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"Sustainable Innovation in Agriculture: Assessment of the Socioeconomic and Environmental Impact of Agricultural Waste Composite Materials"

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Abstract:

Purpose: This study examines the socioeconomic and environmental impacts of producing and utilizing composite materials from agricultural waste, specifically Plantain, rice, coconut, and cashew nut residues in rural communities. It focuses on how these practices can contribute to economic, social, and environmental development by integrating circular economy principles to optimize resource use and minimize waste.

Methodology: A mixed research design was employed, blending both qualitative and quantitative approaches. The Analytic Hierarchy Process (AHP) was used to evaluate and compare production alternatives from a multidimensional perspective. This approach involved expert participation to weigh social, economic, and environmental factors associated with each type of agricultural residue.

Main Findings: The results suggest that producing composite materials from agricultural waste significantly contributes to the economic and social development, as well as to the environmental sustainability of rural communities. Plantain production emerged as the most viable alternative, followed by cashew nut, rice, and coconut, presenting opportunities to enhance local value chains and access to new markets.

Implications: These findings have significant implications for public policy and rural development strategies. They advocate for the adoption of circular economy practices in agriculture and underscore the need for policies supporting innovation and sustainability in agricultural waste management. Furthermore, they highlight the potential of these wastes as resources for composite materials in various industries.

JEL Keywords: - Q01 (Sustainable Development); - Q16 (R&D / Agricultural Innovation); - Q53 (Waste Management); - O13 (Natural Resources and Energy Economics); - O33 (Technology and Technological Change)

Introduction:

The concept of the circular economy, as a sustainable approach, aims to reduce the consumption of natural resources and minimize waste generation by leveraging existing materials within the production and consumption cycle. This approach has garnered significant attention from both academics and practitioners (Kirchherr et al., 2017). The principles of the circular economy are rooted in various schools of thought, including industrial ecology, industrial symbiosis, industrial metabolism, and cleaner production (Lewandowski, 2016). Employing the law of industrial ecology, the circular economy strives to achieve resource efficiency and higher recycling rates (Zeng & Li, 2021).

The circular economy not only addresses environmental concerns but also offers solutions to major challenges such as climate change, waste management, pollution, and biodiversity loss (Bag & Rahman, 2021). It allows for the decoupling of GDP growth from natural resource consumption and environmental degradation (Tambovceva et al., 2021). The transition to a circular economy model is associated with risks, including environmental issues, increased production costs, reduced efficiency, social inequality, and corruption (Dovgal, 2022).

Moreover, the concept of the circular economy is based on the idea of growth through the use of waste as a primary resource with minimal energy consumption and dependence on new natural resources, promoting environmental protection and sustainable development (Popović & Radivojević, 2022). The application of circular economy principles extends to various sectors, including tourism, where the focus is on reducing energy and food waste (Vargas-Sánchez, 2023). Circular economy models have been identified as essential for improving sustainability performance in manufacturing companies (Ghaithan et al., 2023).

In this context, utilizing agricultural waste for the production of composite materials represents an opportunity to promote sustainable practices and generate socioeconomic benefits in rural communities. Agricultural waste from Plantain, rice, coconut, and cashew can be transformed into composite materials with various applications in sectors such as construction, automotive, and packaging.

The reuse of agricultural, industrial, and post-consumer waste for composite production not only offers environmental advantages by turning waste into raw materials but also has the potential to improve the mechanical and tribological properties of materials (Sydow et al., 2021). Composites derived from natural resources, such as rice husk, wheat shell, wood fibers, and textile waste fibers, have low density, reduced environmental impact, and favorable thermal properties, making them promising for various applications (Muthuraj et al., 2019). Moreover, the incorporation of agricultural waste fillers like cashew shell residues in epoxy composites can provide interesting properties to the polymeric matrices (Salazar-Cruz et al., 2022).

The principles of the circular economy, particularly in solid urban waste management, can play a vital role in transforming urban waste into valuable resources for urban agriculture, contributing to sustainability efforts (Machado & Cunha, 2021). Additionally, the development of biodegradable electromagnetic shielding composites using residual porous biochar and poly(butylene succinate) demonstrates the potential to utilize agricultural waste in innovative material applications (Wang et al., 2023).

This research is justified by the need to understand how the production and use of composite materials from agricultural waste can contribute to the environmental, social, and economic development of rural communities and how to overcome the challenges to the adoption and dissemination of these sustainable practices. Furthermore, the findings of this study can be useful to inform public policies and intervention actions aimed at fostering circular economy and sustainable rural development.

Basic Concepts of the Circular Economy

Definition and Principles

The concept of a circular economy presents an alternative economic model to the traditional linear approach of "extract, manufacture, consume, and dispose." Instead of this linear model, the circular economy aims to maximize the use of resources and materials by extracting their utmost value and minimizing waste and pollution (Ghisellini et al., 2016). This economic model is designed to optimize the functioning of industrial systems and extend these principles across the entire economy, creating a new framework for economic development, production, distribution, and product recovery (Ghisellini et al., 2016). The circular economy emphasizes the efficient use of resources through waste reduction, long-term value retention, and establishing closed circuits for products and materials within the bounds of environmental protection and socioeconomic benefits (Ozili, 2021).

Moreover, the circular economy is increasingly recognized not just as an environmental strategy but as an economic strategy (Hao et al., 2020). It implies a shift in business models towards strategies focusing on resource efficiency, waste minimization, and the creation of closed-loop systems (Voukkali, 2023). Transitioning to a circular economy model is essential for sustainable development and improving quality of life by reducing material cycles and waste generation (Wuyts et al., 2020). Legislation, as seen in China, can play a crucial role in promoting the circular economy by setting it as a central development goal and moving away from the linear model of resource consumption and waste generation (Hu et al., 2018).

The circular economy is based on three fundamental principles:

1. Design to eliminate waste and pollution: This principle seeks to design products, processes, and systems in a way that reduces or eliminates waste and pollution from the outset. This approach emphasizes the use of sustainable, non-toxic materials and processes, along with incorporating design practices that facilitate product repair, refurbishment, and recycling (Howaniec, 2022). By focusing on sustainable materials and chemical processes, businesses can contribute to additive manufacturing while considering environmental impacts (Sánchez-Rexach et al., 2020).

2. Maintain products and materials in use: The circular economy promotes the prolonged use of products and materials through practices such as reuse, repair, refurbishment, and recycling. This philosophy is based on reducing, reusing, and recycling products to give them a second life, prioritizing environmental conservation (Ortíz-Palomino & Fernández-Bedoya, 2021). The circular economy seeks to change the linear production model towards efficiency in energy and raw material use, reducing waste

and preventing environmental impacts (Carpio et al., 2022). Furthermore, the circular economy is constantly evolving through its implementation in productive processes and economic systems, with the common goal of reducing environmental impact and using resources efficiently (Saltos et al., 2022).

Attention towards the circular economy has significantly increased globally as a way to promote sustainable development goals, being considered a valuable alternative by policymakers, researchers, and practitioners (Flores et al., 2023). The circular economy is expected to foster economic growth by creating new businesses, job opportunities, and at the same time saving materials (Yáñez, 2021). Additionally, the circular economy implies adopting cleaner production standards, greater producer and consumer responsibility, use of renewable technologies, and appropriate policies to promote sustainability (Cansi & Cruz, 2020).

The circular economy emerges as a model that seeks to preserve and enhance natural capital, optimize resource yield, and improve the effectiveness of the production system, generating environmental, social, and economic benefits (GARABIZA et al., 2021).

Regenerate Natural Systems: This principle focuses on returning biological resources to the environment sustainably and regenerating natural systems. Regenerative agriculture is seen as a vital approach to restoring natural systems and simultaneously improving soil health and biodiversity, as well as agricultural profitability. This paradigm includes reforestation, ecosystem restoration, and maintaining permanent vegetation cover, practices that increase soil carbon, enhance fertility and climate resilience, and promote an efficient nutrient cycle alongside animal welfare, as discussed by Fenster et al. (2021) and Colley et al. (2020).

These regenerative practices are key to addressing global environmental challenges like climate change and soil degradation, highlighting the importance of their implementation to preserve biodiversity and ecosystem services amid growing food insecurity and dwindling resources, as discussed in Rhodes (2012) and Kremen (2020). Although the conceptualization of regenerative agriculture may present difficulties for scientific validation, as pointed out by Daverkosen et al. (2022), the trend towards adopting low-impact practices is essential for developing sustainable agroecosystems, as stated by Teague (2018), emphasizing that the benefits transcend the ecological sphere to also bolster economic sustainability, as corroborated by Taha and Taha (2022).

Economic, Social, and Environmental Impact

The circular economy aims to foster sustainable development and address environmental challenges through waste minimization and resource optimization, a concept identified by Murray et al. (2015) as essential for ecological progress. By adopting its practices, multifaceted benefits touching on environmental, economic, and social aspects are obtained, according to Potârniche et al. (2022). However, measuring these benefits presents challenges, especially due to the lack of a universally recognized measurement standard at both micro and macro levels (Ozili, 2021).

Current indicators tend to focus on economic aspects, leaving environmental and social dimensions in the background, highlighting the importance of a more holistic measurement system that addresses all facets of the circular economy, as suggested by Saidani et al. (2017). Such a system should include factors like the reduction of emissions and pollutants, the strengthening of resource security, the promotion of competitiveness and innovation, the drive for economic growth, and job creation (Potârniche et al., 2022).

In the business realm, Moric et al. (2020) demonstrate that integrating the circular economy elevates company productivity, indicating its positive influence on financial outcomes. Additionally, it offers financial entities, such as banks, new opportunities for investment and diversification towards sustainability (Ozili, 2021).

Specifically in the food industry, the application of circular models can eradicate food waste, thereby bringing significant operational and environmental advantages (Abudu et al., 2022). To fully capitalize on these benefits, an approach that integrates economic, environmental, and social perspectives is required, driving the development of comprehensive measurement methodologies that reflect the full range of advantages of the circular economy (Saidani et al., 2017).

Only then can policymakers, businesses, and other stakeholders make decisions based on solid information and move towards a more sustainable and regenerative economy. To maximize the benefits of the circular economy, an approach that integrates economic, environmental, and social perspectives is essential. This integration drives the development of comprehensive measurement methodologies that reflect the full spectrum of benefits of the circular economy. The circular economy model focuses on preserving and enhancing natural capital, optimizing resource efficiency, and improving the effectiveness of the production system, resulting in environmental, social, and economic benefits (Garabiza et al., 2021). Its aim is to reduce the input of virgin materials and the output of waste from the production chain, in contrast to the traditional linear economic model based on continuous growth, which depletes resources (Saltos et al., 2022).

Research indicates that the circular economy has brought significant economic benefits in Europe but remains underutilized in developing countries due to structural problems in those regions (Castro-Góngora & Mul-Encalada, 2020). The implementation of circular economy strategies is crucial for sustainable development, as the current linear production system, involving the extraction of resources, hostile processing of raw materials, use by consumers, and inadequate disposal of waste is unsustainable (Carpio et al., 2022). Transitioning to a circular economy can provide a competitive advantage for small and medium-sized enterprises, as studies have correlated the dimensions of the circular economy with competitive advantages such as low costs and differentiation (Paredes et al., 2022).

Concurrently, the circular economy presents an opportunity for sustainable entrepreneurship by leveraging natural resources integrated with technology to produce environmentally friendly goods and services that contribute to the regeneration of ecosystems (Piedrahíta et al., 2023). The adoption of the circular economy is considered a means to achieve sustainable development, addressing challenges of pollution and scarcity of natural resources (Alcázar-Espinoza et al., 2018).

Agricultural Waste

Agricultural waste consists of waste materials generated from agricultural activities. These can include crop residues, manure, packaging and processing waste, as well as pesticide and fertilizer waste. The management of these wastes is crucial for environmental sustainability and efficiency in agricultural production. Various studies have highlighted the importance of managing agricultural waste, as it can significantly impact soil quality, water pollution, and biodiversity (Meza-Sepúlveda et al., 2021; Singh et al., 2019; Sharma et al., 2020). Additionally, agricultural waste has been identified as a valuable source of biomass for biogas production, contributing to renewable energy generation (Koryś et al., 2019; Fernando et al., 2010). The potential of agricultural waste in the production of modern materials and high-value products has also been researched (Amran et al., 2021; Sharma et al., 2020). Proper management of these wastes can also contribute to soil health and crop productivity, essential for food security and agricultural sustainability (Fernando et al., 2010).

Effective management and reuse of agricultural waste are key in promoting sustainable agricultural practices and environmental protection. According to Ferronato and Torretta (2019), improper management of these wastes can cause pollution and environmental damage. Syafrudin (2023) highlights the importance of recycling nutrients from agricultural waste to avoid pollution and favor sustainable agricultural methods, a particularly critical aspect in rural areas and the Global South, where, according to Kalina et al. (2021), environmental and economic sustainability depends on responsible agricultural practices. Rockström et al. (2016) state that sustainable agriculture largely depends on proper management and reuse of agricultural waste. Poor management of these wastes, such as burning or landfill disposal, can lead to soil degradation and ecological imbalances, as Wei et al. (2021) point out. In this context, Manga et al. (2022) emphasize the importance of recycling agricultural waste to reduce pollution and maintain ecological balance. Furthermore, Muhaimin et al. (2023) observe the crucial role of women in promoting sustainable agricultural practices, highlighting their increased awareness and contribution to agricultural sustainability.

The valorization and reuse of agricultural waste, especially in applications such as composite materials, are essential for fostering a circular and sustainable economy, as indicated by Ogbu and Okechukwu (2023). This process transforms agricultural waste into valuable products, thus contributing to the reduction of environmental impact and promoting sustainability, a perspective supported by authors such as Gürdil et al. (2021) and Hardyanti et al. (2023). These efforts not only allow the creation of new materials such as biocomposites but also enable the generation of alternative energies. Additionally, Manniello et al. (2020) highlight how the reuse of agricultural waste aligns with the principles of the circular economy, optimizing resource use and minimizing waste. On the other hand, Awogbemi and Kallon (2022) underscore the potential of agricultural waste for applications in biofuels, demonstrating the value-creation opportunities from these wastes. Together, these practices indicate a path toward more sustainable and circular economic practices.

Plantain, rice, coconut, and cashew crop waste have multiple applications: Plantain peels are used in animal feed, composting, and bioplastics, while stems and leaves serve as fertilizer or raw material for paper and natural fibers. Rice husk is utilized as fertilizer, energy, and in composite materials, and the straw in paper production, composting, and biogas. Coconut shells are transformed into activated charcoal and hydroponic substrates, and coconut fibers into textiles and insulating materials. Finally, cashew shells are destined for renewable energies like biogas and biodiesel, and solid waste is converted into fertilizer or animal feed.

The proper management and valorization of these agricultural wastes can reduce environmental pollution, improve resource use efficiency, and foster more sustainable agriculture.

Methodology:

Social, Environmental, and Economic Impact

The Analytical Hierarchical Process (AHP) methodology provides an effective framework for evaluating multiple options based on various criteria. This methodological guide aims to assess the social, environmental, and economic impact of producing composite materials from Plantain, coconut, rice, and cashew residues. Selecting sustainable construction materials through multi-criteria decision-making models is crucial for promoting sustainability in construction projects (Tegegne et al., 2023).

1. Problem Definition and Objective: Clearly establish the objective of the evaluation, in this case, determining the social, environmental, and economic impact of producing composite materials from the mentioned agricultural residues.

2. Hierarchy Creation: Develop a hierarchy of elements that includes the objective at the top, followed by evaluation criteria (social, environmental, and economic impact), and alternatives (Plantain, coconut, rice, and cashew residues) at the lower level.

3. Criteria and Sub-criteria Development: Define and describe the criteria and sub-criteria for each impact area.

4. Expert Selection: Recruit a panel of experts with knowledge in social, environmental, and economic areas to provide unbiased judgments and specialized insights.

5. Paired Comparison: Use the paired comparison method for experts to evaluate the relative importance of each criterion and sub-criterion against others. Experts will also compare the alternatives among themselves with respect to each criterion and sub-criterion.

6. Matrix Calculation and Weighting: Calculate the paired comparison matrices and derive the weights. Each matrix will be normalized, and the priority vector (weights) will be calculated. The consistency of the matrices should be verified.

7. Consistency Analysis: Conduct a consistency analysis for each comparison matrix. If the consistency ratio is acceptable (generally less than 10%), the derived weights can be used. Otherwise, experts will be asked to revise their judgments.

8. Priority Synthesis: Combine the weights of the criteria and sub-criteria with the evaluations of the alternatives to obtain an overall score for each alternative.

9. Sensitivity Analysis: Perform a sensitivity analysis to see how changes in the weights of the criteria affect the outcomes, ensuring that the decision is robust and reliable.

10. Report Preparation: Present the results in a detailed report, including the priorities and rankings of the alternatives, as well as observations from the sensitivity analysis.

11. Recommendations: Formulate recommendations based on the AHP results, considering the objectives and preferences of the stakeholders involved in decision-making.

12. Implementation and Monitoring: Develop an implementation plan based on the recommendations and establish a monitoring system to assess the impact over time.

This approach facilitates a structured and systematic evaluation, enabling decision-makers to better understand and choose the most suitable option for the production of composite materials from agricultural residues, based on social, environmental, and economic criteria.

Hypotheses:

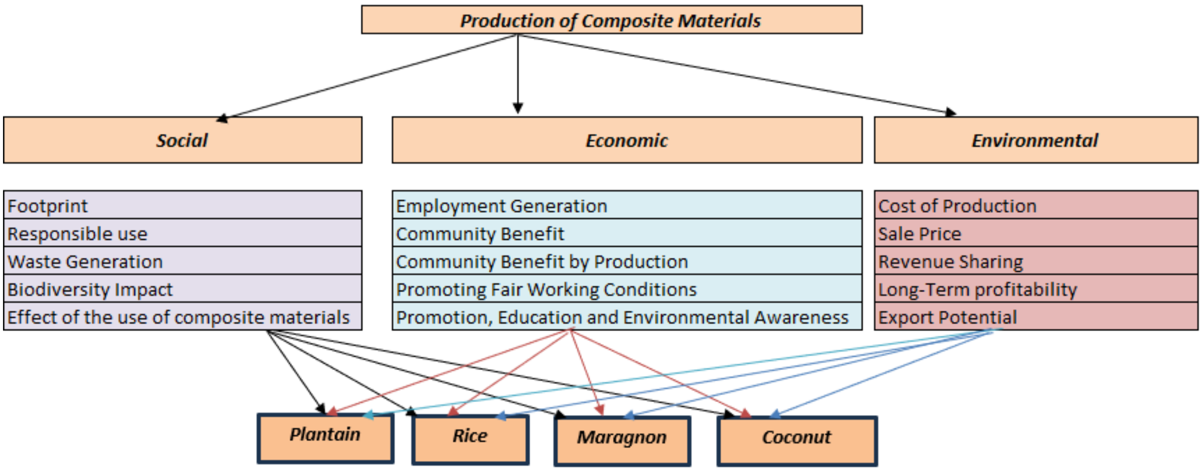
1. The production and utilization of composite materials from agricultural residues have a positive impact on job generation in rural communities.

2. The production and utilization of composite materials from agricultural residues contribute to increasing farmers' income.

3. The production and utilization of composite materials from agricultural residues drive the development of the local value chain and access to new markets.

Employing multiple-choice and Likert scale questions yields precise, quantifiable insights into the potential demand and price sensitivity of customers for composite materials made from agricultural waste. This data enables the fine-tuning of pricing and marketing strategies to enhance product demand.

Next, an expert-targeted survey version is outlined, designed to construct an Analytic Hierarchy Process (AHP) matrix. This matrix will encompass three dimensions, fifteen subfactors, and four alternatives, explored through open-ended questions.



The diagram delineates a framework for the evaluation of composite material production, incorporating social, economic, and environmental dimensions. Utilized frequently in decision-making processes, this type of diagram facilitates a comprehensive assessment of various facets of a project or initiative.

At the apex of the diagram lies "Composite Materials Production," signifying the core focus of the analysis. Subsequent to this central notion, the diagram segregates into three distinct categories, each symbolizing the essential criteria or perspectives for consideration.

1. Social Dimension: This segment encompasses elements such as carbon footprint, responsible usage, waste generation, biodiversity impact, and the ramifications of composite material usage. These are social considerations, emphasizing the societal impact of composite material production.

2. Economic Dimension: This facet covers aspects like job creation, community benefits, the promotion of fair labor practices, and environmental education and awareness. Economic factors assess the financial viability and the socio-economic advantages of the production process.

3. Environmental Dimension: This category pertains to production costs, sales pricing, income distribution, long-term profitability, and export potential. These environmental factors consider the ecological impact and sustainability of composite material production.

At the diagram's base, four material types are listed: "Plantain," "Rice," "Cashew," and "Coconut," representing the agricultural sources of the compounds under evaluation. Color-coded lines link the three primary criteria to these four materials, illustrating an analysis of how each material aligns with social, economic, and environmental factors. This analysis is integral to the Analytic Hierarchy Process (AHP), a decision-making method that involves assigning weights to various criteria and systematically comparing them to discern the optimal choice among alternatives.

Therefore, the diagram serves as a visual representation of a structured method for assessing the impact of producing various composite materials from the listed agricultural sources. It aids stakeholders in understanding the multifaceted implications of their production decisions.

The four alternatives to be assessed against each of the 16 subfactors are as follows:

1. Alternative A: Production of composite materials from Plantain waste.
2. Alternative B: Production of composite materials from rice waste.
3. Alternative C: Production of composite materials from coconut waste.
4. Alternative D: Production of composite materials from cashew waste.

The three dimensions to be considered are:

1. Environmental: The environmental impact of producing and using composite materials.
2. Economic: The costs and benefits associated with the production and sale of composite materials.
3. Social: The social impact of producing and using composite materials.

Expert responses will facilitate the construction of an AHP matrix, enabling the evaluation and comparison of composite material production alternatives based on the identified dimensions and subfactors.

Results

Global and Local Weightings of the Environmental, Social and Economic Criteria for Composite Materials						**Global Factor Weights and Order of Importance**		
Criteria	Global Weights	Order	Factors	Local Weights	Global Weights	Factors	Global Weights	Order
Ambiental	29,1%	15	Footprint	18,13 %	5,28%	Profitability	8,94%	1
		4	Responsible use	28,02 %	8,16%	Export Potential	8,58%	2
		9	Waste generation	23,08 %	6,72%	Biodiversity Impact	8,32%	3
		3	Biodiversity Impact	28,57 %	8,32%	Responsible Use	8,16%	4
		13	Environmental Effect	20,33 %	5,92%	Community Benefits	7,99%	5
Social	34,9%	7	Employment	20,54 %	7,18%	Community Engagement	7,18%	6
		5	Community Benefits	22,87 %	7,99%	Employment	7,18%	7
		6	Community Engagement	20,55 %	7,18%	Fair Workung Conditions	7,04%	8
		8	Fair working conditions	20,16 %	7,04%	Waste Generation	6,72%	9
		14	Environmental Education & Awareness	15,89 %	5,55%	Revenue Sharing	6,23%	10
Economic	35,9%	12	Production costs	16,58 %	5,96%	Sales Price	6,23%	11
		11	Sale Price	17,34 %	6,23%	Production Costs	5,96%	12
		10	Revenue Sharing	17,35 %	6,23%	Environmental Effect	5,92%	13
		1	Profitability	24,87 %	8,94%	Environmental Education & Awareness	5,55%	14
		2	Export Potential	23,87 %	8,58%	Footprint	5,28%	15

Table 1 presents the results from the Analytic Hierarchy Process (AHP). This table allows for the analysis and comparison of the relative importance of environmental, social, and economic criteria for the production of composite materials. AHP is a structured method designed to help organize and analyze complex decisions, based on mathematics and psychology. In this context, the table shows the weighting of each factor within the main criteria: environmental, social, and economic.

Global Weightings: They represent the overall importance assigned to each criterion. These weightings indicate the relative importance of each criterion in the evaluation process on a scale from 0% to 100%. For instance, economic criteria are assigned a weight of 35.9%, followed by social criteria (34.9%) and environmental criteria with a global weight of 29.1%, indicating the significance of each criterion in the overall evaluation.

Local Weightings: They represent the specific local importance of each factor within its respective criterion. These local weightings are percentages that contribute to the global weight within their category. For example, within the "Environmental" category, "Carbon Footprint" has a local weight of 18.13%, contributing 5.28% to the total global weight of all factors.

Environmental Category (29.1% of global weighting):

- Environmental factors account for approximately one-third of the total weight.

- "Biodiversity Impact" is the most heavily weighted factor (20.33%), followed by "Waste Generation" (23.08%) and "Environmental Effect" (28.57%), indicating a strong concern for the environmental impact of the composite materials.

- "Carbon Footprint" has the lowest global weight (5.28%), but is prioritized locally (18.13%), reflecting a widespread concern for carbon emissions and their impact on climate change.

Social Category (34.9% of global weighting):

- Social factors have a slightly higher weight than environmental ones, indicating that social issues are marginally more important for decision-making in this analysis.

- "Employment" and "Community Engagement" have the same weight (20.54%), suggesting that job creation and community integration are of high importance.

- "Environmental Education & Awareness" have the lowest weight (20.15%), which could indicate that while its importance is acknowledged, there are other social factors considered more critical.

Economic Category (35.9% of global weighting):

- The economic category has the highest weighting, suggesting that economic factors are considered slightly more important than environmental or social factors in the overall evaluation.

- "Profitability" is the most significant economic factor (24.87%), consistent with the need for businesses to be financially sustainable.

- The factors "Production Costs" and "Sales Price" have similar weights (16.59% and 17.34% respectively), indicating that costs and selling prices are also important considerations.

General Analysis:

- The table shows that experts have slightly prioritized economic aspects above social and environmental ones, although all three are quite closely weighted.

- Within each criterion, there is a balance among different aspects, with a tendency to prioritize the impact on biodiversity and the environment, employment and community engagement, and profitability and export potential.

- The position of the "Carbon Footprint" in both local and global rankings suggests a duality: it is the least important factor globally but is given enough local importance to be included in the evaluation.

- This analysis indicates that the organization values a balanced approach that does not sacrifice social or environmental responsibility for the sake of economic benefits.

The aforementioned graph displays the percentage weightings of factors related to sustainability and social responsibility within the project.

1. Profitability (8.94%): Profitability emerges as the most critical factor, suggesting that experts deem the generation of economic value in composite material production essential.

2. Export Potential (8.58%): The capability to market products internationally is seen as nearly as crucial as profitability, signaling a consensus on the importance of capturing international markets.

3. Biodiversity Impact (8.32%): The production's impact on biodiversity has been significantly valued by the experts, reflecting an awareness of the industry's ecological responsibility.

4. Responsible Use (8.16%): The emphasis on proper resource management suggests that efficiency and sustainability are key in composite material production.

5. Community Benefits (7.99%): The survey reflects a strong inclination toward creating community value, suggesting that benefits should not be limited to the company but also extend to the local community.

6. Community Engagement (7.18%): Community involvement is considered important, which can be interpreted as an acknowledgment of the value of social capital and local collaboration.

7. Employment (7.18%): Job creation is valued at the same level as community participation, indicating that the creation of job opportunities is a priority.

8. Fair Working Conditions (7.04%): Workplace equity is seen as fundamental, highlighting attention to fair treatment and dignified working conditions.

9. Waste Generation (6.72%): While it is of moderate concern, waste management is recognized as an important aspect, possibly due to a desire to minimize waste in production.

10. Revenue Sharing (6.23%): The equitable distribution of economic benefits is a topic that experts have marked as relevant.

11. Sales Price (6.23%): The parity with revenue sharing indicates that establishing a fair selling price is considered important by the experts.

12. Production Costs (5.96%): A conscious cost control is suggested, although it is not the most emphasized aspect in the production of composite materials.

13. Environmental Effect (5.92%): Slightly less of a concern than production costs, yet it is still recognized, indicating that environmental impact remains an important consideration.

14. Environmental Education & Awareness (5.55%): While not given the highest priority, the need to promote environmental education and awareness is evident, which may positively influence long-term sustainability.

15. Carbon Footprint (5.28%): This factor has the lowest percentage, which could be interpreted as an opportunity for the industry to focus more on reducing carbon emissions.

The next table is the last part of the assessment using the AHP methodology, which is used to select the best agricultural production alternative, such as plantain, rice, maragnon, and coconut, based on environmental, social, and economic categories and subfactors.

Criterial	**Global Weigth**	**Plantain**			**Rice**			**Maragnon**			**Coconut**		
		Exp.	**Valor**	**V*PG**	**Exp.**	**Valor**	**V*PG**	**Exp.**	**Valor**	**V*PG**	**Exp.**	**Valor**	**V*PG**
Carbon Footprint	**5,28%**	B	6,67%	0,35%	B	6,67%	0,35%	A	60,00%	3,17%	M	33,33%	1,76%
Responsible Use	**8,16%**	M	33,33%	2,72%	M	33,33%	2,72%	M	33,33%	2,72%	M	33,33%	2,72%
Waste generation	**6,72%**	B	6,67%	0,45%	M	33,33%	2,24%	B	6,67%	0,45%	A	60,00%	4,03%
Biodiversity Impact	**8,32%**	B	6,67%	0,55%	A	60,00%	4,99%	B	6,67%	0,55%	B	6,67%	0,55%
Environmental Effect	**5,92%**	B	6,67%	0,39%	A	60,00%	3,55%	B	6,67%	0,39%	B	6,67%	0,39%
Employment	**7,18%**	M	33,33%	2,39%	B	6,67%	0,48%	A	60,00%	4,31%	M	33,33%	2,39%
Community Benefits	**7,99%**	A	60,00%	4,79%	B	6,67%	0,53%	M	33,33%	2,66%	M	33,33%	2,66%
Community Engagement	**7,18%**	A	60,00%	4,31%	B	6,67%	0,48%	M	33,33%	2,39%	B	6,67%	0,48%
Fair Working Conditions	**7,04%**	B	6,67%	0,47%	B	6,67%	0,47%	B	6,67%	0,47%	B	6,67%	0,47%
Environmental Education & Awareness	**5,55%**	M	33,33%	1,85%	B	6,67%	0,37%	M	33,33%	1,85%	M	33,33%	1,85%
Production Costs	**5,96%**	M	33,33%	1,99%	M	33,33%	1,99%	M	33,33%	1,99%	M	33,33%	1,99%
Sales Price	**6,23%**	M	33,33%	2,08%	M	33,33%	2,08%	B	6,67%	0,42%	B	6,67%	0,42%
Revenue Sharing	**6,23%**	M	33,33%	2,08%	M	33,33%	2,08%	B	6,67%	0,42%	M	33,33%	2,08%
Profitability	**8,94%**	M	33,33%	2,98%	M	33,33%	2,98%	M	33,33%	2,98%	M	33,33%	2,98%
Export Potential	**8,58%**	A	60,00%	5,15%	B	6,67%	0,57%	A	60,00%	5,15%	A	60,00%	5,15%
Total Score				22,35%			20,25%			21,37%			19,72%
Normalized Score			**26,71%**			**24,20%**			**25,54%**			**23,56%**	

In the upper section, the categories and subfactors evaluated are displayed, with a rating scale ranging from "A" for the highest evaluation, "M" for an average evaluation, and "B" for the lowest evaluation. These letters represent quantitative values corresponding to "A" (0.6000), "M" (0.3333), and "B" (0.0667), which are used to calculate the total score for each production line.

In the lower section, there is a breakdown for each production line where the evaluated subfactors, their global weight within the evaluation, the expert rating ("Exp."), the quantitative value of that rating ("Value"), and the multiplication of the value by the global weight (V*PG), contributing to the total score, are listed.

At the end of each production line column, the "Total Score" is calculated, which is the sum of all V*PG values for that line. Then, the score is normalized to compare across different production lines. Normalization is done by dividing each total score by the sum of all total scores, yielding the "Normalized Score." With these scores, decision-makers can objectively compare the production lines according to the preferences set by the weights of the subfactors and the expert evaluations.

The assessment highlights Plantain production with a score of 26.71 as the optimal alternative, exceptionally integrating economic viability with social and environmental commitment, followed closely by cashew production (25.54). Although rice (24.20) and coconut (23.56) have lower scores, they suggest potential areas for the implementation of specific improvements.

Conclusions

Concluding a study that intricately combines the principles of the circular economy with the Analytic Hierarchy Process (AHP), our findings present a nuanced picture of sustainability in agricultural production. Central to this study was the assessment of social, environmental, and economic impacts, with the AHP methodology ensuring a robust and nuanced analysis. The conclusions drawn not only align with the initial objectives but also carve out a strategic pathway for implementation.

The prioritization of profitability, export potential, and biodiversity underscores a balanced appreciation for both economic imperatives and environmental stewardship. This alignment—where financial viability coexists with ecological consciousness—reflects a holistic understanding of sustainability.

Furthermore, the strong emphasis on community benefits, employment, and fair working conditions shines a light on the social fabric of sustainability. It acknowledges that economic growth and environmental protection must be pursued alongside the enrichment of local communities.

While production costs and the carbon footprint have been assigned relatively lower weightings, their recognition is critical. It signifies an awareness of the need to manage expenditure while also addressing the pressing issue of climate change—a delicate balance that demands both strategic attention and operational excellence.

The equal weighting given to revenue sharing and sales price illustrates the study's commitment to equitable economic practices. It’s a reminder that sustainability transcends profit margins to encompass fairness and responsibility in financial dealings.

These findings are a clarion call to industry and policymakers alike: to integrate sustainable measures that align not only with environmental standards but also with evolving social expectations. The incorporation of agricultural waste into composite materials is poised to contribute to economic efficiency, social welfare, and environmental conservation—truly a trinity of sustainable development.

In summary, this research advocates for a concerted push towards practices that champion the circular economy, particularly highlighting Plantain production as an exemplary path forward. It encourages the industry to seize opportunities for innovation, particularly in improving the carbon footprint and bolstering environmental education, thereby reinforcing a commitment to long-term sustainability and corporate responsibility.

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