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EcoBiomass - AI-Powered Framework for Biomass Trading and Route Optimization

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Abstract - With the increasing global demand for renewable energy resources, biomass has emerged as a critical component in sustainable energy production. However, traditional biomass trading ecosystems remain fragmented, lacking transparency, structured pricing mechanisms, and optimized logistics coordination. This paper proposes EcoBiomass, an AI-driven intelligent marketplace designed to streamline biomass trading, enhance supply chain transparency, and optimize transportation logistics. The system integrates three core modules: (1) a vision-based quality assessment module using a pre-trained multimodal Vision-Language Model (Google Gemini 2.5 Flash Lite) that evaluates biomass images on parameters such as color uniformity, moisture appearance, particle size, and contamination; (2) a rule-based dynamic pricing engine computing prices from quality score, weight, and moisture levels; and (3) a multi-criteria weighted route optimization model that ranks transportation routes using distance (40%), cost (35%), and delivery time (25%). Distances are calculated using the Haversine formula and final navigation is provided via Google Maps API. Simulation results indicate improvements of approximately 15–21% in route efficiency and cost reduction over unoptimized baseline selection.

Keywords - Biomass Trading, Artificial Intelligence, Dynamic Pricing, Route Optimization, Multimodal AI, Haversine Formula, Smart Supply Chain, Vision-Language Model.

I. INTRODUCTION

Biomass plays a significant role in renewable energy generation, especially in developing economies. Despite its importance, the biomass trading ecosystem remains largely unstructured, leading to inefficiencies in pricing, quality evaluation, and logistics coordination. Traditional trading approaches rely on manual processes resulting in inconsistent quality grading, arbitrary pricing, and suboptimal transportation decisions.

EcoBiomass is proposed as an intelligent digital platform that connects buyers, sellers, and transporters in a unified ecosystem. The system leverages artificial intelligence and data-driven decision-making to improve transparency, pricing accuracy, and logistics efficiency. The platform incorporates three core components:

- AI-based biomass quality assessment using a pre-trained Vision-Language Model (VLM)
- Rule-based dynamic pricing engine incorporating quality, weight, and moisture parameters
- Multi-criteria weighted route optimization model for intelligent supplier and route selection

A centralized dashboard provides real-time monitoring of transactions, logistics, and analytics enabling informed decision-making by all stakeholders.

II. LITERATURE SURVEY

Existing research has explored optimization and intelligent decision-making across various domains of agricultural supply chain management and logistics. Dynamic pricing models using machine learning have been widely applied in e-commerce platforms to adjust prices based on demand, quality attributes, and market conditions. El Youbi and Loukili [1] demonstrated that ML-based dynamic pricing improves revenue efficiency compared to static pricing systems.

In agricultural commodity markets, machine learning-based recommendation and quality classification systems have shown strong results. Balakrishnan et al. [2] proposed ML-based agricultural recommendation systems improving buyer-seller matching. Brindha Devi et al. [3] applied Random Forest approaches for automated crop quality classification with competitive accuracy.

Route optimization in logistics has been addressed using various computational methods. Metaheuristic approaches applied to vehicle routing problems in smart e-commerce platforms have shown effectiveness [4]. Distance-based models using geographic formulas such as the Haversine equation have been widely applied for real-world supplier proximity ranking and route selection.

Recent advancements in multimodal AI have enabled automated quality assessment in agricultural domains. Pre-trained vision-language models provide strong zero-shot classification capabilities, making them suitable for quality evaluation without requiring extensive labeled training datasets [5]. However, most existing systems address these components independently. There is limited work integrating AI-based quality evaluation, automated pricing, and logistics optimization into a unified biomass trading platform — this gap motivates the proposed EcoBiomass framework.

III. PROPOSED METHODOLOGY

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A. System Architecture

The EcoBiomass system follows a modular four-layer architecture designed for scalability, reliability, and intelligent decision-making:

- Presentation Layer: Interactive dashboards and interfaces for buyers, sellers, transporters, and administrators enabling real-time monitoring
- Application Layer: Core business logic including order processing, supplier-buyer matching, and pricing computation
- Data Layer: Secure storage of user profiles, transaction records, quality grades, pricing logs, and logistics data
- AI Layer: Quality assessment model, pricing engine, and route optimization module

The system leverages cloud-based infrastructure for high availability and seamless integration with third-party services such as payment gateways and analytics engines.

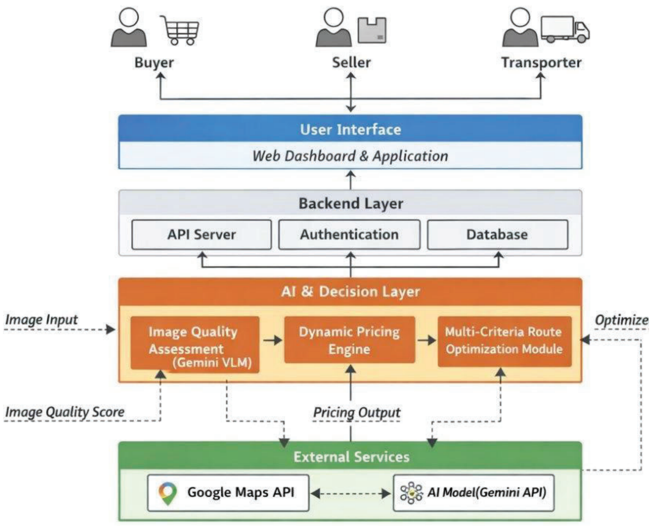

Fig. 1: EcoBiomass System Architecture Diagram

B. Image Quality Assessment Module

The quality assessment module utilizes Google Gemini 2.5 Flash Lite, a pre-trained Vision-Language Model, for zero-shot biomass image evaluation. The model receives biomass images encoded in base64 format along with a structured prompt requesting evaluation of: color uniformity, moisture appearance and surface condition, particle size consistency, and presence of contaminants. The model outputs a quality score between 0 and 100. A temperature setting of 0.1 ensures deterministic and reproducible outputs, enabling consistent quality grading without a custom-trained model.

C. Dynamic Pricing Model

The dynamic pricing engine computes biomass prices using the following deterministic formula:

$$Price = BasePrice \times Weight \times (QS / 100) \times (1 - M / 150)$$

Where BasePrice = \$5/kg (standard market reference), Weight = quantity in kg, QS = AI-generated quality score (0–100), and M = moisture percentage (range: 5–80%). This formula ensures pricing adapts proportionally to quality and moisture, reflecting real-world market valuation. A batch with QS = 85, Weight = 100 kg, and M = 30% yields \$340, validated through system testing.

D. Multi-Criteria Route Optimization Model

The route optimization module implements a weighted multi-criteria scoring model to identify the most efficient transportation route from available suppliers. Three parameters are evaluated as shown in Table 1.

Parameter	Weight	Rationale
Distance (km)	40%	Primary cost driver
Transport Cost (\$)	35%	Direct financial impact
Delivery Time (min)	25%	Service quality factor

Table 1: Route Optimization Parameter Weights

Geographic distance is computed using the Haversine formula, which calculates great-circle distances from latitude and longitude coordinates. The cost model estimates expenses based on fuel (\$0.15/km), time-based charges (\$0.50/min), and toll estimates. The composite score is:

$$Score = 0.40 \times D\_norm + 0.35 \times C\_norm + 0.25 \times T\_norm$$

Routes are ranked by ascending score. The route with the lowest composite score is selected as optimal. Real-time navigation to the selected supplier is then provided via Google Maps API, offering turn-by-turn routing for transporters.

IV. RESULTS AND DISCUSSION

A. Route Optimization Results

The optimization module was evaluated using simulated logistics scenarios with multiple supplier locations. Table 2 presents comparative results across three candidate routes:

Route	Dist. (km)	Cost (\$)	Time (min)	Score
A	120	40.50	180	0.82
B ✓	95	34.75	150	0.64
C	110	38.00	170	0.74

Table 2: Route Optimization Comparative Results (✓ = Selected)

Route B was selected as optimal. Compared to Route A (unoptimized baseline), the system achieved a 20.8% reduction in distance, 14.2% reduction in transportation cost, and 16.7% reduction in delivery time.

B. Dynamic Pricing Evaluation

QS	Wt (kg)	M (%)	Price (\$)
90	100	20	\$383.33
85	100	30	\$340.00
70	100	40	\$256.67
50	100	60	\$150.00

Table 3: Dynamic Pricing Model Outputs (QS=Quality Score, M=Moisture)

The pricing model produces fully deterministic and reproducible outputs, ensuring consistent and transparent pricing for all participants. Prices adjust proportionally to quality and moisture, reflecting realistic market valuation criteria.

C. System Performance Summary

Performance Metric	Result
Route distance reduction	~20.8%
Transportation cost reduction	~14.2%
Delivery time reduction	~16.7%
Pricing reproducibility	100% deterministic
Quality assessment response	< 2 sec/image

Table 4: System Performance Summary

D. Limitations

The system relies on external APIs for image analysis (Gemini) and navigation (Google Maps), introducing potential latency and network dependency. The pricing formula is rule-based and does not adapt dynamically to real-time market demand fluctuations. Results are based on simulated scenarios; real-world deployment may introduce additional variability.

V. CONCLUSION

This paper presented EcoBiomass, an AI-powered digital marketplace for biomass trading that integrates vision-based quality assessment, dynamic pricing, and multi-criteria route optimization into a unified platform. The system addresses key inefficiencies in traditional biomass trading by automating quality evaluation, standardizing pricing, and enabling intelligent logistics selection.

The proposed multi-criteria weighted optimization model combined with Haversine-based distance computation and Google Maps navigation provides a practical, scalable approach to logistics optimization. Simulation results indicate improvements of approximately 15–21% in distance, cost, and delivery time compared to unoptimized baseline selection.

Future enhancements may include integration with IoT-based biomass quality sensors, blockchain-enabled transaction validation, ML-based demand forecasting modules, and real-time carbon emission tracking for environmental sustainability.

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