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Designing a Sustainable Waste Management Model Using Multi-Criteria Decision-Making Methods with an Emphasis on Circular Economy

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1. ABSTRACT

Waste management in industrial areas such as Mahshahr Port, which serves as the beating heart of Iran's oil and gas industries, faces numerous environmental, economic, social, and technical challenges. This research aims to design a sustainable model for waste management, with an emphasis on circular economy principles, by employing multi-criteria decision-making methods, including the Best-Worst method for criteria weighting and VIKOR for option ranking. Data were collected through questionnaires from managers and field data from Mahshahr Port facilities, and analyzed using Python and SPSS software. The results indicate that recycling, with a Q = 0.08 score, is the best option, while landfilling, with a Q = 0.95 score, exhibits the poorest performance. This model contributes to sustainable development by reducing environmental impacts, optimizing costs, and creating social opportunities. The findings underscore the necessity for investment in recycling technologies and the development of educational programs to promote the circular economy.

Keywords: Sustainable Waste Management, Circular Economy, VIKOR Method, Best-Worst Method, Sustainable Development

2. INTRODUCTION

Waste management is pivotal to sustainable development, especially in Iran's petrochemical hub of Mahshahr Port, generating over 10,000 tons of industrial and municipal waste daily—primarily hazardous hydrocarbons, plastics, and chemicals—that strains resources and endangers biodiversity [1]. Inefficient practices exacerbate Persian Gulf ecosystem degradation and public health risks, with over 79% of plastics landfilled, wasting recycling opportunities [2]. Nationally, Iran's 61 million annual tons (global rank 17) include 65% organics suitable for composting or energy recovery, but recycling rates remain low at 10–17% [3], highlighting gaps in existing models.The circular economy—focusing on waste reduction, reuse, and recycling—provides a paradigm for resource optimization and environmental mitigation [4]. In Iran, with 70% organic waste and 0.63 kg per capita daily generation [10], prioritizing 7% plastic recycling and waste-to-energy could drive 10% annual sector growth by 2026 [5]. This study employs multi-criteria decision-making to develop a scalable, sustainable model, ranking options via localized data. Objectives: (1) build an integrated framework; (2) assess alternatives; (3) offer policy recommendations emphasizing emission cuts and resource efficiency.

3. MATERIALS AND METHODS

Data analysis and processing were conducted using specialized software, Python and SPSS. Initially, the Best-Worst Method (BWM) was implemented through linear programming to compute weights for each decision criterion within the [0, 1] interval. Subsequently, the VIKOR method was applied to rank the decision alternatives. Sensitivity analysis was

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further performed to evaluate potential variations. Finally, supplementary statistical analyses were utilized, including multiple regression to investigate inter-criterion relationships and cluster analysis to identify emergent patterns. Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA) were employed in this study to assess significant differences in scores for waste management alternatives (incineration, composting, landfilling, recycling) across environmental, economic, social, and technical criteria. These analyses served to validate the integrity of rankings obtained via the VIKOR method and to explore interactions between criteria and alternatives. Drawing on data gathered from experts and analyses executed with Python and SPSS, the results are delineated below. Modeling commenced with the identification of criteria and alternatives, followed by criterion weighting using the BWM framework. In this investigation, the environmental criterion (C1) was selected as the most favorable (best), and the economic criterion (C2) as the least favorable (worst). The optimization model was solved to minimize the maximum deviation ξ ($\xi = 0.10$; consistency ratio CR = 0.013). VIKOR ranking ensued by calculating the ideal (f^*) and anti-ideal (f^-) solutions, along with utility (S), regret (R), and compromise (Q) indices ($v = 0.5$).

4. RESULTS AND DISCUSSION

The findings of this study, grounded in an intelligent integration of multi-criteria decision-making (MCDM) techniques—including the Best-Worst Method (BWM) for criterion weighting and VIKOR for final ranking—not only affirm the superiority of recycling as the optimal waste management strategy for Mahshahr Port facilities but also elucidate deeper layers of interactions among criteria and alternatives through advanced statistical analyses. In the BWM weighting process, which leverages pairwise expert comparisons (with minimized comparisons to enhance efficiency) and linear optimization modeling, the environmental criterion emerged with a weight of 0.38 as the primary driver. This elevated weighting, stemming from the prioritization of pollution reduction, greenhouse gas emissions mitigation, and Persian Gulf biodiversity preservation, underscores the region's acute ecological vulnerability—where annual influxes exceeding 928 tons of plastics can disrupt marine food chains. The social criterion, weighted at 0.22 and centered on sustainable job creation and community acceptance, naturally ranked second, while the economic and technical criteria, both at 0.20, strike a delicate balance between operational costs and technological feasibility. The low inconsistency ratio (CR=0.013) in BWM—below the 0.1 threshold—bolsters the robustness of these weights, indicating contradiction-free expert judgments. In the VIKOR ranking phase, tailored for resolving conflicts among criteria, recycling was unequivocally identified as the frontrunner with a Q index of 0.08, while landfilling trailed at the opposite end with Q=0.95. Utility (S) values were [0.87 for incineration, 0.40 for composting, 0.72 for landfilling, and 0.18 for recycling], and regret (R) values [0.38, 0.19, 0.22, 0.07], collectively emphasizing recycling's efficacy in minimizing decision regret. Sensitivity analysis, encompassing variations in the strategy coefficient v from 0.2 (group utility focus) to 0.8 (individual regret focus) and ±20% weight fluctuations, validated model stability: recycling's ranking remained unaltered in 95% of scenarios, with Q deviations under 0.05, rendering it apt for real-world applications amid uncertainty. Supplementary statistical validations, designed to corroborate MCDM outcomes, further enriched the insights. Within the circular economy framework—anchored in principles of reduction, reuse, and recycling—recycling serves as a bridge from traditional linear models to sustainable paradigms. By targeting the conversion of hazardous wastes (e.g., 88% of Amirkabir Complex outputs) into resources, it curtails wastefulness and accelerates a projected 10% annual growth in the waste management sector through 2026. Comparative analyses with studies in developing contexts, such as Baltic States evaluations, reveal this study's Q=0.08 outperforms their average of 0.15, yielding superior efficiency. Contra Mahshahr's conventional practices—predominantly landfilling-dependent and capping recycling at 10–17%—this model unlocks potential for over 30% rates, realizable via novel integrations like advanced recycling technologies and AI-driven waste generation forecasting. From an innovation standpoint, this research advances the literature by hybridizing BWM and VIKOR within a geospatial-augmented framework incorporating Geographic Information Systems (GIS), thereby transcending prior boundaries. While antecedent studies have emphasized MCDM in waste management, they seldom adapt these to petrochemical-specific locales—precisely where daily 10,000-ton volumes pose acute public health threats, including escalated respiratory and carcinogenic risks.

5. CONCLUSION

In this study, a sustainable and integrated waste management model was developed for sensitive industrial regions such as Mahshahr Port—one of Iran's principal petrochemical hubs—wherein profound environmental, economic, social, and technical challenges were concurrently explored. Anchored in circular economy principles that prioritize waste minimization, resource reuse, and the valorization of waste into added value, this model leverages multi-criteria decision-making (MCDM) methodologies to rigorously evaluate waste management alternatives. Key findings, derived from criterion weighting via the Best-Worst Method (BWM), reveal the environmental criterion as the paramount driver (weight: 0.38), emphasizing chemical pollution abatement and Persian Gulf biodiversity conservation, while social (0.22) and economic (0.20) criteria forge an essential equilibrium between fostering sustainable employment opportunities and optimizing operational expenditures. Subsequently, application of the VIKOR method for alternative ranking spotlighted recycling as the preeminent strategy, substantiating its superior performance in mitigating adverse environmental impacts—such as plastic ingress into marine ecosystems—and concurrently generating economic value through waste-to-resource conversion. These insights, corroborated by advanced statistical analyses including one-way and multivariate analysis of variance (ANOVA/MANOVA), unveiled significant disparities among alternatives, underscoring recycling's dominance over conventional approaches like landfilling and incineration across all criteria. Sensitivity analysis further

assured model robustness amid fluctuations, affirming its resilience. Beyond its local purview, the significance of these findings extends to national and global sustainable development imperatives. In Mahshahr Port, where voluminous daily industrial waste imperils public health and the Persian Gulf ecosystem, this model not only redresses deficiencies in prior inefficient paradigms but also proffers a pragmatic, implementable framework for policymakers, industry executives, and local communities—augmented by innovative tools such as geospatial analytics and Geographic Information Systems (GIS).

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