Modelling the Cost of Waste Disposal

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RESOURCE AND ENVIRONMENTAL ECONOMICS

Introduction

Importance of Waste Management:

Rising waste generation poses environmental and health risks.

Efficient practices, like recycling, reduce impact and protect public health.

Vital for ensuring a sustainable and healthy future.

Data Overview

Dataset 1: Regional Averages of Specific Costs per Capita

- The key features include:

- Region, Perc. RD (%), Per Capita RU (kg/inhabitant).
- Detailed Cost Breakdown: CRTab, CTSab, CRDab, CTRab, CSLab, CCab, CKab, Other costs, Total Cost per Capita (CTOTab).
- CRTab: Collection and transportation costs of undifferentiated urban waste.
- CTSab: Treatment and disposal costs of undifferentiated urban waste.
- CRDab: Collection and transportation costs of differentiated urban waste.
- CTRab: Treatment and recycling costs of differentiated urban waste.
- CSLab: Street sweeping and cleaning costs.
- CCab: Common costs.
- CKab: Capital remuneration costs.
- Total Cost per Capita (CTOTab): The overall cost of managing the urban hygiene service per inhabitant.

Regional Averages of Specific Costs per Capita

Regional averages of specific costs per capita, Italian regions - Year 2021 (data referring to the sample of municipalities)

Region	Perc. RD (%)	Per capita RU kg/inhabitant	CRTab	CTSab	CRDab	CTRab	CSLab	CCab	CKab	Other costs	CTOTab
			(Euro/inhabitant*year)								
Piedmont	66.1	503.0	9.29pm	1.26pm	47.35	24.52	18.90	31.50	22.95	5.03	**184.81**
Valle d'Aosta	63.6	653.0	9.52pm	33.80	49.74	22.07	11.44	28.88	44.12	2.50	**214.08**
Lombardy	73.4	479.8	13.60	10.76	36.58	8.16pm	24.40	22.83	13.84	4.75	**146.91**
Trentino Alto Adige	72.6	502.1	20.74	6.18pm	37.22	2.32pm	16.73	11.39pm	9.85	0.29	**140.73**
Veneto	76.2	488.3	3.31pm	16.91	42.38	8.11pm	3.45pm	28.14	19.06	3.37	**160.73**
Friuli Venezia Giulia	68.0	490.1	4.33pm	17.03	35.19	8.55pm	12.53	27.11	4.22pm	5.92	**150.88**
Liguria	55.0	545.2	39.26	42.22	64.85	3.19pm	34.31	50.54	25.08	3.76	**275.20**
Emilia Romagna	72.3	641.0	8.40pm	18.03	62.03	29.87	21.74	27.34	28.87	9.24	**217.53**
Tuscany	64.5	597.2	9.32pm	32.70	64.69	35.78	28.68	31.11	27.01	14.69	**255.98**
Umbria	66.7	523.6	10.67	28.74	46.73	5.20pm	17.61	65.63	29.23	4.93	**220.74**
Marche	71.7	533.6	18.63	15.77	50.69	17.64	21.86	23.96	4.53pm	4.15	**169.22**
Lazio	52.6	512.0	27.41	42.04	61.68	13.92	34.14	29.49	8.51pm	2.38	**231.57**
Abruzzo	63.7	465.7	7.35pm	24.44	50.96	10.45pm	17.71	30.78	15.78	6.83	**188.29**
Molise	59.5	392.5	4.31pm	7.25pm	45.54	10.15am	1.27pm	17.93	10.38	2.38	**135.21**
Campania	53.9	477.5	31.66	34.54	56.94	25.69	26.82	7.38pm	20.92	4.08	**220.03**
Puglia	56.3	488.0	8.17pm	25.85	51.06	8.33pm	28.81	31.32	18.11	4.05	**199.71**
Basilicata	63.8	358.6	34.68	11.14pm	49.31	19.29	14.69	21.02	10.02	1.85	**173.98**
Calabria	52.8	417.8	24.95	42.65	42.71	12.48	8.36pm	24.16	5.34pm	1.54	**186.19**
Sicily	46.7	470.8	31.35	35.37	51.04	14.90	9.60pm	28.73	12.74	2.46	**198.20**
Sardinia	74.9	477.5	17.99	7.20pm	70.06	5.35pm	26.67	26.11	23.85	4.90	**206.13**
Italy	**64.4**	**507.6**	**21.68**	**24.38**	**50.70**	**9.17pm**	**23.82**	**27.88**	**7.50pm**	**4.99**	**194.12**

Dataset 2: National Production » Regional Production

- **Key Features**

- Region
- ISTAT Code
- Population
- Separate Waste Collection (t)
- Municipal Waste (t)
- RD (%) and RD Per Capita (kg/inhabitant/year)

National Production » Regional Production

National production » Regional production: Italy

Summary data

Region	ISTAT	Population	Separate waste collection (t)	Municipal waste (t)	RD (%)	RD per capita (kg/inhabitant year)	RU per capita (kg/inhabitant year)
Piedmont	01	4,252,279	1,404,419.327	2,134,952.770	65.78%	330.27	502.07
Valle d'Aosta	02	123,337	47,550.623	74,241.603	64.05%	385.53	601.94
Lombardy	03	9,965,046	3,484,717,559	4,774,012,380	72.99%	349.69	479.08
Trentino Alto Adige	04	1,077,932	393,951,388	542,791,978	72.58%	365.47	503.55
Veneto	05	4,854,633	1,804,268.050	2,368,469.638	76.18%	371.66	487.88
Friuli Venezia Giulia	06	1,197,295	407,555.803	599,861,893	67.94%	340.40	501.01
Liguria	07	1,507,438	453,907.002	822,293,307	55.20%	301.11	545.49
Emilia Romagna	08	4,431,816	2,050,694.811	2,839,418.250	72.22%	462.72	640.69
Tuscany	09	3,676,285	1,410,412.133	2,199,463,893	64.13%	383.65	598.28
Umbria	10	859,572	298,097.008	445,321,447	66.94%	346.80	518.07
Marche	11	1,489,789	562,713,889	785,640.356	71.62%	377.71	527.35
Lazio	12	5,715,190	1,540,431.919	2,883,852.170	53.42%	269.53	504.59
Abruzzo	13	1,273,660	379,502,813	587,164,591	64.63%	297.96	461.01
Molise	14	290,769	65,971.067	112,195,248	58.80%	226.88	385.86
Campania	15	5,590,681	1,449,468.050	2,652,820.469	54.64%	259.27	474.51
Puglia	16	3,912,166	1,066,312,672	1,864,834.849	57.18%	272.56	476.68
Basilicata	17	539,999	121,229.013	193,214,244	62.74%	224.50	357.80
Calabria	18	1,844,586	402,412,842	758,515,649	53.05%	218.16	411.21
Sicily	19	4,801,468	1,044,148,298	2,224,866.500	46.93%	217.46	463.37
Sardinia	20	1,579,181	559,254,374	746,912,386	74.88%	354.14	472.97

Exploratory Data Analysis (EDA)

```python
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error
from sklearn.preprocessing import StandardScaler

# Data
data = {
    'Region': ['Piedmont', 'Valle d\'Aosta', 'Lombardy', 'Trentino', 'Veneto',
               'Venezia', 'Liguria', 'Emilia R', 'Tuscany', 'Umbria',
               'Marche', 'Lazio', 'Abruzzo', 'Molise', 'Campania', 'Puglia', 'Basilicata',
               'Calabria', 'Sicily', 'Sardinia'],
    'ISTAT': [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20],
    'Population': [4252279, 123337, 9965046, 1077932, 4854633, 1197295, 1507438, 4431816, 3676285, 859572,
                   1489789, 5715190, 1273660, 290769, 5590681, 3912166, 539999, 1844586, 4801468, 1579181],
    'RD(t)': [1404419.327, 47550.623, 3484717.559, 393951.388, 1804268.05, 407555.803, 453907.002, 2050694.811, 1410412.133, 298097.008,
              562713.889, 1540431.919, 379502.813, 65971.067, 1449468.05, 1066312.672, 121229.013, 402412.842, 1044148.298, 559254.374],
    'RU(t)': [2134952.77, 74241.603, 4774012.38, 542791.978, 2368469.638, 599861.893, 822293.307, 2839418.25, 2199463.893, 445321.447,
              785640.356, 2883852.17, 587164.591, 112195.248, 2652820.469, 1864834.849, 193214.244, 758515.649, 2224866.5, 746912.386],
    'RD(%)': [65.78, 64.05, 72.99, 72.58, 76.18, 67.94, 55.20, 72.22, 64.13, 66.94,
              71.62, 53.42, 64.63, 58.80, 54.64, 57.18, 62.74, 53.05, 46.93, 74.88],
    'RD per capita (kg/inhabitant year)': [330.27, 385.53, 349.69, 365.47, 371.66, 340.40, 301.11, 462.72, 383.65, 346.80,
                                           377.71, 269.53, 297.96, 226.88, 259.27, 272.56, 224.50, 218.16, 217.46, 354.14],
    'RU per capita (kg/inhabitant year)': [502.07, 601.94, 479.08, 503.55, 487.88, 501.01, 545.49, 640.69, 598.28, 518.07,
                                           527.35, 504.59, 461.01, 385.86, 474.51, 476.68, 357.80, 411.21, 463.37, 472.97]
}

df_combined = pd.DataFrame(data)
```

Data Analysis
MSW Generation Analysis

Total Waste Calculation:

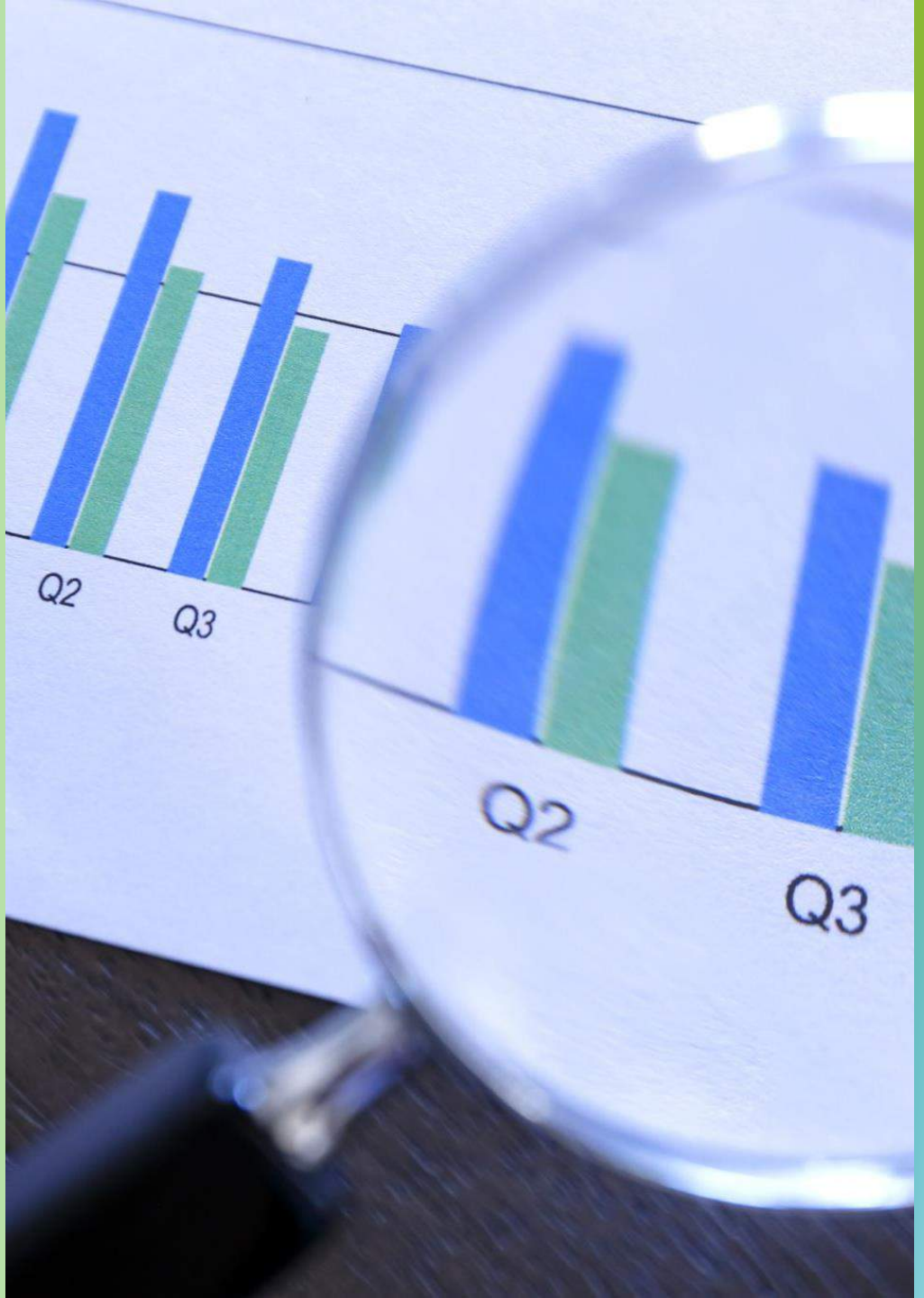
Quantifies municipal solid waste from residential, commercial, and industrial sources.

Recycling Rate Analysis:

Gauges success in sustainability and identifies opportunities for a circular economy.

Per Capita Waste Analysis:

Measures individual contributions to waste generation for tailored strategies.



Linear Regression Model

- **Model Features:**
- Population: The total population of each region.
- RD % (Recyclable Waste Percentage): The percentage of waste that is recyclable.
- RU Per Capita (kg/inhabitant year): The amount of recyclable waste generated per capita.

- We are using a Linear Regression model to understand how population, the percentage of recyclable waste (RD %), and the amount of recyclable waste generated per capita (RU Per Capita) contribute to the total waste generation. These features help us predict the Total Waste per region, providing insights into waste generation patterns.

Model Evaluation

- **Linear Regression Model Performance**
- Training RMSE (Root Mean Squared Error)
- Test RMSE (Root Mean Squared Error)

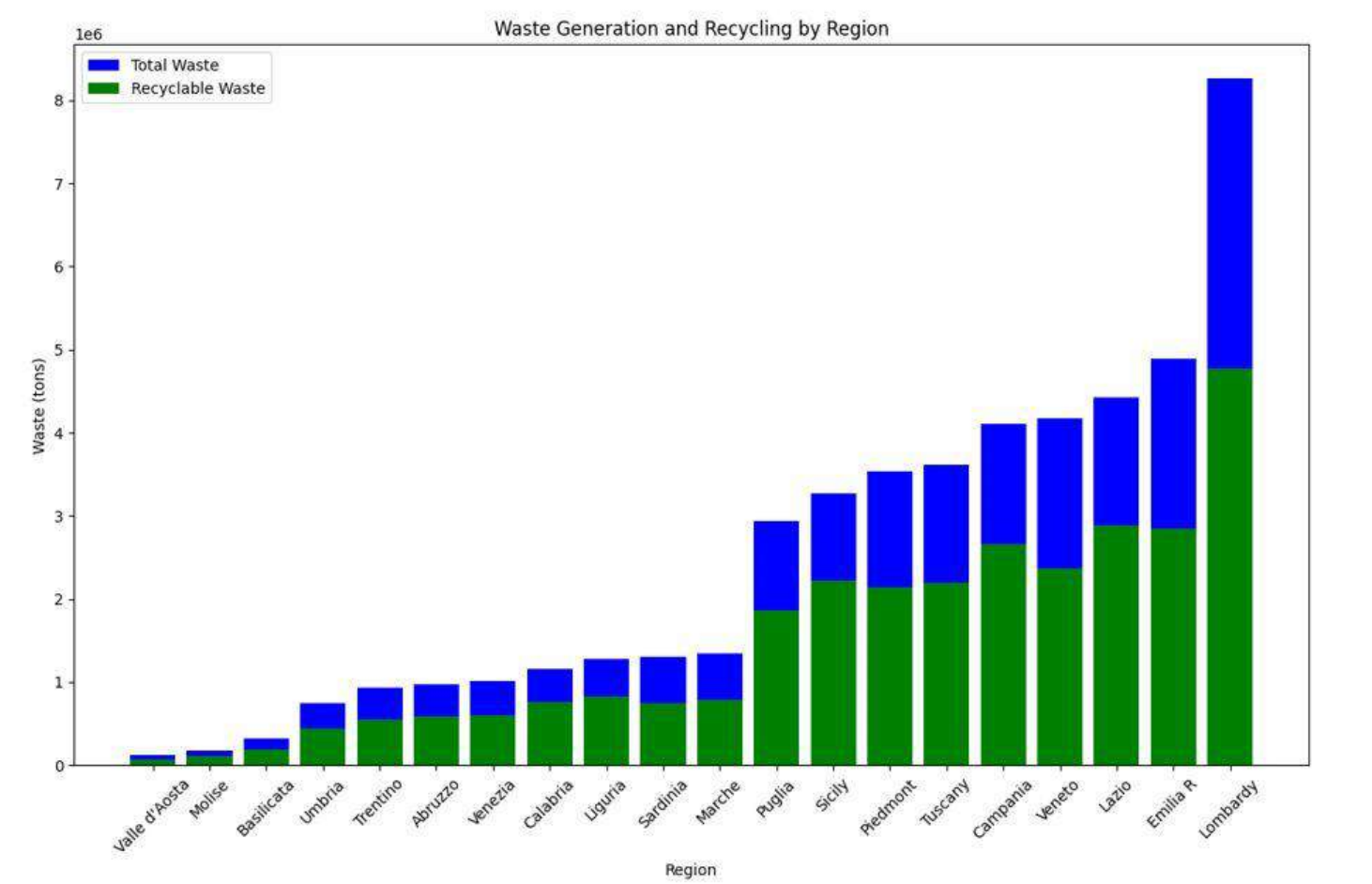
```
# Model Evaluation
train_rmse_combined = mean_squared_error(y_train_combined, y_pred_train_combined, squared=False)
test_rmse_combined = mean_squared_error(y_test_combined, y_pred_test_combined, squared=False)
```

We evaluate the performance of our Linear Regression model using Root Mean Squared Error (RMSE). RMSE measures the average prediction error, providing an indication of how well the model performs on both the training and test datasets. Lower RMSE values indicate better model accuracy.
In our survey we have:
Train RMSE (scaled features): 0.11
Test RMSE (scaled features): 0.12

Visualization Of Model

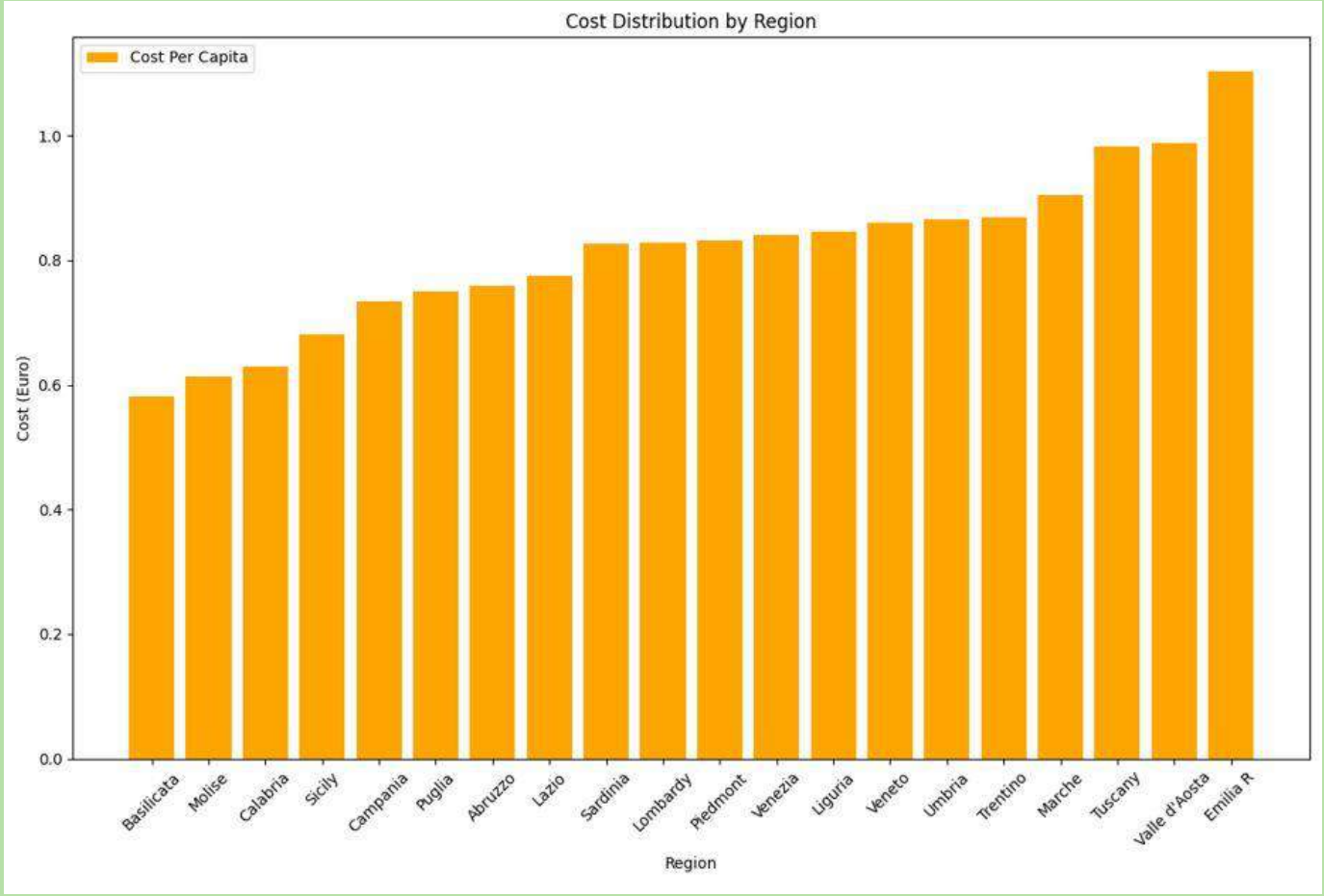
- The visualization includes bar charts illustrating the waste generation and recycling by region, as well as the cost distribution by region.

- **Waste Generation and Recycling by Region:** Bar chart showcasing total waste and recyclable waste by region
- **Visualization Explanation**
- The blue bars represent the total waste generated by each region.
- The green bars represent the recyclable waste within the total waste.
- This visualization helps in understanding the distribution of waste generation and the proportion that is recyclable.



Visualization Of Model

- **Cost Distribution by Region:** Bar chart showcasing cost per capita by region
- **Visualization Explanation**
- The orange bars represent the cost per capita associated with waste disposal in each region.
- This visualization provides insights into the economic aspects of waste management, indicating regions with higher or lower costs per capita.



Waste Generation and Recycling by Region and Cost Distribution by Region

- **Observations:**
- Lombardy and Emilia Romagna exhibit the highest total waste generation, emphasizing their significant contributions to the overall waste output.
- Valle d'Aosta and Molise, on the other hand, demonstrate lower total waste generation, indicating a potential focus on waste reduction strategies in these regions.

- **Observations:**
- Emilia Romagna stands out with the highest cost per capita, underscoring the economic investment in waste management in this region.
- Valle d'Aosta, despite its low waste generation, exhibits a higher cost per capita, suggesting unique challenges or specialized waste disposal methods.
- Regions such as Basilicata and Molise show lower costs per capita, indicating potential efficiencies or differences in waste management practices.

Regional Waste Management Strategies

- **Strengthen Waste Reduction:**
  - Implement robust programs, focusing on high-generation regions.
- **Cross-Regional Collaboration:**
  - Foster knowledge-sharing on successful models, particularly from Valle d'Aosta and Molise.
- **Evaluate High-Cost Investments:**
  - Assess impacts of comprehensive waste management, especially in regions like Emilia Romagna.

Potential Changes and Improvements

- **Targeted Approaches for Challenges:** Develop policies addressing unique challenges in high-cost regions like Valle d'Aosta.
- **Replicate Cost-Efficient Practices:** Implement observed efficient waste management practices from lower-cost regions.
- **Regional Cost Optimization:** Analyze factors influencing expenses in specific regions for targeted improvements.
- **Robust Monitoring:** Implement effective monitoring for continuous improvement, considering regional nuances.
- **Public Awareness Campaigns:** Launch comprehensive campaigns tailored to regional needs for responsible waste disposal.