

Prioritization of Waste Management Strategies in the Sugar Industry Using an Integrated SWARA–WASPAS Approach

Jyotsna Harariya

School of Aviation, Logistics and Tourism Management (SALTM)

Galgotias University

Abstract

The sugar industry is one of the most significant agro-based industries in India and generates large quantities of waste such as bagasse, bagasse ash, press mud, and spent wash. Improper management of these wastes can lead to environmental pollution, resource wastage, and increased operational costs. Therefore, selecting the most suitable waste management strategy has become an important challenge for sugar mills. This study aims to prioritize waste management strategies in the sugar industry using an integrated Multi-Criteria Decision-Making (MCDM) framework consisting of the Step-wise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum Product Assessment (WASPAS) methods.

Three evaluation criteria were considered: Economic Viability, Technical Feasibility, and Environmental & Compliance Impact. Primary data were collected from ten experts including environmental officers, plant managers, engineers, and consultants from the sugar industry. SWARA was applied to determine the importance weights of the criteria, while WASPAS was used to evaluate and rank seven alternative waste management strategies.

The SWARA results revealed that Economic Viability (0.447) is the most important criterion, followed by Technical Feasibility (0.313) and Environmental & Compliance Impact (0.240). The WASPAS results showed that Cogeneration Upgrade (110 kg/cm²) achieved the highest overall score (0.982) and ranked first among the alternatives. Spent Wash: MEE + Incineration ranked second (0.878), while 2G Ethanol from Bagasse/Trash ranked third (0.838). The findings indicate that sugar industry experts prefer waste management solutions that simultaneously provide economic benefits, technical practicality, and environmental sustainability. The study offers a structured framework that can support strategic decision-making and sustainable waste utilization in the sugar industry.

Keywords: Sugar Industry, Waste Management, SWARA, WASPAS, MCDM, Sustainability, Circular Economy, Cogeneration.

1. Introduction

The Indian sugar industry plays a significant role in economic development, employment generation, and rural livelihoods. India is among the world's largest producers of sugar and operates hundreds of sugar mills across different states. Along with sugar production, the industry generates substantial quantities of waste, including sugarcane bagasse, bagasse fly ash, filter mud, press mud, and spent wash. Although some of these wastes are utilized for energy generation and agricultural purposes, a considerable portion remains underutilized.

Recent studies have highlighted the importance of circular economy principles and cleaner production practices in improving industrial sustainability. Waste-to-value approaches such as bioenergy generation, ethanol production, composting, wastewater treatment, and construction material manufacturing have emerged as promising alternatives for effective waste utilization. However, selecting the most appropriate waste management strategy is a complex decision because it involves multiple economic, technical, and environmental considerations.

Multi-Criteria Decision-Making (MCDM) methods provide a systematic approach for evaluating alternatives under multiple criteria. Among these methods, SWARA is widely used for determining criteria weights based on expert judgments, while WASPAS is effective for ranking alternatives. Therefore, this study integrates SWARA and WASPAS to prioritize waste management strategies in the sugar industry.

Objectives of the Study

1. To identify suitable waste management strategies in the sugar industry.
2. To determine the relative importance of evaluation criteria using SWARA.
3. To rank waste management alternatives using WASPAS.
4. To provide recommendations for sustainable waste management practices.

2. Research Methodology

The study adopted a quantitative research approach using primary data collected through a structured questionnaire survey. Responses were obtained from ten industry experts comprising environmental and sustainability officers, plant managers, technical engineers, and consultants.

Evaluation Criteria

Three criteria were selected based on literature review and expert consultation:

- Economic Viability (C1)
- Technical Feasibility (C2)
- Environmental & Compliance Impact (C3)

SWARA Method

Steps of SWARA Method:

Step 1: "We applied the SWARA method to turn real-world expert insights into precise mathematical weights for our criteria."

Step2: Give ranking to the criteria we had industry experts sort the criteria from very poor to excellent, based on what actually matters

Step 3: Finding the Relative Gap (S_j)

Once the criteria were ranked, we measured how much more important each factor was compared to the one right above it, revealing the exact "importance gap" between them.

(a) S_j represents the comparative importance of the current criterion compared to the previous criterion.

(b) This step helped measure how much less important one criterion is compared to another.

Step 4: Calculation of Coefficient (K_j)

The coefficient value for each criterion was then calculated using the comparative importance values.

Formula:

$$K_j = S_{j+1}$$

Where: $\cdot K_j$ = Coefficient value $\cdot S_j$ = Comparative importance value.

This step helped adjust the importance level of each criterion systematically.

Step 5: Calculation of Recalculated Weight (Q_j)

The recalculated weight of each criterion was then determined.

Formula: $Q_j = Q_{j-1} K_j$

Where:

Q_j = Recalculated weight K_j = Coefficient value

Step 6: Calculation of Final Normalized Weights (W_j)

Finally, the normalized weight of each criterion was calculated.

Formula: $W_j = Q_j \div \sum Q_j$

W_j = Final normalized weight of criterion Q_j = Recalculated weight

WASPAS method (Weighted Aggregated Sum Product Assessment)

Step 1: Preparation of Decision Matrix

Step 2: Normalization of Decision Matrix

$$\text{Formula : } x_{ij}^* = \frac{x_{ij}}{\max(x_{ij})}$$

Step 3: Calculate Weighted Sum Model (WSM)

$$Q_i^{(1)} = \sum_{j=1}^n w_j x_{ij}$$

Step 4: Calculate Weighted Product Model (WPM)

$$Q_i^{(2)} = \prod_{j=1}^n x_{ij}^{w_j}$$

Step 5: Calculate WASPAS score

$$Q_i = 0.5 Q_i^{(1)} + 0.5 Q_i^{(2)}$$

Step 6: Rank alternatives according to final scores.

3. Results and Data Analysis

Table 3. Expert Responses for Criteria Ranking

Respondent C1 C2 C3

Mean Rank 1.4 2.0 2.6

The lowest mean value indicates the highest importance. Economic Viability received the highest priority.

Table 4. SWARA Weight Calculation

Criteria	Mean Rank S_j	K_j	Q_j	W_j	
Economic Viability	1.4	-	1.000	1.000	0.447
Technical Feasibility	2.0	0.429	1.429	0.700	0.313
Environmental Impact	2.6	0.300	1.300	0.538	0.240

Table 5. Criteria Ranking

Criteria	Weight	Rank
Economic Viability	0.447	1
Technical Feasibility	0.313	2
Environmental Impact	0.240	3

Table 9. Mean Values of Alternative Ratings

Alternative	Economic	Technical	Environmental
A1	6.0	7.3	6.8
A2	5.2	6.0	7.4
A3	6.1	6.4	5.2
A4	7.5	7.3	7.2
A5	6.8	5.5	6.4
A6	5.9	5.9	5.1
A7	5.3	5.2	5.5

Table 10. Normalized Decision Matrix

Alternative	Economic	Technical	Environmental
A1	0.800	0.973	0.906
A2	0.693	0.800	0.986
A3	0.813	0.853	0.693
A4	1.000	0.973	0.960
A5	0.907	0.733	0.853
A6	0.787	0.786	0.680
A7	0.707	0.693	0.733

Table 11. Weighted Sum Matrix (WSM)

Alternative	WSM Score
A1	0.880
A2	0.797
A3	0.797
A4	0.982

Alternative WSM Score

A5	0.840
A6	0.761
A7	0.709

Table 12. Weighted Product Matrix (WPM)

Alternative WPM Score

A1	0.876
A2	0.789
A3	0.794
A4	0.982
A5	0.836
A6	0.760
A7	0.709

Table 13. Final WASPAS Ranking

Alternative Final Score Rank

A4	0.982	1
A1	0.878	2
A5	0.838	3
A3	0.795	4
A2	0.793	5
A6	0.760	6
A7	0.709	7

4. Discussion of Findings

The results demonstrate that Economic Viability is the most influential criterion in selecting waste management strategies. This finding indicates that industry experts prioritize strategies that provide financial returns, reduce operational costs, and generate additional revenue.

The WASPAS analysis identified Cogeneration Upgrade (110 kg/cm²) as the most preferred strategy. The strategy performs well across all evaluation criteria and enables efficient utilization of bagasse for electricity and steam generation. This improves energy efficiency and creates additional revenue through power generation.

Spent Wash: MEE + Incineration ranked second due to its strong environmental performance and regulatory compliance benefits. The third-ranked alternative, 2G Ethanol from Bagasse/Trash, highlights the growing importance of renewable fuel production and waste valorization.

Overall, the findings suggest that waste management initiatives that combine economic benefits with environmental sustainability are more likely to be adopted by sugar mills.

5. Conclusion

This study applied an integrated SWARA–WASPAS framework to prioritize waste management strategies in the sugar industry. The findings revealed that Economic Viability is the most important decision criterion, followed by Technical Feasibility and Environmental & Compliance Impact.

Among the evaluated alternatives, Cogeneration Upgrade (110 kg/cm²) emerged as the best strategy, followed by Spent Wash: MEE + Incineration and 2G Ethanol from Bagasse/Trash. These alternatives offer a balanced combination of profitability, operational practicality, and environmental sustainability.

The study confirms that waste management should be viewed not merely as a regulatory requirement but as a strategic opportunity for resource recovery, revenue generation, and sustainable industrial development.

6. Limitations

- The study was based on only ten expert respondents.
- Only three evaluation criteria were considered.
- Results depend on expert judgment and may vary across industries.
- Emerging waste management technologies were not included.
- The findings are specific to the Indian sugar industry context.

References

- Blomsma, F., & Brennan, G. (2017). The emergence of circular economy: A new framing around prolonging resource productivity. *Journal of Industrial Ecology*, 21(3), 603–614.
- Gbadeyan, O. J., Sibiya, L., Linganiso, L. Z., & Deenadayalu, N. (2024). Waste-to-energy: The recycling and reuse of sugar industry waste for different value-added products. *Biofuels, Bioproducts and Biorefining*, 18, 1639–1657.
- Jiménez Borges, R., et al. (2024). Delphi/AHP-based method for biomass sustainable assessment in the sugar industry. *Eng*, 5(3), 2300–2319.
- Mardiana, S., Widhiastuti, R., & Erningpraja, L. (2020). Management and employees' perception analysis on sugar industry waste management based on cleaner production. *BIOEx Journal*, 2(1), 442–449.
- Nunes, L. J. R., et al. (2020). Sugarcane industry waste recovery using thermochemical conversion technologies. *Applied Sciences*, 10(18), 6481.
- Sarkar, S. (2019). Problems of sugar industry management system in India. *IRJET*, 6(8), 1105–1109.
- Tighnavard Balasbaneh, A., Aldrovandi, S., & Sher, W. (2025). Multi-criteria decision-making approaches for circular economy and cost assessment. *Sustainability*, 17(11), 5007.
- Yan, H., Qamruzzaman, M., & Kor, S. (2023). Green investment and clean energy for sustainable development. *Sustainability*, 15(18), 13591.