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A Simulation-Based Matching System for Utilizing Clean Energy from Agri-livestock Waste

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Abstract

In order to mitigate greenhouse gas emissions and air pollution derived from agricultural and livestock waste and to enhance the resilience of the clean energy supply chain, a simulation-based matching system for utilizing clean energy from agri-livestock waste was developed. Building upon a prior research entitled "An Inventory of Greenhouse Gases and a Map of Biomass Energy Utilization in Agriculture and Animal Husbandry Biomass Waste," the system is designed to evaluate the efficacy of waste matchmaking in reducing air pollution, generating clean energy, and lowering carbon emissions via simulated logistics. The methodology was twofold. The first, "Matchmaking Order Generation," utilized public datasets and Taiwan agriculture statistics, employing not only traditional data-driven methods of the biomass weight-driven approach and Monte Carlo simulation, but also importing generative artificial intelligence models based on Generative Adversarial Networks and Large Language Models. The second phase, "Transportation Carbon Footprint Assessment," addressed the Traveling Salesman Problem by implementing two modern, bio-inspired metaheuristic algorithms: a hybrid Ant-Bee Colony optimization and a Quantum-inspired Genetic Algorithm. Concurrently, generative artificial intelligence models were also developed for this optimization task, with performance evaluated based on execution time, total transport distance, and carbon footprint. The results indicated that while the generative artificial intelligence approach achieved a substantial 59.8% reduction in carbon footprint across 20 disposal sites, it demanded significantly longer computational times. In contrast, metaheuristic algorithms exhibited a pronounced advantage in execution speed, requiring only 0.2% of the computational time of the generative artificial intelligence models while achieving comparable carbon footprint outcomes. This study provides a critical evaluation framework for advancing low-carbon logistics and intelligent dispatching in Taiwan. It supports the policy objectives of a circular economy and carbon management, providing a robust, integrated paradigm for emerging applications in agricultural carbon inventories, carbon credits, and sustainable agriculture.

Keywords: Generative Artificial Intelligence, Transportation Carbon Footprint, Metaheuristic Algorithms, Circular Economy, Agri-livestock Waste.

INTRODUCTION

Sustainable development in the agricultural and livestock sector is critical under global climate change and energy transition pressures. Improper management of agricultural residues and livestock waste contributes to air pollution and greenhouse gas emissions, particularly

methane. Converting such waste into clean energy can reduce carbon emissions, support a circular economy (Abedin et al., 2025), and strengthen the resilience of clean energy supply chains (Chidozie et al., 2024). This study extends previous work on greenhouse gas inventories and biomass energy mapping, developing a logistics simulation framework to model waste-to-energy transportation routes and assess its effectiveness in mitigating emissions and producing clean energy.

MATERIALS AND METHODS

The study consisted of two stages, both implemented in Python. The first stage, Order Matching Generation, integrated four approaches—biomass-weight-driven, Monte Carlo simulation, GAN, and a large language model (LLM, Gemini-2.5-flash)—to generate optimized orders from public datasets and Taiwan agricultural statistics. The second stage, Transportation Carbon Footprint Assessment, evaluated four optimization methods: hybrid Ant-Bee optimization, quantum-inspired genetic algorithm, GAN, and generative AI combining GAN and LLM models (Tran et al., 2025).

RESULTS & DISCUSSION

Each method was evaluated over 30 repeated experiments, with the best solutions reported. The large language model (LLM) achieved the shortest path distance (423.74 km) and the highest carbon reduction (59.8%), but required ~60 seconds to converge, limiting real-time applicability. In contrast, metaheuristic algorithms, particularly the hybrid Ant-Bee optimization, converged within 0.11 seconds—only 0.2% of the LLM's computation time—though with higher carbon emissions (137.93 kg CO₂e) and longer paths (510.85 km). The quantum-inspired genetic algorithm offered intermediate performance (129.90 kg CO₂e, 481.10 km, 2.14 s), balancing efficiency and robustness. GAN-based planning achieved near-LLM carbon reduction (115.52 kg CO₂e) and path distance (427.83 km) while drastically reducing computation time to 1.95 seconds, highlighting its potential for low-carbon, high-efficiency logistics.

CONCLUSIONS

This study provides a critical evaluation framework for low-carbon logistics and intelligent dispatching, comparing the performance of generative AI and metaheuristic algorithms in terms of carbon reduction and computational efficiency. The findings highlight the trade-offs between emission control and processing speed, supporting circular economy and carbon management policies while offering an integrated, forward-looking paradigm for applications in agricultural carbon inventories, carbon trading, and sustainable agriculture

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REFERENCES

- Abedin, T., Pasupuleti, J., Paw, J.K.S., Tak Y.C., Islam M.R., Basher M.K., and Nur-E-Alam, M. 2025. From waste to worth: advances in energy recovery technologies for solid waste management. *Clean Techn Environ Policy*.
- Chidozie, B., Ramos, A., Vasconcelos, J., and Ferreira, L. P. 2024. Development of a Residual Biomass Supply Chain Simulation Model Using AnyLogistix: A Methodical Approach. *Logistics*, 8(4), 107.
- Comert, S.E., and Yazgan, H.R. 2023. A new approach based on hybrid ant colony optimization-artificial bee colony algorithm for multi-objective electric vehicle routing problems, *Engineering Applications of Artificial Intelligence*, Volume 123, Part B, 106375.
- Tran, C. D., Nguyen-Tri, Q., Binh, H. T. T., & Thanh-Tung, H. (2025). Large language models powered neural solvers for generalized vehicle routing problems. *ICLR 2025 Workshop AgenticAI*, Singapore.