

## 1. Architecture Overview

EcoPackAI is designed using a **modular and scalable architecture** that separates concerns across multiple layers to ensure flexibility, maintainability, and future expansion.

### Architecture Layers:

- **User Interface Layer**  
Web-based interface for collecting product requirements and displaying recommendations and insights.
- **Data Ingestion Layer**  
Handles structured datasets containing material properties, environmental metrics, and product constraints.
- **Data Processing Layer**  
Performs data cleaning, normalization, feature scaling, and transformation for ML models.
- **Machine Learning Layer**  
Trained predictive and recommendation models for cost, carbon footprint, and sustainability scoring.
- **Recommendation Engine**  
Combines model outputs and rule-based constraints to generate ranked eco-friendly packaging options.
- **Visualization & BI Layer**  
Dashboards and charts to communicate insights such as cost comparison and carbon reduction.
- **Deployment Layer**  
Containerized services deployed to cloud infrastructure with monitoring and CI/CD support.

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## 2. Dataset Description

EcoPackAI uses **structured and semi-structured datasets** combining packaging material properties and sustainability indicators.

### Key Dataset Attributes:

- Material name and category
- Strength and durability metrics
- Weight capacity
- Cost per unit
- Carbon footprint score
- Recyclability percentage
- Biodegradability score
- Regulatory and compliance indicators

The dataset supports **multi-objective optimization**, enabling the system to balance cost efficiency, sustainability, and performance requirements.

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### **3. Machine Learning Model Explanation**

EcoPackAI employs a **hybrid recommendation approach**:

#### **a) Predictive Models**

- **Random Forest Regressor**  
Used to predict material cost and environmental impact due to its robustness and interpretability.
- **XGBoost Regressor**  
Applied for higher accuracy in sustainability and carbon footprint prediction.

#### **b) Recommendation Logic**

- **Content-based filtering** ranks materials based on similarity to user requirements.
- Model predictions are combined with sustainability rules to produce final ranked recommendations.

This hybrid approach ensures **accurate, explainable, and context-aware recommendations**.

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### **4. Evaluation Metrics**

EcoPackAI is evaluated using both **machine learning performance metrics** and **business-impact metrics**.

#### **Model Evaluation Metrics:**

- Precision@K
- Recall@K
- NDCG (Normalized Discounted Cumulative Gain)

#### **Sustainability & Business Metrics:**

- Cost savings percentage
- Average carbon footprint reduction
- Sustainability score improvement
- Recommendation relevance score

These metrics ensure the system performs well both technically and environmentally.

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### **5. BI Dashboard Explanation**

The EcoPackAI dashboard provides **interactive and real-time insights** for decision-makers.

#### **Dashboard Features:**

- Recommended packaging materials with ranking
- Carbon footprint comparison charts
- Cost analysis across alternative materials
- Sustainability KPIs (recyclability, biodegradability)
- Feature importance and model insights

The dashboard enables **data-driven sustainable packaging decisions** with clear visual explanations.

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## 6. Deployment Steps

EcoPackAI follows a structured deployment workflow:

1. Environment setup and dependency installation
2. Dataset preprocessing and feature engineering
3. Machine learning model training and evaluation
4. Backend API development for recommendations
5. Frontend and dashboard integration
6. Docker containerization
7. Cloud deployment
8. CI/CD pipeline setup for automated updates
9. Monitoring and logging for performance tracking

This ensures a **production-ready and scalable system**.

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## 7. Screenshots

**EcoPackAI**

Sustainable Packaging Recommendation

**RECOMMENDATION SELECTION**

Pharmaceuticals
High
Domestic
Medium

Generate Output
Clear Inputs

**MATERIAL PREDICTION**

Material	Predicted Cost	Predicted CO2	Suitability Score
PLA Bioplastic	5.96	6.18	0.86
Bamboo Fiber Packaging	5.96	7.97	0.81
Bamboo Corrugated Sheet	5.96	7.97	0.81

**Avg CO2 Reduction**  
**27.54%**  
Average across 19 runs

**Avg Cost Savings**  
**3.76**  
Average across 19 runs

**EXPORT**

PDF Summary
Excel Ranking

Clear History

Material Comparison
Sustainability Ranking

**MATERIAL COMPARISON**

X-axis: Material names | Y-axis: Suitability score

Material	Avg Suitability Score
Jute Sack	0.45
Recycled Steel	0.70
Standard Glass	0.20
PLA Bioplastic	0.95
Bamboo	0.90
Bamboo Fiber Packaging	0.90
Bamboo Corrugated Sheet	0.90
Edible Film (Starch/Protein)	0.95
PPA Bioplastic	0.95
Seaweed-Based Packaging	0.90
Double Wall Corrugated Panel	0.90
Paper Honeycomb Board	0.90
Molded Fiber Bottle Holder	0.70
Plywood Packaging Sheet	0.95
Thin Wooden Crate	0.95

## CO2 Reduction Analysis

X

CO<sub>2</sub> Reduction Trend Over Time



## Cost Savings Analysis

X

Cost Savings Trend Over Time



Material