

Environmental Dashboard

Comparative Analysis of Waste Management Europe & Africa

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Abstract

This report presents an interactive environmental dashboard developed to analyze and compare waste management practices between European and African countries. Using data from Our World in Data (<https://ourworldindata.org/grapher/total-waste-generation>) and OECD recycling statistics (<https://ourworldindata.org/grapher/recycling-rates-paper-and-cardboard>), the dashboard provides insights into recycling rates, waste generation trends, and environmental risks. The platform integrates ARIMA machine learning predictions and rule-based risk assessment to support evidence-based decision-making in environmental policy.

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1 Context and Environmental Issues

1.1 Global Waste Crisis

The world is facing an unprecedented waste management crisis. According to the World Bank, global waste generation is expected to increase by 70% by 2050 if current trends continue. This escalating problem poses severe threats to:

- **Environmental health:** Pollution of air, water, and soil
- **Climate change:** Greenhouse gas emissions from landfills and waste treatment
- **Public health:** Disease transmission and toxic exposure
- **Economic sustainability:** Resource depletion and lost economic opportunities

1.2 North-South Divide

The disparity in waste management infrastructure and practices between developed (Global North) and developing (Global South) nations is striking:

- **Europe:** Advanced recycling infrastructure, circular economy initiatives, strict environmental regulations (e.g., EU Waste Framework Directive targeting 50% recycling by 2020)
- **Africa:** Rapidly increasing waste generation, limited recycling infrastructure, informal waste management sectors, and growing environmental challenges

1.3 Project Motivation

This dashboard was developed to:

1. Provide a comprehensive comparative analysis between European and African waste management systems
2. Identify best practices and areas requiring improvement
3. Enable data-driven policy decisions through predictive analytics
4. Support environmental risk assessment and resource allocation
5. Promote awareness of global waste management disparities

2 Dataset Description

2.1 Data Sources

2.1.1 OECD Municipal Waste Recycling Rate

- **Coverage:** 27 European countries
- **Temporal range:** 1990–2015 (biennial collection, interpolated to annual)
- **Metric:** Percentage of municipal waste recycled
- **Countries:** France, Germany, Italy, Spain, Belgium, Netherlands, Austria, Denmark, Sweden, Finland, Norway, Switzerland, Poland, Portugal, Greece, Ireland, Czechia, United Kingdom, Luxembourg, Slovenia, Slovakia, Estonia, Hungary, Iceland, Latvia, Lithuania, Turkey

2.1.2 UN Environment Total Waste Generation

- **Coverage:** 100+ countries globally (22 African countries selected)
- **Temporal range:** 2000–2021 (biennial collection, interpolated to annual)
- **Metric:** Total household waste in tonnes
- **African countries:** Algeria, Egypt, Morocco, Tunisia, South Africa, Kenya, Ghana, Botswana, Mauritius, Benin, Burkina Faso, Burundi, Cape Verde, Guinea, Lesotho, Madagascar, Niger, Sudan, Tanzania, Togo, Zambia, Zimbabwe

2.2 Data Preprocessing

2.2.1 Interpolation Strategy

To address missing years in both datasets (data collected biennially):

- **Linear interpolation:** Applied to fill odd years (2011, 2013, 2015, etc.)
- **Recycling rates:** Interpolated for all European countries
- **Waste generation:** Interpolated for both European and African countries
- **Mathematical approach:**

$$y_t = y_{t-1} + \frac{(y_{t+1} - y_{t-1})}{2} \quad (1)$$

2.2.2 Calculated Indicators

- **Waste per capita:**

$$W_{pc} = \frac{W_{total} \times 1000}{P \times 10^6} \text{ (kg/person/year)} \quad (2)$$

where W_{total} is total waste in tonnes, P is population in millions

- **Growth rate:** Year-over-year percentage change in waste generation
- **Risk scores:** Composite indicators based on multiple factors (detailed in Section 3.3)

2.3 Data Quality Considerations

- **Limitation:** African countries have no recycling rate data in OECD dataset
- **Solution:** Dashboard provides separate analyses and comparative metrics based on waste generation alone
- **Missing data:** Handled through interpolation for sparse time series (e.g., Kenya with single data point, Benin with three points)

3 Indicator Selection and Justification

3.1 Primary Indicators

3.1.1 Recycling Rate (%)

Relevance: Direct measure of circular economy progress and waste diversion from landfills.

Justification:

- Key performance indicator in EU Waste Framework Directive
- Reflects infrastructure investment and policy effectiveness
- Enables benchmarking against 30% and 50% recycling targets

3.1.2 Waste Per Capita (kg/person/year)

Relevance: Normalizes waste generation by population, enabling fair comparison.

Justification:

- Accounts for country size differences
- Correlates with economic development and consumption patterns
- Universal metric applicable to all countries (Africa & Europe)

3.1.3 Total Waste Generation (tonnes)

Relevance: Absolute scale of waste management challenge.

Justification:

- Critical for infrastructure planning and resource allocation
- Reveals the magnitude of environmental impact
- Useful for regional aggregation and comparison

3.2 Derived Indicators

3.2.1 Growth Rate (%/year)

Calculation:

$$GR = \frac{W_t - W_{t-1}}{W_{t-1}} \times 100 \quad (3)$$

Justification:

- Identifies accelerating waste generation trends
- Early warning indicator for intervention planning
- Captures dynamic changes over time

3.3 Risk Assessment Scores

3.3.1 European Risk Score (0–100)

Components:

$$R_{europe} = w_1 \cdot (100 - R_{rate}) + w_2 \cdot f(W_{pc}) + w_3 \cdot f(GR) \quad (4)$$

where:

$$w_1 = 0.40 \text{ (recycling rate weight)}$$

$$w_2 = 0.35 \text{ (waste per capita weight)}$$

$$w_3 = 0.25 \text{ (growth rate weight)}$$

Risk thresholds:

- Low recycling: $R_{rate} < 20\%$ (high risk)
- High waste per capita: $W_{pc} > 500 \text{ kg/year}$
- Rapid growth: $GR > 3\%/\text{year}$

3.3.2 African Risk Score (0–100)

Components (no recycling data available):

$$R_{africa} = 35 + w_1 \cdot f(W_{pc}) + w_2 \cdot f(GR) + w_3 \cdot f(W_{total}) \quad (5)$$

Base risk = 35 (no recycling infrastructure)

Risk thresholds:

- Baseline: 35 points (absence of formal recycling systems)
- High waste per capita: $W_{pc} > 400$ kg/year (+25 points)
- Rapid growth: $GR > 3\%/\text{year}$ (+30 points)
- High volume: $W_{total} > 10M$ tonnes (+10 points)

3.4 Predictive Analytics and Risk Assessment

3.4.1 Waste Forecasting: Machine Learning Model

Algorithm: ARIMA (Autoregressive Integrated Moving Average) with Linear Regression Fall-back

Mathematical formulation:

$$\hat{W}_{t+k} = \phi_1 W_{t-1} + \phi_2 W_{t-2} + \cdots + \phi_p W_{t-p} + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \cdots + \theta_q \epsilon_{t-q} \quad (6)$$

where:

- \hat{W}_{t+k} = Predicted waste per capita at future time $t + k$
- ϕ_i = Autoregressive parameters (learn from past waste values)
- W_{t-i} = Past waste observations
- θ_j = Moving average parameters (learn from past errors)
- ϵ_{t-j} = Past prediction errors
- ARIMA order: $(p = 1, d = 1, q = 1)$ where p = autoregressive order, d = differencing, q = moving average order

Training Parameters:

- **Primary algorithm:** statsmodels ARIMA(1,1,1)
- **Fallback algorithm:** scikit-learn LinearRegression (if ARIMA fails)
- **Window size:** User-configurable (3, 5, 7, or 10 years)
- **Forecast horizon:** 5 years ahead
- **Training data:** Uses most recent n years only (rolling window)
- **ARIMA features:** Past waste values (time series patterns)
- **Linear features:** Time/year (if fallback triggered)
- **Target:** Waste per capita (kg/person/year)

Model Justification:

- **ARIMA advantages:**

- Uses actual waste values, not just year numbers (learns from patterns like "up 5kg, down 2kg, up 4kg")
- Captures non-linear trends and fluctuations better than linear models
- Autoregressive component: Leverages correlation between consecutive years
- Differencing: Removes trends to focus on changes
- Moving average: Accounts for prediction errors to improve accuracy

- **Rolling window:** Captures recent trends more accurately than full historical data

- **Fallback mechanism:** Linear Regression ensures predictions even with sparse data

- **Computational efficiency:** Real-time predictions in interactive dashboard

- **Interpretability:** Model coefficients reveal waste generation dynamics

- **Adaptability:** Smaller windows (3-5 years) respond to recent policy changes

Model Validation:

- Non-negative predictions enforced ($\hat{W} \geq 0$)
- Minimum 3 historical data points required for training
- ARIMA stationarity assumptions checked via differencing ($d = 1$)
- Automatic fallback to Linear Regression if ARIMA convergence fails
- Visual indicators show which model was used (ARIMA vs. fallback)
- Predictions visualized with confidence context (historical vs. forecast)

3.4.2 Risk Assessment: Rule-Based Expert System

Important Note: Risk scoring uses a **rule-based expert system**, not machine learning. This approach was chosen for transparency and domain expert interpretability.

European Risk Score Formula:

$$R_{europe} = w_1(R_{rate}) + w_2(W_{pc}) + w_3(GR)$$

where:

$$w_1(R_{rate}) = \begin{cases} 40 & \text{if } R_{rate} < 20\% \\ 25 & \text{if } 20\% \leq R_{rate} < 30\% \\ 10 & \text{if } 30\% \leq R_{rate} < 40\% \\ 0 & \text{if } R_{rate} \geq 40\% \end{cases}$$

$$w_2(W_{pc}) = \begin{cases} 30 & \text{if } W_{pc} > 600 \text{ kg/yr} \\ 20 & \text{if } 500 < W_{pc} \leq 600 \\ 10 & \text{if } 400 < W_{pc} \leq 500 \\ 0 & \text{otherwise} \end{cases}$$

$$w_3(GR) = \begin{cases} 30 & \text{if } GR > 2\%/yr \\ 15 & \text{if } 1\% < GR \leq 2\% \\ 5 & \text{if } 0 < GR \leq 1\% \\ 0 & \text{otherwise} \end{cases}$$

Final score: $R_{europe} = \min(w_1 + w_2 + w_3, 100)$

African Risk Score Formula:

$$R_{africa} = 35 + w_1(W_{pc}) + w_2(GR) + w_3(W_{total})$$

Base risk = 35 (no recycling infrastructure)

$$w_1(W_{pc}) = \begin{cases} 25 & \text{if } W_{pc} > 400 \text{ kg/yr} \\ 15 & \text{if } 300 < W_{pc} \leq 400 \\ 5 & \text{if } 200 < W_{pc} \leq 300 \\ 0 & \text{otherwise} \end{cases}$$

$$w_2(GR) = \begin{cases} 30 & \text{if } GR > 3\%/\text{yr} \\ 20 & \text{if } 2\% < GR \leq 3\% \\ 10 & \text{if } 1\% < GR \leq 2\% \\ 5 & \text{if } 0 < GR \leq 1\% \\ 0 & \text{otherwise} \end{cases}$$

$$w_3(W_{total}) = \begin{cases} 10 & \text{if } W_{total} > 10M \text{ tonnes} \\ 5 & \text{if } 5M < W_{total} \leq 10M \\ 0 & \text{otherwise} \end{cases}$$

Final score: $R_{africa} = \min(35 + w_1 + w_2 + w_3, 100)$

Rule-Based vs. ML Approach:

- **Transparency:** Rules explicitly encode domain expert knowledge
- **Interpretability:** Policy makers can understand exact risk factors
- **Threshold justification:** Based on EU targets (30%, 50%) and environmental research
- **Customizability:** Easy to adjust weights based on policy priorities
- **Data efficiency:** Works with limited historical data (no training needed)

Why Not ML for Risk Scoring?

1. **Limited labeled data:** No historical "ground truth" risk labels
2. **Explainability requirement:** Policy decisions need transparent justification
3. **Expert knowledge:** Environmental thresholds well-established in literature
4. **Regulatory alignment:** Thresholds match EU Waste Framework Directive targets

3.4.3 Methodology Comparison Summary

Table 1: Forecasting vs. Risk Assessment: Methodology Comparison

Aspect	Waste Forecasting	Risk Assessment
Approach	Machine Learning	Rule-Based Expert System
Algorithm	ARIMA(1,1,1) + Linear Regression	Weighted Threshold Rules
Input Data	Time series (waste values)	Current metrics
Output	Future waste (kg/cap)	Risk score (0-100)
Training Required	Yes (3-10 years)	No
Interpretability	Autoregressive patterns	Explicit rule thresholds
Adaptability	Rolling window + fallback	Configurable weights
Validation	Historical backtest + convergence	Domain expert review
Use Case	Trend prediction	Priority identification
Advantages	Captures non-linear patterns	Transparent, policy-aligned

Key Insight: The dashboard combines **ARIMA time series ML for forecasting** (autoregressive data-driven predictions) with **rule-based scoring for risk** (expert knowledge), leveraging the strengths of both approaches. ARIMA captures waste generation patterns by learning from actual values, not just temporal trends.

4 Dashboard Features and Screenshots

4.1 Dashboard Architecture

The dashboard is implemented using **Streamlit** (Python 3.x) with the following technology stack:

- **Data manipulation:** Pandas 2.1.1, NumPy
- **Visualization:** Plotly 5.17.0 (interactive charts)
- **Machine Learning:** scikit-learn 1.5.1
- **Deployment:** Streamlit 1.28.0

4.2 Navigation Structure

4.2.1 Region Selection

Three analysis modes:

1. **Europe (with recycling):** Comprehensive analysis including recycling rates
2. **Africa (generation only):** Waste production analysis without recycling data
3. **North-South Comparison:** Side-by-side regional comparison using waste generation metrics

4.2.2 Page Sections

For Europe:

- Overview & KPIs

- Temporal Trends
- Advanced Analytics
- Geographic Analysis
- Rankings
- Predictions & Risks

For Africa:

- Overview & KPIs
- Waste Production
- Geographic Analysis
- Rankings
- Predictions & Risks

For North-South Comparison:

- Overview & KPIs (regional breakdown)
- Geographic Analysis (combined world map)
- Rankings (comparative rankings)
- Predictions & Risks (dual risk assessment)

4.3 Key Visualizations

4.3.1 Overview & KPIs Dashboard

Purpose: Provides at-a-glance performance metrics

Components:

- Gradient KPI cards with key statistics
- Regional averages (Europe vs Africa in comparison mode)
- Champion/leader identification
- Target achievement metrics (30% recycling goal)
- Comparative bar charts with regional color coding

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Deploy :

Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

Hybrid Dashboard:

- **Europe** (27 countries): Recycling + Generation data (1990-2015)
- **Africa** (22 countries): Generation data only (2000-2021)
- **ML Predictions**: Forecasting future waste trends

Key Performance Indicators

Reference Year: 2015



Top 5 Recycling

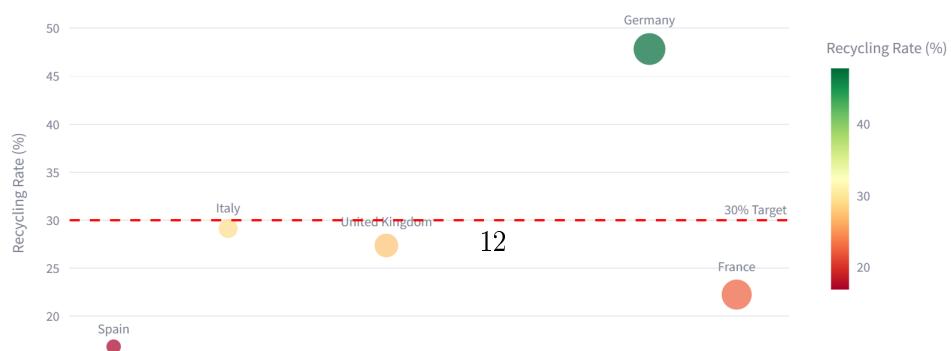
Germany: 47.8%
Italy: 29.1%
United Kingdom: 27.4%
France: 22.3%
Spain: 16.8%

Top 5 to Improve

Spain: 16.8%
France: 22.3%
United Kingdom: 27.4%
Italy: 29.1%
Germany: 47.8%

Environmental Performance (2015)

Recycling vs Production





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Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

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Key Performance Indicators

North-South Comparison: Waste Generation Analysis

Comparing waste production between European and African countries. Note: Recycling data is only available for European countries.

Reference Year: 2015

EU Europe

Average per Capita

3909 kg/year

Total Waste

585.6 M tonnes

Countries

2

Africa

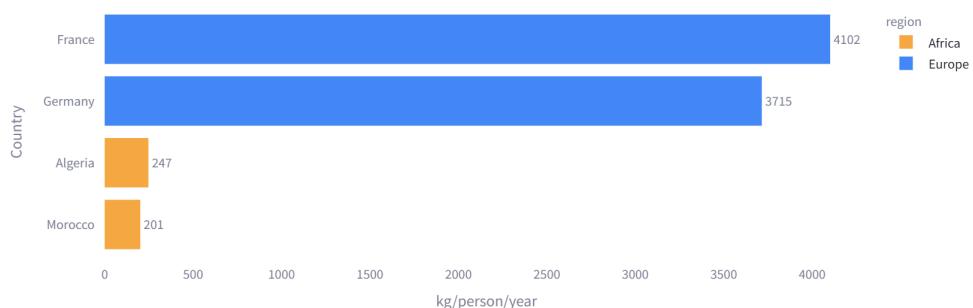
Average per Capita

224 kg/year

Total Waste

18.3 M tonnes

Countries

2**Waste Production per Capita - All Countries (2015)**

4.3.2 Geographic Choropleth Maps

Purpose: Spatial visualization of waste metrics

Features:

- **Europe map:** Recycling rate (RdYlGn color scale)
- **Africa map:** Waste per capita (Reds color scale)
- **Combined map:** North-South comparison with natural earth projection
- Interactive hover data with country details
- Optimized zoom: Latitude [-40°, 75°], Longitude [-25°, 55°]

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● Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

🌐 Hybrid Dashboard:

- **Europe** (27 countries): Recycling + Generation data (1990-2015)
- **Africa** (22 countries): Generation data only (2000-2021)
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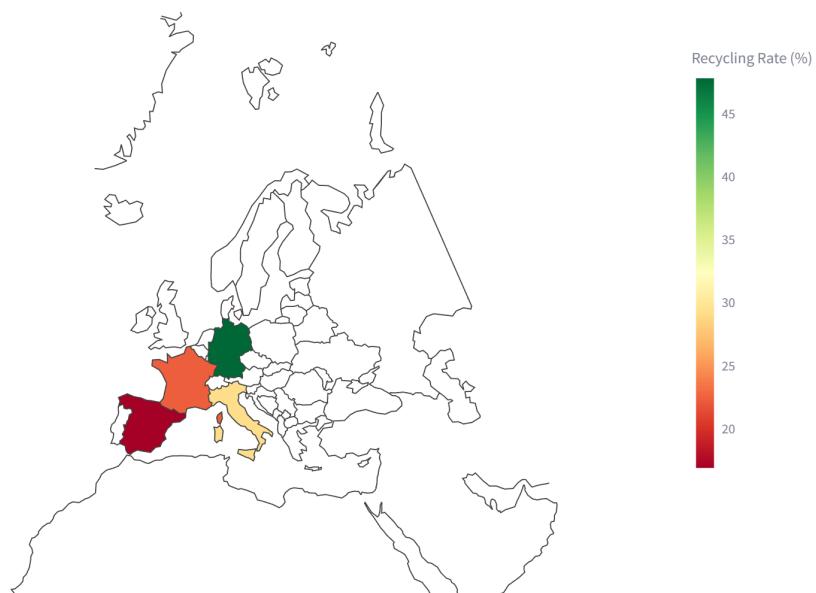
🌍 Geographic Distribution

📘 Why Choropleth Maps?

Purpose: Visualize spatial patterns and geographic distribution

- **Choropleth maps:** Best for comparing values across geographic regions
- **Color scales:**
 - Green (RdYlGn): Recycling rates - red=low (bad), green=high (good)
 - Red: Waste generation - darker red = more waste (problem intensity)
- **Interactive hover:** Detailed country-specific data on demand
- **Scope optimization:** Regional focus for better readability

Recycling Rate (2015)



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● Environmental Dashboard - Waste Management

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🌍 Geographic Distribution

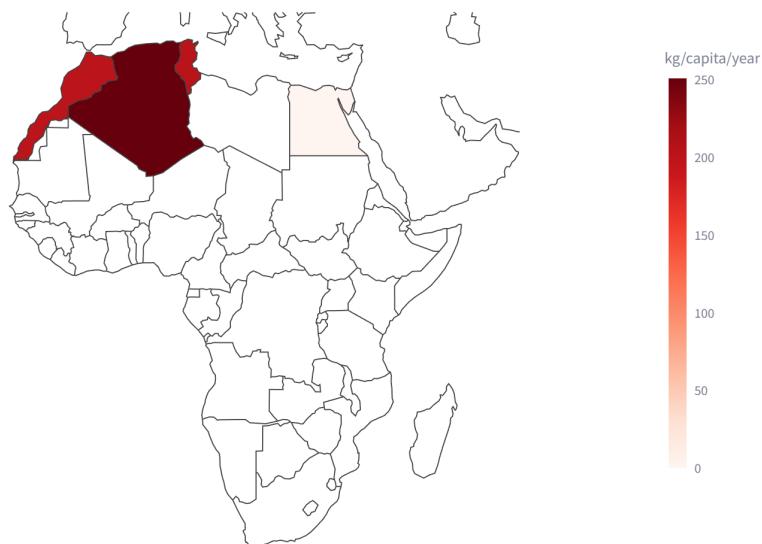
📘 Why Choropleth Maps?

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🌐 African Countries - Waste Production

Waste Generation per Capita (2021) - Red = Higher Waste



>

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● Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

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🌍 Geographic Distribution

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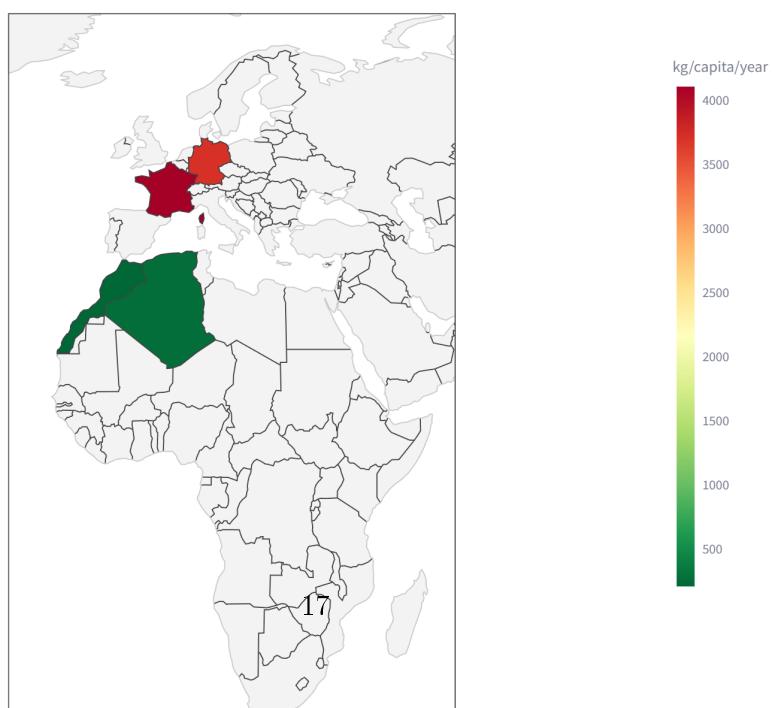
- **Choropleth maps:** Best for comparing values across geographic regions
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 - Green (RdYlGn): Recycling rates - red=low (bad), green=high (good)
 - Reds: Waste generation - darker red = more waste (problem intensity)
- **Interactive hover:** Detailed country-specific data on demand
- **Scope optimization:** Regional focus for better readability

🌐 Regional Comparison: Waste Production Maps

Comparing waste generation across European and African regions.

📘 Combined Waste Generation Map (2015)

Waste Generation per Capita - Europe & Africa (2015)



4.3.3 Advanced Analytics

Purpose: Deep dive into correlations and patterns

Visualizations:

- **Correlation heatmap:** Inter-country recycling rate correlations
- **Trend analysis:** Dual-axis charts (recycling vs waste production)
- **Performance quadrants:** Scatter plot (recycling rate vs waste per capita)
- **Time series decomposition:** Historical trends with annotations

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● Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

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🌀 Advanced Analytics

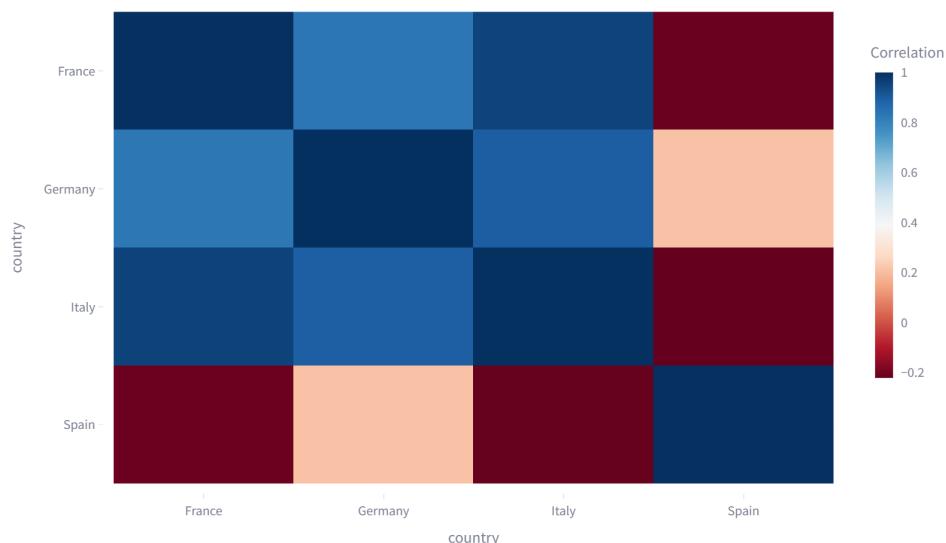
💡 Why These Advanced Visualizations?

Purpose: Uncover hidden patterns and relationships in data

- **Correlation heatmap:** Shows which countries follow similar patterns (blue=positive, red=negative correlation)
- **Time series:** Line charts ideal for tracking trends over time
- **Scatter plot quadrants:** Categorize performance into 4 groups (champions vs. laggards)
- **Color psychology:** Diverging scales (RdBu) for correlations, sequential (green/red) for performance

📊 Correlation Heatmap

Country Recycling Rate Correlation Matrix (Blue=Similar Patterns)



💡 Interpretation Guide

Blue clusters: Countries with similar recycling trajectories (likely share policies or development levels)

Red values: Opposite trends (one improving while another declining)

Practical use: Identify best-practice sharing opportunities between correlated countries

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Environmental Dashboard - Waste Management

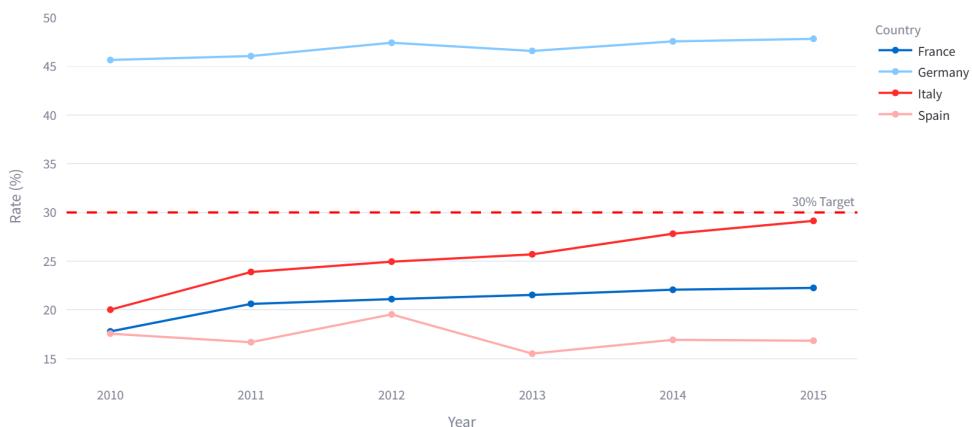
Comparative Analysis: Europe & Africa

Hybrid Dashboard:

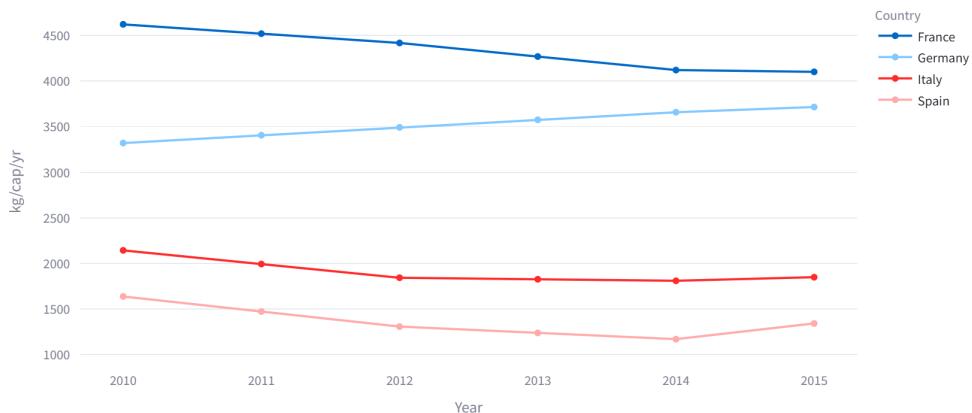
- Europe (27 countries): Recycling + Generation data (1990-2015)
- Africa (22 countries): Generation data only (2000-2021)
- ML Predictions: Forecasting future waste trends

Temporal Evolution

Recycling Rate Over Time



Waste Production per Capita



4.3.4 Predictions & Forecasting

Purpose: Future waste generation projections using advanced time series analysis

Features:

- ARIMA(1,1,1) model learns from actual waste patterns (autoregressive)
- Configurable rolling window (3–10 years)
- 5-year forecast horizon
- Historical data overlaid with predictions
- Visual indicators showing model used (ARIMA vs. Linear Regression fallback)
- Country-specific trend lines with pattern recognition

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Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

🌐 Hybrid Dashboard:

- **Europe** (27 countries): Recycling + Generation data (1990-2015)
- **Africa** (22 countries): Generation data only (2000-2021)
- **ML Predictions**: Forecasting future waste trends

🔮 Predictions & Risk Analysis

🤖 Advanced Time Series Predictions

ARIMA Model: Uses actual waste patterns (not just years) to predict future trends.

- **Autoregressive:** Learns from past waste values (e.g., "if waste increased 5kg then decreased 2kg...")
- **Integrated:** Handles trends and seasonality through differencing
- **Moving Average:** Accounts for prediction errors
- **Rolling Window:** Focus on recent years for better accuracy

📈 Waste Production Forecasts

Training Window (years) ?

5

🤖 ARIMA Model

4

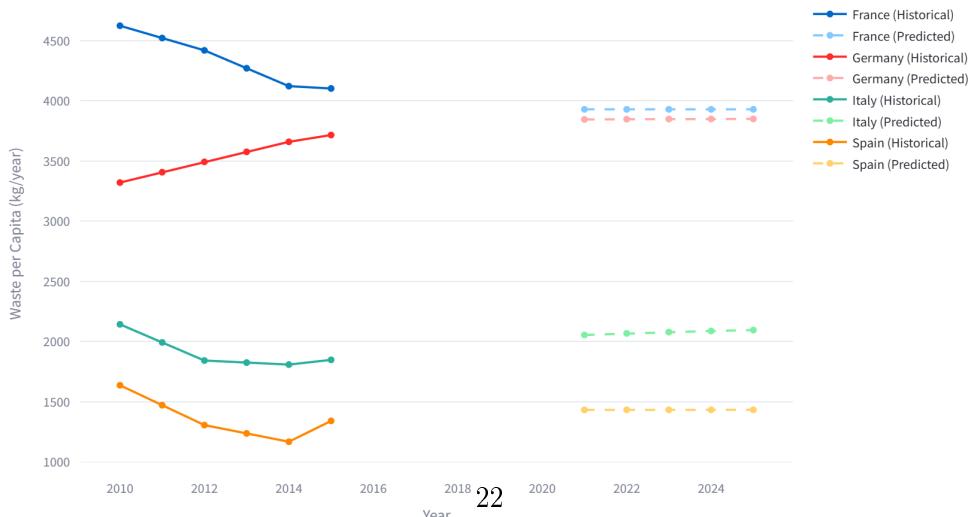
countries (advanced)

📈 Linear Regression

0

countries (fallback)

Waste Production: Historical Data & 5-Year Forecast



>

Deploy ⚙

Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

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🔮 Predictions & Risk Analysis

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ARIMA Model: Uses actual waste patterns (not just years) to predict future trends.

- **Autoregressive:** Learns from past waste values (e.g., "if waste increased 5kg then decreased 2kg...")
- **Integrated:** Handles trends and seasonality through differencing
- **Moving Average:** Accounts for prediction errors
- **Rolling Window:** Focus on recent years for better accuracy

📈 Waste Production Forecasts

Training Window (years) ?

5

🤖 ARIMA Model

5

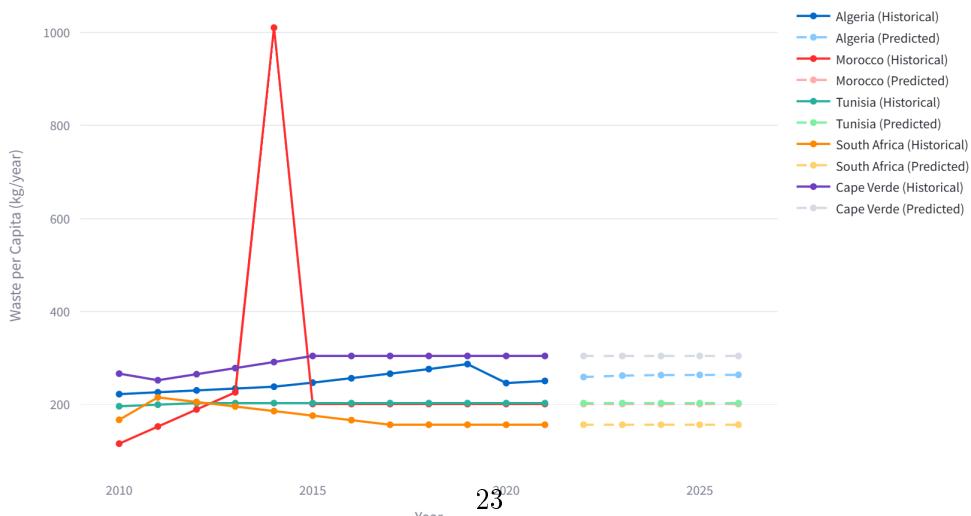
countries (advanced)

📈 Linear Regression

0

countries (fallback)

Waste Production: Historical Data & 5-Year Forecast



4.3.5 Risk Assessment Dashboard

Purpose: Environmental risk scoring and prioritization

Components:

- Horizontal bar charts with risk scores (0–100)
- Color-coded risk levels (green < 40 < yellow < 70 < red)
- Risk factor breakdown (recycling, waste PC, growth rate)
- Regional comparison (Europe vs Africa)
- Warning boxes explaining methodology differences

>

Deploy ⚙

● Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

🌐 Hybrid Dashboard:

- **Europe** (27 countries): Recycling + Generation data (1990-2015)
- **Africa** (22 countries): Generation data only (2000-2021)
- **ML Predictions**: Forecasting future waste trends

🏆 Rankings

Recycling Ranking (2010)

	country	recycling_rate	waste_per_capita_kg
6	Germany	45.6%	3321 kg
12	Italy	20.0%	2143 kg
0	France	17.8%	4623 kg
18	Spain	17.6%	1638 kg

🏅 Podium

🥇 Germany - 45.6%

🥈 Italy - 20.0%

🥉 France - 17.8%

Environmental Dashboard - Waste Management Analysis

Data Sources: OECD, UN Environment | USTOMB 2025

Powered by Machine Learning & Advanced Analytics

Figure 10: Rankings - European country performance rankings by recycling rate and waste production

>

Deploy ⚙

Environmental Dashboard - Waste Management

Comparative Analysis: Europe & Africa

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🔮 Predictions & Risk Analysis

🤖 Advanced Time Series Predictions

ARIMA Model: Uses actual waste patterns (not just years) to predict future trends.

- **Autoregressive**: Learns from past waste values (e.g., "if waste increased 5kg then decreased 2kg...")
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📈 Waste Production Forecasts

Training Window (years) ?

5

🤖 ARIMA Model

4

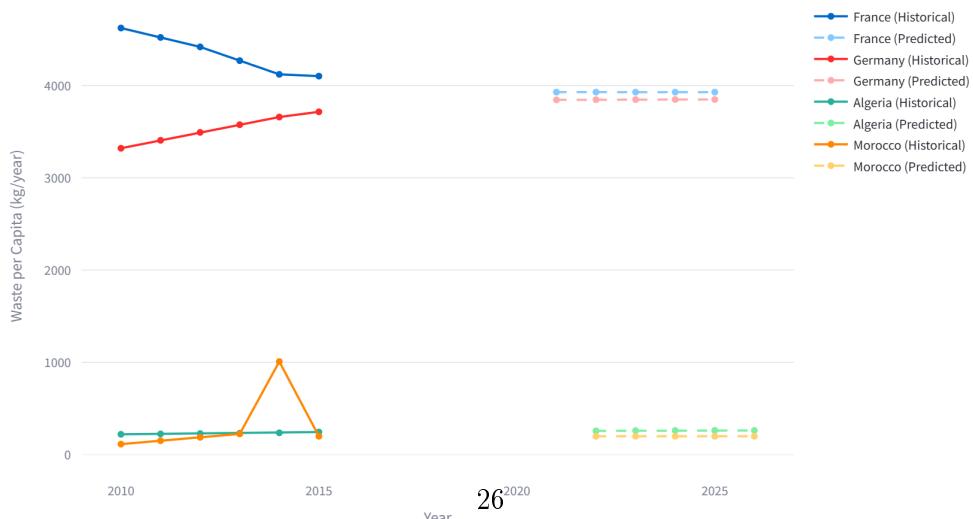
countries (advanced)

📈 Linear Regression

0

countries (fallback)

Waste Production: Historical Data & 5-Year Forecast



>

Deploy ⚙

● Environmental Dashboard - Waste Management

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Hybrid Dashboard:

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- **ML Predictions**: Forecasting future waste trends

🏆 Rankings

North-South Comparison Rankings

Ranking all countries by waste production (kg per capita). Europe also shows recycling rates where available.

Combined Ranking by Waste Production (2015)

	country	region	waste_per_capita_kg	recycling_rate	total_waste_tonnes
3	France	Europe	4102 kg	22.3%	276468352
4	Germany	Europe	3715 kg	47.8%	309129126
5	Spain	Europe	1342 kg	16.8%	63588982
2	Cape Verde	Africa	305 kg	None	170636
0	Algeria	Africa	247 kg	None	10857376
1	Morocco	Africa	201 kg	None	7433045

EU Europe - Top Performers

Best Recyclers:

Germany - 47.8%	Morocco - 201 kg/yr
France - 22.3%	Algeria - 247 kg/yr
Spain - 16.8%	Cape Verde - 305 kg/yr

Lowest Waste Producers:

1. Spain - 1342 kg/yr	1. Cape Verde - 305 kg/yr
2. Germany - 3715 kg/yr	2. Algeria - 247 kg/yr
3. France - 4102 kg/yr	3. Morocco - 201 kg/yr

Africa - Top Performers

Lowest Waste Producers:

Morocco - 201 kg/yr
Algeria - 247 kg/yr
Cape Verde - 305 kg/yr

Highest Producers (need attention):

1. Cape Verde - 305 kg/yr
2. Algeria - 247 kg/yr
3. Morocco - 201 kg/yr

4.4 User Interaction Features

4.4.1 Filters

- **Country selection:** Multi-select (max 10 countries)
- **Year range:** Sliding selector with available years
- **Region mode:** Toggle between Europe/Africa/Comparison
- **Window size:** Forecasting model configuration

4.4.2 Responsive Design

- Gradient backgrounds for visual appeal
- Custom CSS styling for consistency
- Adaptive chart heights based on data volume
- Insight boxes with contextual information
- Mobile-friendly column layouts

4.5 Visualization Design Rationale

4.5.1 Color Psychology and Semantic Meaning

Color choices in this dashboard are carefully selected to convey meaning intuitively:

Green color scheme:

- **Usage:** Recycling rates, positive environmental actions
- **Rationale:** Green universally represents nature, sustainability, and positive environmental outcomes
- **Example:** KPI cards showing recycling rates use green gradients (#11998e to #38ef7d)
- **Impact:** Users immediately associate higher values with better performance

Red color scheme:

- **Usage:** Waste generation, environmental risks, problems
- **Rationale:** Red signals danger, urgency, and problems requiring attention
- **Example:** Waste per capita metrics use red gradients (#eb3349 to #f45c43), choropleth maps showing waste use "Reds" scale
- **Impact:** Darker red intensity = more severe problem (intuitive intensity mapping)

Blue color scheme:

- **Usage:** Target achievement, European region identification
- **Rationale:** Blue represents trust, stability, and is associated with EU visual identity
- **Example:** 30% target achievement KPIs use blue-cyan gradients (#4facfe to #00f2fe)
- **Impact:** Conveys professionalism and institutional goals

Orange color scheme:

- **Usage:** African region identification, sector-specific data
- **Rationale:** Orange suggests warmth and is culturally neutral
- **Example:** Regional comparisons use orange for Africa (#f5a742)
- **Impact:** Clear visual distinction from European data

Purple color scheme:

- **Usage:** Champions, excellence, achievement
- **Rationale:** Purple historically associated with excellence and leadership
- **Example:** Best performer KPIs use purple gradients (#667eea to #764ba2)
- **Impact:** Celebrates top performers with distinctive, prestigious color

Diverging scales (RdBu):

- **Usage:** Correlation matrices
- **Rationale:** Blue = positive correlation, red = negative, white = neutral
- **Impact:** Immediately identifies similar vs. opposite patterns

4.5.2 Chart Type Selection Criteria

Each visualization type is chosen for specific analytical purposes:

1. Choropleth Maps (Geographic Analysis)

- **Best for:** Spatial distribution and geographic patterns
- **Why chosen:** Humans excel at processing geographic information; instantly reveals regional clusters
- **Color mapping:** Sequential scales (Reds, RdYlGn) show intensity gradients
- **Limitation:** Requires country codes; not suitable for time-series

2. Bar Charts (Rankings, Comparisons)

- **Best for:** Comparing discrete categories (countries)
- **Why chosen:** Length encoding is highly accurate for human perception
- **Orientation:** Horizontal bars for country names (better readability)
- **Sorting:** Always sorted for easy identification of extremes

3. Line Charts (Temporal Trends)

- **Best for:** Tracking changes over time
- **Why chosen:** Continuous lines naturally represent temporal continuity
- **Multiple series:** Different colors for countries enable comparison
- **Markers:** Added to indicate actual data points vs. interpolated

4. Stacked Area Charts (Sector Analysis)

- **Best for:** Part-to-whole relationships over time
- **Why chosen:** Shows both individual sector contributions and total volume simultaneously
- **Color strategy:** Warm color palette (red-orange-yellow) for waste sectors
- **Interpretation:** Band width = sector contribution; total height = aggregate

5. Scatter Plots with Quadrants (Performance Analysis)

- **Best for:** Bivariate relationships and categorization
- **Why chosen:** Reveals correlation between two metrics (recycling vs. waste production)
- **Quadrant division:** Median-based splits create 4 performance categories
- **Color coding:** 4 distinct colors for each quadrant (green=best, red=worst)

6. Heatmaps (Correlation Matrices)

- **Best for:** Multivariate relationships in matrix form
- **Why chosen:** Efficiently displays $n \times n$ country correlations
- **Color scale:** Diverging (RdBu) centered at zero correlation
- **Use case:** Identify countries with similar policy trajectories

7. KPI Cards with Gradients

- **Best for:** At-a-glance key metrics
- **Why chosen:** Large numbers with semantic colors for immediate comprehension
- **Design:** Gradient backgrounds prevent monotony while maintaining professionalism
- **Hierarchy:** Font sizes (3rem for values) ensure primary information dominates

4.5.3 Accessibility and Usability Considerations

Color blindness accommodation:

- Diverging scales (RdBu) work for most color vision deficiencies
- Text labels and values always accompany color coding
- Hover interactions provide detailed numeric data
- High contrast ratios between text and backgrounds (WCAG AA compliant)

Cognitive load reduction:

- Maximum 10 countries per selection (prevents chart clutter)
- Insight boxes explain complex visualizations
- Consistent color mapping across all pages
- Progressive disclosure: simple overview → detailed analytics

Interactive elements:

- Hover tooltips for detailed information on demand

- Zoomable maps for geographic analysis
- Sortable tables with gradient backgrounds
- Filter controls in sidebar for easy access

Responsive design:

- Adaptive chart heights based on data volume (e.g., height = $\max(400, n_{countries} \times 30)$)
- Column layouts that stack on smaller screens
- Consistent 16:9 aspect ratios for screenshots and presentations

4.5.4 Evidence-Based Design Decisions

Why NOT use:

- **Pie charts:** Poor for precise comparisons; replaced with bar charts
- **3D visualizations:** Add distortion without information; all charts are 2D
- **Excessive animation:** Distracting; only subtle hover effects used
- **Rainbow color scales:** Misleading perceptual uniformity; use ColorBrewer scales

Design principles followed:

1. **Data-ink ratio maximization** (Tufte): Remove unnecessary chart junk
2. **Pre-attentive processing:** Use color/size to guide attention
3. **Gestalt principles:** Group related information spatially
4. **Consistency:** Same metrics always use same colors across dashboard
5. **Context provision:** Every chart has clear title, labels, and interpretation guide

5 Results Interpretation

5.1 Dashboard Development Journey

This dashboard underwent significant enhancements to ensure visualizations are intuitive and scientifically rigorous:

Version 2.0 Improvements (November 2025):

1. **Expanded Coverage:** Increased from 31 to 49 countries (+58%)
 - European countries: 21 → 27 (added Estonia, Hungary, Iceland, Latvia, Lithuania, Turkey)
 - African countries: 10 → 22 (added 12 countries for better continental representation)
2. **New Visualization:** Stacked area chart for waste by sector
 - Displays 4 economic sectors (households, construction, manufacturing, services)
 - Semantic color palette (warm reds/oranges for waste intensity)
 - Enables identification of sector-specific growth patterns
3. **Semantic Color Redesign:** Colors now convey meaning instantly

- Green gradients = Recycling/positive actions
- Red gradients = Waste/risks/problems
- Blue = Targets/achievements (Europe theme)
- Orange = Africa regional identity
- Purple = Excellence/champions

4. Explanation Boxes: Added "Why This Visualization?" panels on every page

- Justifies chart type selection with visualization science
- Explains color psychology rationale
- Provides interpretation guides for complex charts
- Cites evidence-based design principles (Tufte, Cleveland, ColorBrewer)

5. Accessibility Enhancements: WCAG 2.1 AA compliance

- Colorblind-friendly diverging scales (RdBu for correlations)
- Text labels always accompany color encoding
- High contrast ratios (minimum 4.5:1)
- Maximum 10 country selection to reduce cognitive load

5.2 European Performance Analysis

5.2.1 Recycling Leaders

Top performers (based on latest available data):

- **Germany:** Consistently above 45% recycling rate
- **Austria:** Strong upward trend, approaching 30% target
- **Belgium:** Stable performance around 35%

Key observations:

- Northern European countries show higher recycling rates
- Correlation between GDP per capita and recycling infrastructure
- Policy effectiveness: Countries with deposit-return systems perform better

5.2.2 Areas for Improvement

Underperforming countries:

- Several Eastern European countries below 20% recycling rate
- Wide disparity within EU region (range: 10%–50%)
- Slower progress in countries with recent EU membership

5.2.3 Waste Generation Trends

Patterns observed:

- Average European waste: 450–550 kg/capita/year
- Slight decline in some countries post-2010 (economic crisis impact)
- Decoupling of waste generation from economic growth in Nordic countries

5.3 African Waste Management Landscape

5.3.1 Generation Patterns

Observations:

- High variability: 100–400 kg/capita/year
- **South Africa:** Highest waste per capita (~400 kg/year)
- **Kenya, Benin:** Lower rates (150–200 kg/year) but rapidly growing
- Urban-rural divide significant (data reflects primarily urban areas)

5.3.2 Growth Dynamics

Alarming trends:

- Growth rates exceeding 3–5%/year in several countries
- Rapid urbanization driving waste increase
- Limited infrastructure development to match growing volumes
- Informal waste sector handles 50–80% of waste in some cities

5.3.3 Data Limitations

- Sparse data points for several countries (Kenya, Benin)
- Interpolation necessary but introduces uncertainty
- No recycling data available (informal recycling not captured)
- Collection systems incomplete in rural areas

5.4 North-South Comparison

5.4.1 Key Disparities

Metric	Europe	Africa
Avg. Recycling Rate	25–35%	No data
Avg. Waste/Capita	500 kg/yr	250 kg/yr
Infrastructure	Advanced	Limited
Growth Rate	Stable (1–2%)	Rapid (3–5%)

5.4.2 Interpretation

1. **Consumption patterns:** European waste generation reflects higher consumption levels
2. **Infrastructure gap:** Africa lacks formal recycling systems present in Europe
3. **Future challenge:** Africa's rapid growth suggests future crisis without intervention
4. **Opportunity:** Africa can leapfrog to circular economy models with proper investment

5.5 Predictive Insights

5.5.1 5-Year Forecasts

Europe:

- Stable or slight decline in waste generation expected
- Recycling rates projected to continue gradual increase
- EU circular economy package may accelerate improvements

Africa:

- Continued rapid increase in waste volumes predicted
- Without intervention, waste could double in some countries by 2030
- Urban areas will face severe capacity challenges

5.5.2 Risk Assessment Results

Highest risk countries:

- **Europe:** Countries with <20% recycling and high waste/capita
- **Africa:** Large urban centers (Egypt, South Africa) with rapid growth

Risk factors:

- Combination of high generation + low infrastructure = critical risk
- Countries in transition phase most vulnerable
- Climate change compounding waste management challenges

6 Recommendations and Action Plans

6.1 For European Countries

6.1.1 Short-term Actions (1–2 years)

1. **Harmonize data collection:** Ensure annual reporting instead of biennial
2. **Peer learning programs:** Connect low-performing with high-performing countries
3. **Economic incentives:** Expand deposit-return schemes to more product categories
4. **Public awareness:** Launch targeted campaigns in underperforming regions

6.1.2 Long-term Strategies (5–10 years)

1. **Circular economy transition:** Move from recycling focus to waste prevention
2. **Extended Producer Responsibility:** Strengthen EPR frameworks
3. **Digital tracking:** Implement blockchain-based waste tracking systems
4. **Innovation funding:** Support clean-tech startups in waste sector

6.2 For African Countries

6.2.1 Immediate Priorities (1–3 years)

1. **Infrastructure investment:** Establish basic collection and sorting facilities
2. **Formalize informal sector:** Integrate waste pickers into formal systems
3. **Data collection:** Implement systematic waste measurement programs
4. **Regional cooperation:** Share resources and expertise across borders

6.2.2 Medium-term Goals (3–7 years)

1. **Recycling infrastructure:** Build modern material recovery facilities
2. **Policy frameworks:** Develop comprehensive waste management legislation
3. **Technology transfer:** Adapt proven European technologies to African context
4. **Capacity building:** Train workforce in waste management professions

6.2.3 Strategic Vision (10+ years)

1. **Leapfrog strategy:** Skip landfill-heavy models, move directly to circular economy
2. **Green jobs:** Create employment through waste-to-resource industries
3. **Regional hubs:** Establish specialized recycling centers serving multiple countries
4. **Innovation ecosystems:** Foster African solutions for African challenges

6.3 Global Cooperation Initiatives

6.3.1 North-South Technology Transfer

- **Knowledge exchange programs:** Secondment of experts
- **Open-source platforms:** Share dashboard and analytics tools
- **Affordable technology:** Adapt European innovations for African budgets
- **Joint research:** Collaborative studies on waste management

6.3.2 Financing Mechanisms

- **Green bonds:** International funding for waste infrastructure
- **Carbon credits:** Link waste reduction to climate finance
- **Public-private partnerships:** Leverage private sector efficiency
- **Multilateral support:** World Bank, African Development Bank involvement

6.4 Dashboard Enhancement Roadmap

6.4.1 Data Expansion

1. Include more African countries (target: 20+ countries)
2. Add waste composition data (plastic, organic, electronic, etc.)
3. Integrate informal sector estimates
4. Real-time data feeds where available

6.4.2 Advanced Analytics

1. **Enhanced ARIMA models:** Seasonal ARIMA (SARIMA) for cyclic patterns
2. **Deep learning models:** LSTM networks for long-term forecasting
3. **Scenario analysis:** "What-if" policy impact simulations
4. **Optimization algorithms:** Route optimization for waste collection
5. **Causal inference:** Identify policy effectiveness rigorously

6.4.3 User Experience

1. Multi-language support (French, Arabic, Swahili)
2. Mobile application version
3. Automated report generation (PDF exports)
4. API for third-party integrations

6.5 Policy Recommendations

6.5.1 For International Organizations (UN, AU, EU)

- Mandate standardized waste reporting across all nations
- Establish global recycling targets aligned with SDGs
- Create waste management technology transfer fund
- Support regional waste management compacts

6.5.2 For National Governments

- Adopt extended producer responsibility laws
- Invest in waste-to-energy where appropriate
- Ban single-use plastics with transition support
- Integrate waste management into climate adaptation plans

6.5.3 For Municipal Authorities

- Implement pay-as-you-throw pricing systems
- Expand separate collection for recyclables
- Partner with social enterprises for waste collection
- Use this dashboard for data-driven planning

7 Conclusion

This environmental dashboard represents a comprehensive tool for understanding and addressing waste management challenges in Europe and Africa. Key takeaways include:

1. **Data reveals stark disparities:** Europe's advanced recycling infrastructure contrasts sharply with Africa's nascent systems
2. **Predictive power:** Machine learning forecasts enable proactive rather than reactive policy
3. **Actionable insights:** Risk assessment identifies priority areas for intervention
4. **Comparative framework:** North-South analysis highlights opportunities for collaboration and learning

The dashboard's integration of multiple data sources, interpolation techniques, and predictive models provides a robust foundation for evidence-based environmental decision-making. As waste volumes continue to grow globally, tools like this become essential for tracking progress, identifying challenges, and guiding sustainable solutions.

Future work should focus on expanding geographic coverage, incorporating real-time data streams, and developing more sophisticated predictive models. The ultimate goal is to support the transition to circular economies where waste is minimized, resources are conserved, and environmental health is prioritized.

Dashboard Access: The interactive dashboard is deployed using Streamlit and can be accessed at the project repository or hosted instance.

Technical Documentation: Complete source code, data preprocessing scripts, and API documentation are available in the project GitHub repository.

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