school.

Table 1. Number of wooden items found at school
Tabela 1. Número de itens de madeira encontrados na escola

Item	Amount
Total number of classrooms in the school	15
Capacity of each room in terms of desks	26
Number of desk type 1 (wood + metal) at school	240
Number of type 2 desks (100% wood) in the school	150
Number of windows per room	6
Teacher's desk and chair per classroom	1
Door (door + frame) per room	1
Painting per room	1

In each wooden items, length (m), width (m) and thickness (m), moisture content, and apparent density were measured. Dimensions were obtained using a measuring tape and calipers, and moisture content was measured with an electric meter (three repetitions per item). These parameters allow characterizing the physical behavior of the wood in service and comparing different types of articles and compositions. The apparent density of the species was calculated based on the average moisture content of the wooden items (Table 2).

The biogenic carbon estimate followed the EN 16449:2014 standard.

$$P_{CO2} = \pi r^2 = \frac{44}{12} \text{ x } cf \text{ x } \frac{\rho w \times Vw}{1+\frac{w}{100}}$$

where P_{CO2} is the stored CO_2 (kg), cf is the carbon fraction of woody biomass (oven dry mass), 0.5 as the default value, ρw *is* the apparent density of the wood (kg/m³), Vw *is* the volume of the wooden items at that moisture content (m³) and w is the moisture content of the wooden items (%).

The data were processed using Microsoft Excel. For items composed of multiple components, such as doors (door leaf and frame), windows (frame and sashes), and other wooden structures containing several elements, the total volume of each item was calculated as the sum of the partial volumes of its individual components. The overall volume was subsequently obtained by summing the volumes of all sampled items. For mixed desks composed of wood and metal, only the wooden components were included in the volume estimation and carbon storage calculations. The average CO_2 storage was determined according to wooden items type and room and subsequently extrapolated to the total number of rooms in the school. Differences among item categories were assessed using analysis of variance (ANOVA), followed by Tukey's post hoc test, in PAST v.4.03 software.

RESULTS

Dimensional characteristics, moisture content, and apparent density of wooden articles found in the classroom

Table 2 presents the average results of measurements of volume, moisture content, and apparent density of wooden items in the classroom, namely, tables, chairs, doors, windows, and the blackboard.

It is observed that the larger items, such as the door (1.4872 m³) and the window (0.5130 m³), have significantly larger volumes than the other elements, which is consistent with their large dimensions and structural functions. The teacher's chair and the blackboard have smaller volumes, varying approximately between 0.0407 and 0.0182 m³, reflecting their smaller size and subdivision into several components.

Table 2. Volume, moisture content and average apparent density of wooden items
Tabela 2. Volume, teor de umidade e densidade aparente média de artigos de madeira

Wooden items	Components	Average dimensions (mm)	volume (m³)	Moisture content (%)	Apparent density (12%) (g/cm³)
Double seat	Height to the tabletop	697	-	-	-
	Height to seat	426	-	-	-
	Height to the backrest	561	-	-	-
	Height to the shelf	561	-	-	-
Mixed desk (wood + metal) – type 1	Tabletop	1100 x 402 x 22	0.2386 (4.5%) *	7.6 (12.3%)	0.759 (11.5%)
	Shelf	1100 x 210 x 22			
	Seat	1100 x 224 x 22			
	Lean against	1100 x 150 x 22			
solid wood desk – type 2	Tabletop	1100 x 402 x 22	0.3952 (1.5%)		
	Shelf	1100 x 210 x 22			
	Seat	1100 x 224 x 22			
	Lean against	1100 x 150 x 22			
	Seat leg	447 x 88 x 50			
	Backrest leg	549 x 540 x 50			
	Backrest support wood	798 x 54 x 30			
	Support wood for the tabletop	890 x 60 x 30			
Teacher's Desk	Tabletop	1200 x 520 x 22	0.2580 (0.1%)		
	Shelf	477 x 260 x 22			
	Leg	719 x 500 x 26			
Professor's chair	Seat	420 x 441 x 22	0.0407 (0.7%)		
	Leg	440 x 448 x 22			
	Lean against	410 x 40 x 22			
Window	Window frame	1336 x 640 x 32	0.5130 (6.3%)		
	Window frames	1330 x 590 x 23			
Door	-	2030 x 800 x 30	1.4187 (5.4%)		
Door frame	-	2070 x 900 x 50			
Painting	-	2600 x 1400 x 20	0.0182 (2.7%)		

* The number in parentheses represents the coefficient of variation.

The average moisture content of the articles was 7.6%. This result suggests that the wood was relatively dry, possibly due to the environmental conditions of the classroom (indoor environment, ventilated and protected from humidity), which contributes to greater dimensional stability and a lower risk of defects such as warping or cracking.

The average apparent density obtained was 0.759 g/cm³, a typical value for medium to high density woods such as *Afzelia quanzensis*, frequently used in school furniture in Mozambique due to its mechanical strength and durability.

Amount of CO_2 stored by type of item

Figure 1 presents the estimated values of embodied CO_2 (kg CO2) associated with different wooden items present in a classroom. A statistically significant variation in CO_2 values is observed among the different items analyzed.

The best results are attributed to door (1834.68 kg of CO_2) and to window (663.42 kg of CO_2). This behavior is mainly explained by the larger volume of material used, the constructive complexity of these elements, and the presence of additional components, such as frames, finishes, and, in the case of windows, integration with other materials. Studies indicate that building elements with greater mass tend to concentrate higher embodied emissions throughout their life cycle (QIAN *et al.*, 2025).

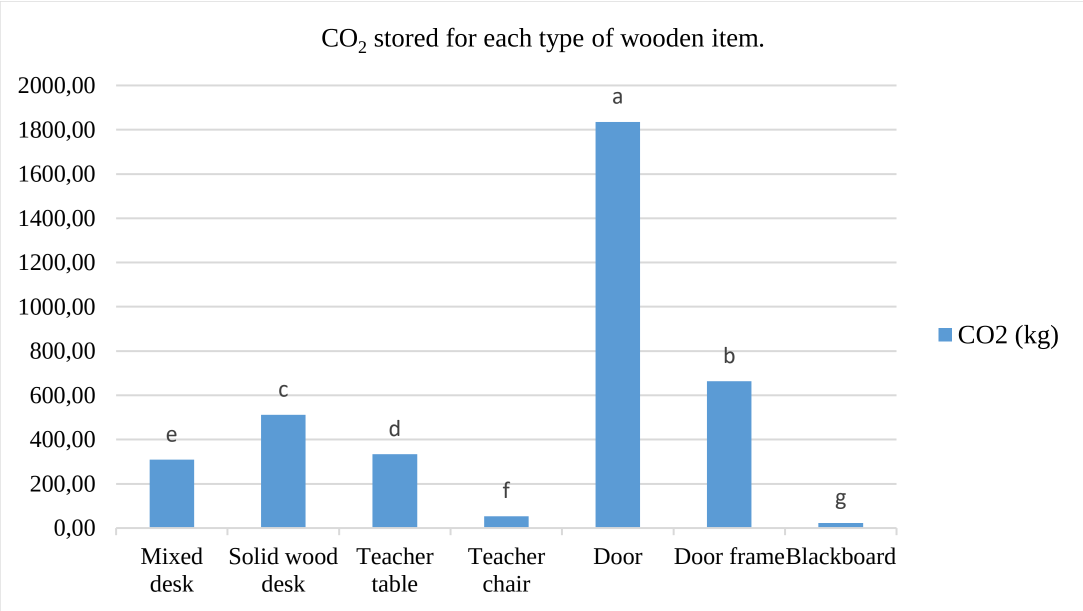

Figure 1Amount of CO_2 stored in the different types of items in the room
Figura 1. Quantidade de CO_2 armazenada nos diferentes tipos de itens da sala

Among the furniture, it was found that items made entirely of wood have higher CO_2 values than models that combine different materials. The 100% Wood desk (511.08 kg of CO_2) has a higher impact than the mixed desk (308.56 kg of CO_2), showing that the greater amount of wood used directly influences the result.

The teacher's desk (333.65 kg of CO_2) has an impact commensurate with its lower structural complexity compared to other, more massive furniture. The chair, on the other hand, the professor (52.63 kg of CO_2) has a relatively low impact due to the smaller volume of wood and structural simplicity.

The frame (23.54 kg of CO_2) presents the lowest value in the table, reflecting its reduced volume of wood and also its more simplified production process. Similar results are found in studies that analyze finishing components and lightweight furniture, which tend to present lower environmental impacts when compared to structural or sealing elements (BRAGA *et al.*, 2025).

Amount of CO_2 stored in the classroom and school.

CO_2 stored estimates associated with wooden items found in a standard classroom are presented (Figure 2) considering two distinct scenarios: (i) classrooms equipped only with mixed desks and (ii) classrooms equipped with 100% wooden desks. Subsequently, the values obtained per classroom were extrapolated to the scale of the entire school.

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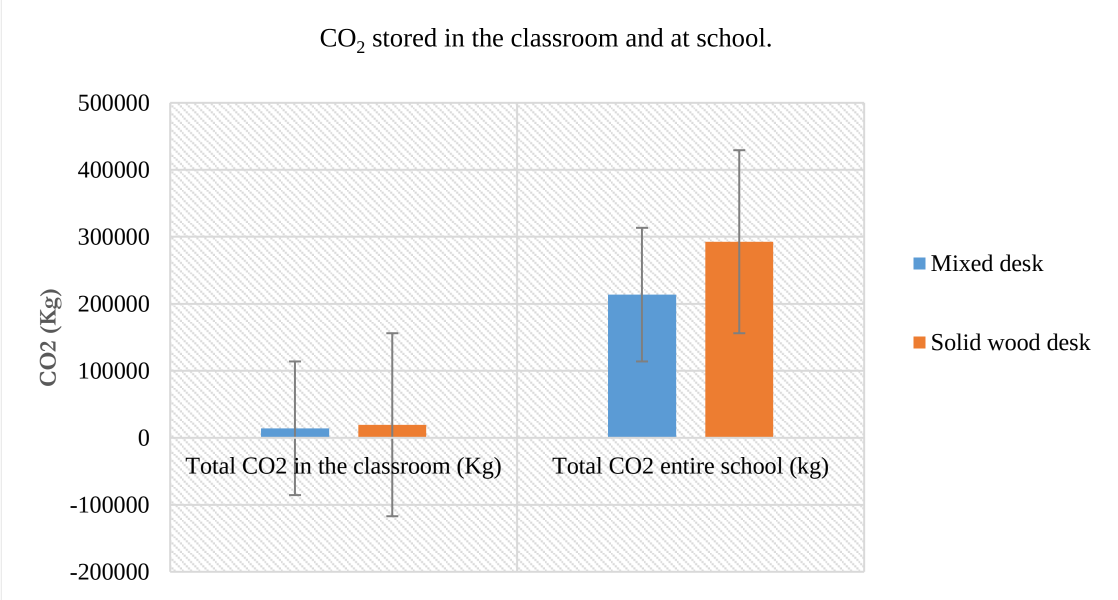

Figure 2. CO_2 stored in the classroom and extrapolated to the entire school
Figura 2. CO_2 armazenado na sala de aula e extrapolado para toda a escola

In the scenario with mixed desks in the classroom, the total CO_2 stored attributed to the desks amount to 4628.4 kg, while in the scenario with 100% wooden desks this value reaches 7666.2, highlighting a significant increase associated with the replacement of the type of student furniture.

The total CO_2 stored per classroom, considering all existing items, were estimated at 14,247.58 kg for the scenario with mixed desks and 19,513.10 kg for the scenario with 100% wood desks, resulting in an absolute difference of approximately 5,265.5 kg of CO_2 per classroom.

When extrapolated to the entire school, the results indicate total CO_2 stored of 213,713.70 kg in the scenario with mixed desks and 292,696.5 kg in the scenario with 100% wood desks. ANOVA showed significant differences ($p < 0.05$) between the scenarios. The greatest storage potential in the school occurs when classrooms are equipped exclusively with solid wood desks.

Amount of CO_2 stored in the school under real conditions.

CO_2 storage under the actual school conditions considered the data in Table 1, revealing a predominance of type 1 desks (62% of the total) over type 2 desks (38%). The analysis of variance (ANOVA) detected statistically significant differences ($p < 0.05$) in CO_2 storage capacity between the desk types. Extrapolating these results to the 15 classrooms in the school, an estimated 244,091.7 kg of CO_2 was stored, equivalent to 290.58 kg/m² (considering 56 m² per classroom).

DISCUSSION

The results confirm that the composition of wooden furniture directly influences the biogenic carbon stock in school environments. Solid wood desks (type 2) retained more CO_2 than mixed desks (wood and metal – type 1), thanks to the higher volumetric proportion of wood, the main carbon reservoir. This finding aligns with studies that correlate wood density, product durability, and carbon sequestration capacity (DZHURKO *et al.*, 2024; NEGRO; BERGMAN, 2019).

The importance of wood in construction and furniture is widely recognized. Yao *et al.* (2023) estimate that if 30% to 60% of new global urban buildings predominantly used wood, they would avoid 25.6 to 39 gigatons of CO_2 equivalent by 2100. Similarly, Dzhurko *et al.* (2024) show reductions of 32.6% in embodied CO_2 in wood buildings versus brick, and 40.4% versus concrete. Such evidence indicates that the use of wood in institutional environments such as schools contributes to climate mitigation, provided it comes from responsible forest management, ensures durability, and avoids premature release of CO_2 at the end of its life, according to ECOS (2023).

CO_2 stored, although the furniture does not dominate the environmental impact of the classroom. The scenario with 100% wood desks increased CO_2 stored due to the greater volume of material and the extraction, processing, and manufacturing factors, as indicated by life cycle assessments (LCA) of forest products (ZHANG *et al.*, 2023). Permanent elements, such as windows and doors (glass, aluminum), lead the emission balance, aligning with the literature (IPCC, 2014; RÖCK *et al.*, 2020).

On an institutional scale, the difference between scenarios becomes relevant: extrapolation to the entire school revealed an increase of 5,265.52 kg of CO_2 with 100% wood desks. This reinforces the need to integrate sustainability criteria and LCA in the specification of school furniture, especially in public projects with standardization (IORDAM *et al.*, 2018; EMAMI *et al.*, 2016; IPCC, 2021, SEBESTYÉN, 2024).

In the analyzed case study, Eduardo Mondlane Secondary School the furniture stock stores approximately 224.09 tons of CO_2-equivalent, a value consistent with findings reported for built environments (BUCHHOLZ *et al.*, 2021). The replacement of conventional materials with solid wood can generate measurable climate-change mitigation benefits, even at relatively small scales. Integrating this approach into sustainable public procurement policies and ecological design strategies may contribute to accelerating the transition toward a more sustainable and low-carbon economy, particularly by promoting low-carbon agricultural and forestry systems in tropical countries such as Mozambique.

CONCLUSIONS

- The results of this study demonstrate that wood products used in the infrastructure and furniture of Eduardo Mondlane Secondary School constitute important reservoirs of biogenic carbon, confirming their contribution to carbon storage within the school environment. Desks made entirely of wood exhibited greater carbon storage capacity than mixed-material desks; however, both types contributed to the retention of significant amounts of CO_2.
- These findings support the hypothesis that wooden products used in school infrastructure represent a viable sustainability strategy for climate change mitigation. The study highlights the potential of wood-based furniture to function as long-term carbon sinks, reinforcing the importance of promoting the use of wood products in educational institutions as part of broader greenhouse gas mitigation and sustainable development policies.

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