***ECO-AI: AI-Driven Waste Optimization for Sustainable Agriculture - Documentation***

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***I. Introduction***

Project Overview

The ECO-AI project addresses the challenge of inefficient waste collection and its impact on sustainable agriculture in urban areas, focusing on Huye District, Rwanda. Current waste management often results in unsystematic collection, leading to overflowing bins, pollution, and lost opportunities for organic waste reuse. ECO-AI introduces an AI-based system that predicts waste generation, optimizes collection routes, and supports organic manure production, contributing to sustainable agriculture.

Relevance to Sustainable Agriculture

*ECO-AI supports sustainability by:*

Reducing pollution caused by uncollected waste.

Converting organic waste into high-quality manure.

Creating a circular economy model for urban organic waste.

Aligned UN Sustainable Development Goals (SDGs)

SDG 2: Zero Hunger

SDG 11: Sustainable Cities and Communities

SDG 13: Climate Action

Target Audience

Huye District waste management authorities

Urban farmers and agricultural cooperatives

Local policymakers and development agencies

***II. System Description***

System Architecture

Data Collection Layer

Sources:

Mobile App/USSD (used by waste workers)

GPS trackers on trucks

OpenWeatherMap API for weather data

Optional: Smart bin sensors (future upgrade)

Data Preprocessing

Database: PostgreSQL

**Tasks**: Data cleaning, transformation, feature engineering

AI Prediction Engine

**Models:**

LSTM (Long Short-Term Memory) for time-series waste generation prediction

Random Forest Regressor for waste quantity prediction

Libraries: TensorFlow, Scikit-learn

Routing Optimization System

Algorithm: Genetic Algorithm

Inputs: Waste hotspots, volume estimates, road network (OpenStreetMap), vehicle capacity, travel time

Admin Dashboard

Platform: Django (backend), Plotly (visualization)

Functions:

Real-time monitoring

Route tracking

KPI reports

Vehicle/worker management

Data Flow Summary

Data collected via app, GPS, and APIs

Stored in PostgreSQL

AI predictions generated

Routes optimized

Displayed in dashboard

Key Features

Accurate waste forecasting

Optimized fuel-efficient routing

Real-time dashboard

Scalable to other urban areas

***III. Dataset Description***

Overview

The system uses a mix of real and synthetic data collected over 6 months from three sectors in Huye: Ngoma, Tumba, and Matyazo.

***Data Sources***

Real Data: Mobile entries + GPS trackers

Synthetic Data: Generated using Python scripts (factors: population, market activity)

Weather: OpenWeatherMap + Rwanda Meteorology Agency

Roads/Geospatial: OpenStreetMap, GPS coordinates

Calendar: National holidays, market days

***Data Formats***

CSV files: waste\_generation.csv, weather\_data.csv

GeoJSON: waste\_routes.geojson

SQLite: eco\_ai.db (internal settings)

Preprocessing Techniques

Imputation for missing values (median)

Outlier removal (IQR method)

One-hot encoding for categorical variables

Min-max scaling for numerical values

Feature engineering (day\_of\_week, time\_since\_last\_collection, etc.)

***IV. Methodology***

*1. Waste Generation Prediction (LSTM)*

Architecture: 2 LSTM layers (64 units each) + dense output

Inputs: Past 7 days’ data, weather, calendar

Split: 70% training, 15% validation, 15% testing

Loss Function: Mean Squared Error

Optimizer: Adam

Metrics: RMSE, MAE

***Output***: Predicted waste weight (kg/day)

*2. Waste Quantity Prediction (Random Forest)*

Model: 100-tree Random Forest

Inputs: Sector type, density, LSTM output

Output: Predicted waste quantity

Metrics: RMSE, R²

*3. Route Optimization (Genetic Algorithm)*

Fitness Function: Minimize distance, maximize collected waste

***Constraints:***

Truck capacity: 3 tons

Operating time: 8am – 4pm

Tools: Python + DEAP library

System Implementation

Languages: Python, JavaScript

Backend: Django

Frontend: Leaflet, Chart.js

Libraries: TensorFlow, Scikit-learn, Pandas, GeoPandas

Database: PostgreSQL

APIs: OpenWeatherMap, OpenStreetMap

Deployment: On-premise server (future: AWS EC2)

Community Involvement and Co-Design

The system was co-designed with input from waste workers, agronomists, and urban farmers in Huye. Their insights shaped the mobile interface, dashboard layout, and predictive model explainability.

***V. Results and Evaluation***

AI Model Performance

LSTM:

RMSE: 4.7 kg

MAE: 3.2 kg

R²: 0.87

Random Forest:

RMSE: 7.9 kg

R²: 0.81

Route Optimization Gains

Travel Distance ↓ 23%

Collection Time ↓ 18%

Fuel Usage ↓ 14%

***VI. Conclusion***

ECO-AI proves that AI can help cities like Huye manage waste more efficiently while supporting agriculture. Through AI prediction and optimized routing, this project reduces environmental waste, boosts soil productivity, and supports a cleaner urban environment. It's a scalable model for other Rwandan towns — and even broader across East Africa.

***VII. References***

Rwanda Meteorology Agency

OpenWeatherMap API Docs

OpenStreetMap Docs

TensorFlow & Scikit-learn Docs

Huye District Waste Records (Pilot Report 2024)