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EVALUATION OF LIFE CYCLE ASSESSMENT (LCA) AND SOUND ABSORPTION PROPERTIES OF COMPOSITE MATERIALS MADE FROM COCONUT AND SUGARCANE FIBERS

Nuushuun Archie GBOE✉, Raimondas GRUBLIAUSKAS

Vilnius Gediminas Technical University, Vilnius, Lithuania

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Abstract. Agriculture plays a crucial part in the economic growth of several developing nations; however, it creates 1,300 million tons of waste each year, which generates environmental issues. Noise pollution, particularly in urban environments, is an expanding global health issue for emotional and physical health. Conventional synthetic sound absorption materials used for sound absorption pose environmental and health risks; therefore, agricultural wastes including coconut fiber and sugarcane fiber, are being sought for safer alternatives. Natural fibers as sustainable sound-absorbing solutions draw increasing research attention. This paper evaluates the Life Cycle Assessment of agriculture waste based on the SWM-GHG calculator to compare the waste management approaches by calculating the GHG emission related to the recycling and disposal of wastes from cradle to grave, and sound absorption properties of coconut and sugarcane fibers in composite materials. A non-toxic PVA binder was utilized to prepare samples with densities of 75, 100, and 125 kg/m^3, and sound absorption was evaluated based on ISO 10534-2. The results show a cost-benefit trade-off in waste management where higher recycling reduces GHG emissions but increases costs; the Default Scenario results in the highest emissions (20,439 t CO_2e/yr) at the lowest cost, and Scenario 3 results in the lowest emissions (5,148 t CO_2e/yr) at the highest cost. Also, sugarcane fiber (75 kg/m^3) achieved the highest absorption coefficient (0.94 at 800 Hz), while coconut fiber (125 kg/m^3) reached 0.91 at 1000 Hz, making both suitable for acoustic applications, with coconut fiber excelling in mid to high frequencies and sugarcane fiber in low to mid frequencies, particularly at lower densities.

Keywords: Life Cycle Assessment, greenhouse gas emission, coconut fiber, sugarcane fiber, sound absorption coefficient, noise pollution.

✉Corresponding author. E-mail: *nuushuun-archie.gboe@vilniustech.lt*

1. Introduction

Population estimations differ from 3.7 billion in 1970 to 7.9 billion in 2021 with projections for 9 billion by 2050 and 11 billion by 2100 (Koop & van Leeuwen, 2017). This presents a future food security challenge, due to meeting this growing food demand, crop output has increased considerably, causing a rise in agricultural waste (Wang et al., 2024). Farming creates 23.7 million tons of food daily, higher food production has raised environmental strain leading to soil degradation, water resources, air pollution, etc affecting public health and ecosystem sustainability. On a worldwide scale, over 2.5 billion tons of food is lost yearly – over one-third of food production is created. Agriculture also makes up 21% of worldwide GHGs (Duque-Acevedo et al., 2020). In a more interconnected and urbanized world, noise pollution has emerged as a significant yet often overlooked environmental issue. It is an unavoidable result of modern life, defined by the tremendous presence of unwanted noise in our surroundings (Hemmat et al., 2023).

Noise pollution has a gradual and often subtle effect. It could result in instant irritability, but its damaging effects are stronger when subjected to damaging sounds for an extended time. Contrary to air and water pollution, which are physical pollutants, noise pollution is caused by sound waves that disrupt the normal waves of the same kind in the environment (Aluko & Nna, 2015). Noise pollution is life-threatening. Noise-induced hearing Loss (NIHL) is among the most prevalent and extensively discussed health consequences. Chronically raised noise levels can cause numerous negative health consequences, including mental harm. Loud sounds have been linked with increased aggression, chronic anxiety, and exhaustion. With noise having these kinds of an effect on populations there's a growing demand for sound reduction and absorption

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solutions. Fiberglass and rock wool, used extensively in sound absorbers in developing nations, are synthetic, and present substantial environmental and health consequences. It is crucial to address this issue with an eco-friendly perspective, recognizing the urgent need for sustainable materials to tackle these environmental challenges (Kolya & Kang, 2024).

The absorption of sound by natural fibers such as sugarcane fiber and coconut fiber continues to be investigated in many studies. Along with their environmental advantages, these fibers have been found to have good potential for sound absorption (Balbay et al., 2024). Therefore, it is crucial to thoroughly evaluate the sound absorption capabilities of these materials and advocate for their use in appropriate applications (Kolya & Kang, 2024). Natural fibers have attracted considerable attention for their environmental advantages and acoustic qualities. Sound absorbers created out of natural materials are becoming popular because of their biodegradability and sustainability promoting the "Green environmentally friendly movement." Natural fibers of agricultural wastes like coconut fiber and sugarcane fiber could be utilized as cost-effective, biodegradable, and recyclable sound absorption materials (Gboe & Grubliauskas, 2023).

Coconuts are fruits that grow year-round on sandy soil, primarily in tropical and rainforest regions, near coasts where they get adequate water and sunlight. 62.5 million tons of coconut are produced annually in over ninety nations. Fresh coconuts are used for beverages, and animal feed by people. Items including wall decor are produced from the husks; clothes and bags are made from the fibers. Nevertheless, burning or improper disposal of coconut waste (like husks and shells) leads to a block, air pollution, and poor sanitation drains, which might result in mosquito breeding grounds (Obeng et al., 2020). Sugarcane is grown over huge tracts in tropical areas of different regions for manufacturing sugar (sucrose) for consumption (Renouf et al., 2010). The worldwide sugar industry produces around 279 million metric tons of sugarcane waste yearly and South Africa contributes over 1.353 million metric tons yearly. In South Africa, more than half of this waste is reused in cogeneration facilities (Putra et al., 2013). Sugarcane waste presents environmental and health risks because of its solid, semisolid, and liquid types (Ungureanu et al., 2022). Agriculture wastes are frequently deposited in landfill sites without gas restoration or even in open dumps, causing greenhouse gas emissions. On the other hand, collection, recovery, incineration, and other treatments provide more sustainable choices to minimize environmental impact (Michel Devadoss et al., 2021).

This research aims to examine the Life Cycle Assessment using the SWM-GHG calculator for comparison of waste management strategies by calculating the greenhouse gas (GHG) emission associated with both the recycling and disposal of waste throughout its entire life cycle, from "cradle to grave" and the sound absorption coefficient of composite materials made from agricultural waste fibers (coconut and sugarcane fibers) combined with a non-toxic binder (PVA, or polyvinyl acetate). The objective is to propose these materials as environmentally friendly options for constructing acoustic sound-absorbing panels. These materials can be used in buildings to reduce noise levels.

2. Materials and methods

2.1. Life Cycle Assessment (LCA) for Green House (GHG) emission

The Life Cycle Assessment (LCA) of sugarcane fiber and coconut fiber categorized as food waste was conducted using the SWM GHG calculator evaluating GHG emissions from various waste management strategies. It estimates emissions over the life of the waste including residual waste, recycling streams, and future degradation emissions. Recycling processes create secondary raw materials that replace primary ones leading to emissions savings calculated according to the LCA methodology. This study dealt with the production, open dumping, and burning of agricultural wastes referred to as food waste. Three scenarios were analyzed using the calculator: Present scenario (default), business-as-usual future (Scenario 1), advanced waste management system (Scenario 2) along contemporary program based on European standards (Scenario 3).

2.2. Materials preparation

Coconut fibers have been derived from coconut husks cut into 0.5–1.0 mm length. Sugarcane fibers are a by-product of "kin juice" production after the juice is extracted from sugarcane stalks. All materials were dried at 25 °C for two days (eight hours per day). Following sun drying the materials were dried out at 75 °C further to get rid of remaining moisture. The moisture content was monitored by periodically weighing the materials to ensure thorough drying (Gboe & Grubliauskas, 2023).

As shown in Figure 1, the dried materials were mixed with PVA D2 glue, chosen for its strong adhesive properties. The materials were placed in a mixing container, and the glue was added. They were manually stirred with a spatula for 1.5 minutes to ensure proper bonding. The mixture was then placed into cylindrical shape molds with a diameter of 29.9 mm and thicknesses of 50 mm. Parchment paper was used to prevent the mixture from sticking to the mold. Samples were air-dried at ambient temperature for 48 hours before removal from molds. Six samples for each material type were prepared to determine the sound absorption coefficient by the transfer function technique with an impedance tube system: a) Coconut fiber and b) sugarcane fiber. Three specimens were prepared to check for measurement consistency and accuracy, following the procedure outlined in Table 1.

Figure 1. Preparation of samples from raw materials to trimmed materials and mold specimen steps: a) sugarcane fiber; b) coconut fiber

Table 1. Preparation of samples and compositional ratios

Sample description	Mass, g±0.2	Thickness, mm	Density, kg/m^3	PVA D2 glue binder, wt % ±0.2
75 kg/m^3–50	2.39	50	75	2.39
100 kg/m^3–50	3.19	50	100	3.19
125 kg/m^3–50	3.99	50	125	3.99

2.3. Determination method of sound absorption coefficient in impedance tube

The sound absorption coefficient was measured based on ISO 10534-2 standard by transfer function technique and two-microphone technique defined by the International Organization for Standardization (1998, 2023). The research used a 30 mm internal diameter tube with a firm back to hold the samples and recorded sound absorption with a frequency range of 160 to 5000 Hz, plotting results in 1/3 octave bands. For the lower frequency range (160–1000 Hz), microphones No. 1 and No. 2 were utilized; for higher frequencies (1000–5000 Hz), the microphones had been set apart. Data were collected by a data acquisition system plugged into a computer user interface in a strictly controlled lab condition (250 °C and 50% relative humidity).

3. Experimental results and discussion

The experiment provides a detailed report on the Life Cycle Assessment (LCA) for Greenhouse Gas (GHG) emissions and contains data on the sound absorption coefficients of various raw materials, such as the density, thickness, and frequency range. The results were analyzed to investigate the relationship between these factors and the sound absorption performance of natural composite fiber materials. The findings highlight the connection between material composition, physical properties, and sound-absorbing behaviour, offering valuable insights into the factors that influence the sound-absorption characteristics of natural fibers.

3.1. Life Cycle Assessment (LCA) results for Greenhouse Gas (GHG) emissions

Figures 2 and 3 shows the Life Cycle Assessment (LCA) for Greenhouse Gas (GHG) emissions, the waste is divided into four categories: recycled, scattered, burned-open, and wild dump, for each scenario. The waste management scenarios analysis reveals a GHG emissions cost trade-off. The Default Scenario provides the highest emissions (20,439 t CO_2e/yr) with the lowest price, while Scenario 3 contains the lowest emissions (5,148 t CO_2e/yr) at the highest price. Scenarios 1 and 2 offer intermediate solutions that balance emissions reduction with costs. Budget constraints must be well balanced with environmental targets: higher recycling rates, lower emissions, but this increases the cost per unit CO_2e due to investments in sustainable practices.

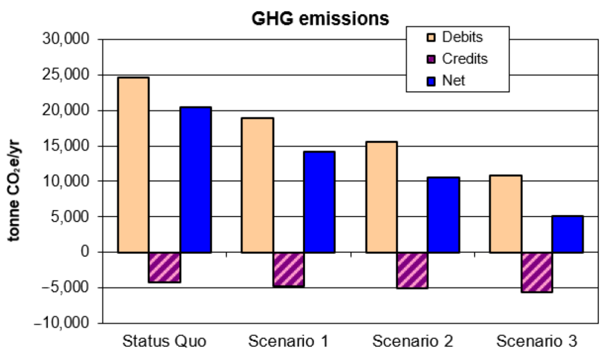

Figure 2. Analysis of GHG emissions across different scenarios

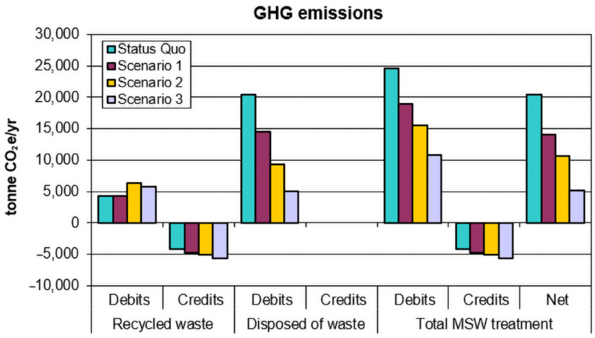

Figure 3. Analysis of GHG emissions for recycling and disposal across different scenarios

Studies demonstrate the need for integrated strategies: Shrestha et al. (2023) discovered that Scenario 3 (composting and landfilling) was the very least environmentally friendly choice at Banepa in Nepal, while Scenario 4 (anaerobic digestion) offered probably the lowest GWP. Similarly, Brancoli and Bolton (2019) identified Scenario 3 (sorting, composting, landfilling, and incineration) as optimal, minimizing GWP, AP, and HTP. These results highlight that advanced waste treatment methods, including recycling, anaerobic digestion, and incineration, can significantly enhance sustainability while addressing environmental challenges.

3.2. Sound absorption coefficient

- Coconut Fiber (CF 75 kg/m^3, 100 kg/m^3 and 125 kg/m^3 in 50 mm mold)

Figure 4 shows experimental results for coconut fiber samples at three densities: 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3 in 50 mm mold, in lower frequencies (160–500 Hz), in mid-range frequencies (500–2000 Hz) and in higher frequencies (2000–5000 Hz).

For the 75 kg/m^3 sample, the highest sound absorption at low frequencies is 0.21 at 500 Hz, in the mid-range it reaches 0.61 at 1250 Hz, and at high frequencies, it peaks at 0.75 at 4000 Hz. In the 50 mm mold, the peak absorption for this sample occurs at 4000 Hz, with a maximum value of 0.75 at 4000 Hz. The thickness of the mold (50 mm) significantly enhances sound absorption, especially at high frequencies, with a peak of 0.75 at 4000 Hz, and it also improves absorption at lower frequencies. For the 100 kg/m^3 sample, the highest sound absorption in low frequencies is 0.28 at 500 Hz, in the mid-range it is 0.82 at 1250 Hz, and at high frequencies, it peaks at 0.89 at 4000 Hz. The 100 kg/m^3 sample in the 50 mm mold shows substantial improvement across all frequencies, with peak absorption shifting to 4000 Hz, where it reaches 0.89, making it more effective at high frequencies. For the 125 kg/m^3 sample, the highest sound absorption at low frequencies is 0.39 at 500 Hz, in the mid-range it peaks at 0.91 at 1000 Hz, and in high frequencies, it reaches 0.84 at 3150 Hz. The 125 kg/m^3 sample performs best in mid-range frequencies, with a peak absorption of 0.91 at 1000 Hz. It also significantly improves absorption at lower frequencies making it the most effective sample for low to mid frequencies among all configurations.

- Sugarcane Fiber (SF 75 kg/m^3, 100 kg/m^3 and 125 kg/m^3 in 50 mm mold)

Figure 5 shows experimental results for sugarcane fiber samples at three densities: 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3 in 50 mm mold, in lower frequencies (160–500 Hz), in mid-range frequencies (500–2000 Hz) and in higher frequencies (2000–5000 Hz).

For the sample with a density of 75 kg/m^3, the sound absorption coefficient peaks within the 630 Hz to 1000 Hz range, with a maximum value of 0.94 at 800 Hz. At lower frequencies, the highest absorption of 0.56 occurs at 500 Hz. In the mid-frequency range, the peak absorption is 0.94 at 800 Hz, while at higher frequencies, it reaches 0.88 at 5000 Hz. This sample demonstrates enhanced sound absorption across all frequencies, with particularly strong performance in the mid and high ranges. For the sample with a density of 100 kg/m^3, the sound absorption coefficient peaks between 500 Hz and 800 Hz, with a maximum value of 0.94 at 630 Hz. At lower frequencies, the highest

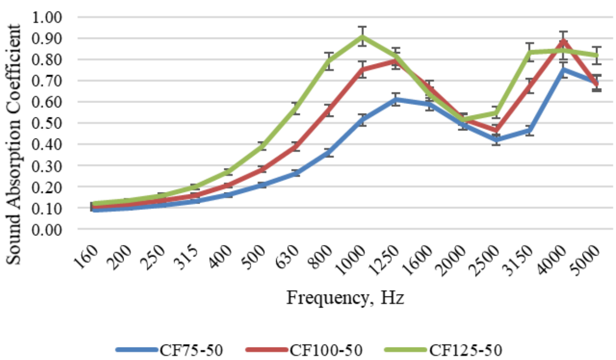

Figure 4. Experimental results of sound absorption coefficient measurements using an impedance tube for coconut fiber samples (with densities of 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3) in 50 mm mold

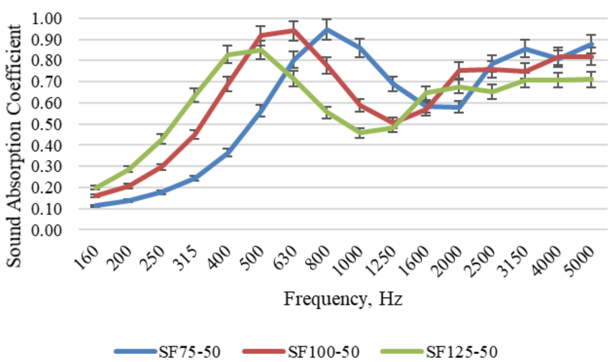

Figure 5. Experimental results of sound absorption coefficient measurements using an impedance tube for sugarcane fiber samples (with densities of 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3) in 50 mm mold

absorption is 0.92 at 500 Hz, while in the mid-range, it reaches 0.94 at 630 Hz. At higher frequencies, the absorption peaks at 0.82 between 4000 Hz and 5000 Hz. This sample exhibits strong sound absorption in the low and mid-frequency ranges, with a moderate performance at high frequencies.

For the sample with a density of 125 kg/m³, the sound absorption coefficient peaks between 400 Hz and 630 Hz, reaching a maximum of 0.85 at 500 Hz. The highest absorption at low frequencies is 0.85 at 500 Hz, while in the mid-range, it peaks at 0.71 at 630 Hz. In the high-frequency range, the absorption reaches 0.71 between 4000 Hz and 5000 Hz. This sample demonstrates stronger absorption at low frequencies, with stable performance across mid and high ranges.

4. Conclusions

The study explores the Life Cycle Assessment based on the SWM GHG calculator is performed by comparing waste management strategies by calculating the greenhouse gas (GHG) emission and the sound absorption qualities of composite materials derived from agricultural waste fibers (coconut and sugarcane fibers). Advanced waste management approaches, such as MRFs with composting, anaerobic digestion, and incineration, lead to considerably reduced GHG footprints but higher costs. For instance, Scenario 3 decreased greenhouse gas (GHG) emissions to 5,148 t CO_2e/yr. These findings underscore the necessity to balance emissions reduction, cost-effectiveness, and resource recovery for sustainable MSW management.

Coconut and sugarcane show good sound absorption capabilities based on density, thickness, and frequency. Higher-density coconut fibers (100–125 kg/m³) absorb sound effectively in mid and high frequencies, with thicker samples improving low-frequency absorption (e.g., a 125 kg/m³, 50 mm sample reached a peak of 0.91 at 1000 Hz). In contrast, sugarcane fibers perform better in low and mid frequencies, particularly at lower densities, offering consistent absorption across ranges. Coconut fibers are ideal for mid to high-frequency noise control, while sugarcane fibers excel at low-frequency sound insulation. Selection depends on the target frequency range.

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KOMPOZITINIŲ MEDŽIAGŲ IŠ KOKOSO BEI CUKRANENDRIŲ PLUOŠTŲ GYVAVIMO CIKLO ANALIZĖ IR GARSO SUGERTIES TYRIMAS

N. A. Gboe, R. Grubliauskas

Santrauka

Žemės ūkis atlieka svarbų vaidmenį augant daugelio besivystančių šalių ekonomikai, tačiau kasmet sukuria apie 1300 milijonų tonų atliekų, kurios sukelia aplinkosauginių problemų. Triukšmo tarša, ypač urbanizuotose teritorijose, tampa vis aktualesne problema, darančia įtaką emocinei ir fizinei sveikatai. Įprastos sintetinės garsą sugeriančios medžiagos, naudojamos triukšmui slopinti, kelia pavojų aplinkai ir žmonių sveikatai, todėl ieškoma saugesnių alternatyvų iš žemės ūkio atliekų, tokių kaip kokoso ir cukranendrių pluoštas. Natūralūs pluoštai kaip tvarios garsą sugeriančios medžiagos vis labiau domina tyrėjus. Šiame darbe vertinamas žemės ūkio atliekų gyvavimo ciklas, siekiant palyginti skirtingas atliekų rūšis pagal šiltnamio efektą sukeliančių dujų (ŠESD) emisijas nuo žaliavos gavimo iki jų galutinio pašalinimo („nuo lopšio iki kapo“). Nagrinėjamos iš kokoso ir cukranendrių pluoštų pagamintų kompozitinių medžiagų kompozitų garso sugerties savybės remiantis ISO 10534-2. Mėginiams buvo naudotas netoksiškas PVA rišiklis, o jų tankiai buvo 75, 100 ir 125 kg/m³. Rezultatais nustatyta, kad atliekų tvarkymo srityje egzistuoja sąnaudų ir naudos balansas – perdirbimas sumažina ŠESD emisijas, tačiau didina išlaidas: pagal numatytąjį scenarijų gaunamos didžiausios emisijos (20 439 t CO_2 ekv./metus) už mažiausius kaštus, o pagal 3 scenarijų gaunamos mažiausios emisijos (5 148 t CO_2 ekv./metus). Be to, cukranendrių pluoštas (75 kg/m³) pasiekė didžiausią garso sugerties koeficientą (0,94 esant 800 Hz), o kokoso pluoštas (125 kg/m³) – 0,91 esant 1000 Hz. Kokoso pluoštas geriau sugeria vidutinių ir aukštų dažnių garsus, o cukranendrių pluoštas – žemų ir vidutinių dažnių, ypač esant mažesniam tankiui.

Reikšminiai žodžiai: gyvavimo ciklo vertinimas, ŠESD emisijos, kokoso pluoštas, cukranendrių pluoštas, garso sugerties koeficientas, triukšmo tarša.