Natural Resources for Human Health

eISSN: 2583-1194

Original Research

Received 16 May 2026
Revised 01 July 2026
Accepted 11 July 2026

Natural Resources for Human Health 2026, Vol. 6 (12s): 196–200

KEYWORDS:
Sugarcane bagasse, Sustainable optimization, By- production utilization, Industrial waste management, Waste minimization.

From Waste to Resource: An Optimization Model for Sustainable Utilization of Sugarcane Bagasse

U. Modenisha[1] and W. Ritha[2*]

[1]Research Scholar, Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli, Tamil Nadu, India.
[2]Associate Professor, Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli, Tamil Nadu, India.
Corresponding author: *ritha_prakash@yahoo.co.in, modenishahcc@gmail.com

ABSTRACT: Sugarcane Bagasse Ash is a waste product that is commonly used in the concrete industry. It can be used as a partial substitute for cement in concrete mixes and is a good choice for making concrete mixes because it has good pozzolanic properties. This study creates a Linear programming optimization framework for the sustainable management of agro-industrial waste. It focuses on how to best use sugarcane bagasse to find the best way to use it for energy generation, making sugarcane bagasse ash to replace cement, and getting rid of it, all while keeping costs and environmental impact to a minimum. The results show that sugarcane bagasse ash use is only possible when the economy reaches a certain level. Sensitivity analysis shows that making the system more efficient cuts down on waste disposal a lot, but changing the cost of disposal doesn't have much of an effect. The results show how important it is to use integrated utilization strategies to make resources more efficient and lessen the environmental impact, especially carbon emissions, which supports sustainable industrial practices.

INTRODUCTION

Approximately 15 countries, including Brazil, India, Pakistan, Thailand, and others, account for nearly 87.4% of the world's total production of sugarcane, one of the most widely grown crops [1]. Over 1.5 billion tonnes of sugarcane are produced worldwide each year, producing a substantial quantity of by-products. Among these, bagasse is a significant residue that makes up about 40–45% of sugarcane after juice is extracted [2]. It produces about 8–10% ash known as sugarcane bagasse ash (SCBA), which is frequently used as fuel in the sugar industry [3]. Brazil produces 2.5 tonnes of SCBA annually [4], whereas India, the second-largest producer with approximately 350 million tonnes of sugarcane annually, produces a significant amount of SCBA with almost 10 million tonnes being dumped [5]. The need for more sustainable waste management techniques is highlighted by the fact that improper disposal of this ash on open land pollutes the soil and water [6]. The production of cement alone contributes significantly to global emissions, releasing roughly 0.85 tonnes of CO_2 per tonne of cement [7]. The potential of SCBA as a sustainable material is still underutilized, despite the fact that burning bagasse is thought to be carbon-neutral because of the equilibrium between CO_2 absorption during plant growth and release during burning [8, 9].

According to studies, SCBA can be successfully added to concrete as a pozzolanic material, enhancing its qualities and lessening its negative effects on the environment [10,11]. Recently, the construction industry has become unsustainable [12]. These findings highlighted the need for additional scientific study to create new generation concrete that is both affordable and sustainable without sacrificing its durability and strength. Paris et al. [13] have presented a thorough analysis of the use of waste products as supplemental cementitious material (SCM) in cement to make concrete. Due to SCBA's potent pozzolanic qualities and capacity to increase the mechanical strength and durability of concrete, recent research has thoroughly examined its use as a partial substitute for cement [14]. By lowering cement consumption and related CO_2 emissions, the use of SCBA and other agro-based materials like rice husk ash and metakaolin has been demonstrated to improve sustainability.

However, the majority of current research pays little attention to how such agro-waste can be best distributed among conflicting uses, instead concentrating on material characteristics and experimental validation. Decision-making models that incorporate operational, environmental, and economic factors are conspicuously lacking. Thus, the goal of this research is to create an optimization-based framework that maximizes the value of bagasse in construction and energy applications while minimizing waste disposal.

MATHEMATICAL MODEL

Notations

x_1 : Amount of bagasse used fuel

x_2 : Bagasse amount used for SCBA production

y : Amount of disposed bagasse

Parameters

T_B : Total bagasse generated

CP_F : Fuel processing cost

CP_S : SCBA processing cost

D_C : Cost of disposal

EB_F : Economic benefit from fuel

EB_S : Economic benefit from SCBA

E_P : Emission penalty for disposal

ES_F : Emission savings from fuel

ES_S : Emission savings from SCBA

PC_S : Processing capacity of maximum SCBA

η : Utilization efficiency factor

Objective function

The objective is to minimize total cost including environment effects:

$$\text{Min } Z = CP_F x_1 + CP_S x_2 + D_C y + E_P y - (EB_F x_1 + EB_S x_2 + EB_S x_1 + ES_S x_2)$$

Constraints

Mass Balance constraint

$$x_1 + x_2 + y = T_B$$

SCBA capacity constraint

$$x_2 \le PC_S$$

eISSN: 2583-1194

Utilization efficiency constraint

$$x_1 + x_2 \leq \eta T_B$$

Non-negativity constraints

$$x_1 + x_2 + y \geq 0$$

PROBLEM DESCRIPTION

The sugar industry produces a lot of bagasse, which is useful for producing energy and converting it into SCBA for cement placement. Bagasse is underutilized by many industries, and its use is not always optimal due to capacity, efficiency, or economic viability issues. As a result, some waste is disposed of, which raises environmental concerns, reduces potential economic value, and puts pressure on the cement industry to reduce cement consumption because of its high carbon emissions. Although SCBA has been recognized as a sustainable substitute material, its uptake is contingent upon operational and financial considerations. A systematic approach is created to determine how waste should be used for energy, transformed into SCBA for cement applications, and disposed of effectively while taking cost, environmental impact, and practical constraints into consideration. In order to improve resource efficiency and lessen the impact on the environment, this study develops an optimization-based framework to assist in agro-waste utilization decision-making.

NUMERICAL EXAMPLE

This model is based on the idea that a sugar factory makes 1800 tonnes of bagasse per day, which is based on the fact that the plant can process 6000 tonnes per day and produces about 30% of its own waste. Secondary data from existing literature include the bagasse generation rate of 30%, the SCBA cement replacement range of 10-20%, CO_2 emission aspects in cement production, and general cost structures related to transport and processing. For the model to work, some things had to be assumed, like the costs of processing fuel and SCBA, the costs of disposal, the economic benefits of using SCBA, the savings and penalties for emissions, the SCBA capacity limit (400 tonnes/day), and the utilization efficiency factor [14].

RESULT AND DISCUSSION

The mathematical model was optimized using Julia programming language, along with the JuMP optimization package and GLPK solver, under a utilization efficiency of $\eta = 0.9$ using the base parameter values, resulting in an optimal allocation with fuel utilization of 1220 tonnes, SCBA utilization of 400 tonnes, and a rate of disposal of 180 tonnes. When compared to other options, the results indicate that using SCBA to its maximum permitted capacity has a greater level of economic and environmental benefit. A residual fraction of 180 tonnes of waste is disposed of due to operational inefficiencies imposed by the utilization constraint, while the useable waste is allocated to energy recovery. The obtained object value was negative, indicating that the advantages of recovering resources outweigh the expenses associated with processing and disposal. The waste utilization strategy is therefore economically viable. Further, the findings demonstrate how turning agricultural waste into high-value goods like SCBA can greatly aid in lowering emissions and promoting environmental sustainability. The efficiency parameter η was varied from 0.7 to 1.0 in order to perform a sensitivity analysis. The results showed that the amount of disposal decreased linearly as η increased, and at $\eta = 1$. The disposal was reduced by fully utilizing the waste. This illustrates how minimizing waste disposal depends heavily on operational efficiency. The quantity of waste sent for disposal is greatly decreased by even modest efficiency gains. These findings demonstrate how appropriate technological and operational advancements in the management and processing of agricultural waste improve sustainable outcomes.

A threshold behaviour is revealed by the SCBA benefit sensitivity analysis. SCBA is not used for lower values of EB_S = 100, and it is fully utilized for values greater than 140. This indicates that SCBA is highly sensitive to its economic value, such as its market price or the savings from replacing cement. These thresholds imply that the use of SCBAs can be greatly increased by market demand for sustainable building materials, policy incentives, or subsidies.

The optimal solution remained unchanged despite variations in disposal costs. For all tested values, disposal stayed at 180 tonnes. This indicates that economic factors do not govern disposal in the model. but rather by the system's imposed limitation on the efficiency of utilization. Therefore, improving processing capacity and efficiency is the only way to reduce waste; raising disposal costs won't cut waste on its own.

This study offers a number of useful insights:

- Due to practical constraints, it is not always feasible to utilize all of the waste.
- SCBA is a practical way to repurpose waste, particularly when it is profitable.
- More than just raising disposal costs, increasing efficiency contributes to waste reduction.
- Pollution and CO_2 emissions can be decreased by using waste in various ways.

The study shows that agro-waste management decision-making can be successfully guided by an integrated optimization framework. The model highlights important elements influencing sustainable waste utilization and finds the best allocation strategies by striking a balance between economic and environmental factors.

CONCLUSION

Sugarcane bagasse utilization is the main focus of a sustainable agro waste optimization. By dividing waste into energy use, SCBA-based cement replacement, and disposal, this model integrated the economic and environmental aspects. SCBA utilization becomes a high-value pathway when it is accompanied by favorable economic conditions. Waste reduction is more effective when operational efficiency is increased. All things considered, the model offers a straightforward framework for decision-making that can assist businesses in making better use of waste while lowering their impact on the environment, particularly CO_2 emissions. The current study takes into account important aspects of agro-waste utilization, including processing capacity, operational effectiveness, and economic-environmental trade-offs. However, limited data availability simplifies some real-world complexities. In particular, the model does not specifically account for elements like seasonal variations in waste generation, market demand variability for SCBA, storage limitations, and transportation logistics. Future studies can expand the suggested model by adding more practical restrictions like demand uncertainty, storage constraints, and transportation costs. To account for seasonal differences in the production of agro-waste, the model can also be extended into a multi-period framework.

REFERENCE

[1] Zaheer, M. M., & Tabish, M. (2023). The durability of concrete made up of sugar cane bagasse ash (SCBA) as a partial replacement of cement: a review. *Arabian Journal for Science and Engineering*, *48*(4), 4195-4225. https://doi.org/10.1007/s13369-023-07698-9

[2] Modani, P. O., & Vyawahare, M. R. (2013). Utilization of bagasse ash as a partial replacement of fine aggregate in concrete. *Procedia Engineering*, *51*, 25-29. https://doi.org/10.1016/j.proeng.2013.01.007

[3] Loh, Y. R., Sujan, D., Rahman, M. E., & Das, C. A. (2013). Sugarcane bagasse—The future composite material: A literature review. *Resources, conservation and recycling*, *75*, 14-22. https://doi.org/10.1016/j.resconrec.2013.03.002

[4] Cordeiro, G. C., Toledo Filho, R. D., Fairbairn, E. M., & Tavares, L. M. (2021, July). 10 Years of Research on Sugar Cane Bagasse Ash as Supplementary. In *Proceedings of the 3rd RILEM Spring Convention and Conference (RSCC 2020): Volume 2: New Materials and Structures for Ultra-durability* (p. 183). Springer Nature. https://doi.org/10.1007/978-3-030-76551-4_17

[5] Cordeiro, G. C., Tavares, L. M., & Toledo Filho, R. D. (2016). Improved pozzolanic activity of sugar cane bagasse ash by selective grinding and classification. *Cement and Concrete Research*, *89*, 269-275. https://doi.org/10.1016/j.cemconres.2016.08.020

[6] Jagadesh, P., Ramachandramurthy, A., & Murugesan, R. (2018). Overview on properties of Sugar Cane Bagasse Ash (SCBA) as pozzolan. https://www.cabidigitallibrary.org/doi/full/10.5555/20193420462

[7] Rajamma, R., Ball, R. J., Tarelho, L. A., Allen, G. C., Labrincha, J. A., & Ferreira, V. M. (2009). Characterisation and use of biomass fly ash in cement-based materials. *Journal of hazardous materials*, *172*(2-3), 1049-1060. https://doi.org/10.1016/j.jhazmat.2009.07.109

[8] Aprianti, E., Shafigh, P., Bahri, S., & Farahani, J. N. (2015). Supplementary cementitious materials origin from agricultural wastes–A review. *Construction and building materials*, *74*, 176-187. https://doi.org/10.1016/j.conbuildmat.2014.10.010

[9] Montakarntiwong, K., Chusilp, N., Tangchirapat, W., & Jaturapitakkul, C. (2013). Strength and heat evolution of concretes containing bagasse ash from thermal power plants in sugar industry. *Materials & Design*, *49*, 414-420. https://doi.org/10.1016/j.matdes.2013.01.031

[10] Rukzon, S., & Chindaprasirt, P. (2012). Utilization of bagasse ash in high-strength concrete. *Materials & Design*, *34*, 45-50. https://doi.org/10.1016/j.matdes.2011.07.045

[11] Khalil, M. J., Aslam, M., & Ahmad, S. (2021). Utilization of sugarcane bagasse ash as cement replacement for the production of sustainable concrete–A review. Construction and Building Materials, 270, 121371. https://doi.org/10.1016/j.conbuildmat.2020.121371

[12] Wi, K., Lee, H. S., Lim, S., Song, H., Hussin, M. W., & Ismail, M. A. (2018). Use of an agricultural by-product, nano sized Palm Oil Fuel Ash as a supplementary cementitious material. *Construction and Building Materials*, *183*, 139-149. https://doi.org/10.1016/j. conbuildmat.2018.06.156

[13] Paris, J. M., Roessler, J. G., Ferraro, C. C., DeFord, H. D., & Townsend, T. G. (2016). A review of waste products utilized as supplements to Portland cement in concrete. *Journal of cleaner production*, *121*, 1 https://doi.org/10.1016/j.jclepro.2016.02.013

[14] Sylvere, N., Omar, T., Youness, A., El Farissi, L., & Lina, G. (2025). Innovative applications of sugarcane bagasse in the global sugarcane industry. *Processes*, *13*(12), 3796. https://doi.org/10.3390/pr13123796