Urban solid waste generation and GDP per capita: a global analysis through the lens of the environmental Kuznets curve

Geração de resíduos sólidos urbanos e PIB per capita: uma análise global através das lentes da curva de Kuznets ambiental

Generación de residuos sólidos urbanos y PIB per cápita: un análisis global a través de la lente de la curva medioambiental de Kuznets

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ABSTRACT
This study aimed to analyze the relationship between daily per capita solid waste generation and per capita GDP of 192 countries. The ordinary least squares method was employed to test the hypothesis of the Environmental Kuznets Curve. The results suggest an inverted N-shaped relationship between the variables, revealing distinct patterns among the countries analyzed. In the first part of the curve, comprising 164 countries with a per capita GDP of up to $36,191, there is a positive association between per capita GDP and solid waste generation. As the per capita GDP increases, so does the generation of solid waste. In the second part of the curve, 26 countries...
fall within the per capita GDP range of $36,191 to $82,786. In this segment, there is a negative relationship between the variables, indicating that as per capita GDP rises, solid waste generation decreases. Finally, in the third part of the environmental curve, two countries exhibit a per capita GDP above $82,786. In this segment, a positive relationship between solid waste generation and per capita GDP reemerges.

**Keywords:** solid waste, per capita GDP, Kuznets environmental curve.

**RESUMO**
Este estudo teve como objetivo analisar a relação entre a geração diária de resíduos sólidos per capita e o PIB per capita de 192 países. O método dos mínimos quadrados ordinários foi empregado para testar a hipótese da Curva de Kuznets Ambiental. Os resultados sugerem uma relação em forma de N invertido entre as variáveis, revelando padrões distintos entre os países analisados. Na primeira parte da curva, que compreende 164 países com um PIB per capita de até US$ 36.191, há uma associação positiva entre o PIB per capita e a geração de resíduos sólidos. À medida que o PIB per capita aumenta, o mesmo ocorre com a geração de resíduos sólidos. Na segunda parte da curva, 26 países se enquadraram na faixa de PIB per capita de US$ 36.191 a US$ 82.786. Nesse segmento, há uma relação negativa entre as variáveis, indicando que, à medida que o PIB per capita aumenta, a geração de resíduos sólidos diminui. Finalmente, na terceira parte da curva ambiental, dois países apresentam um PIB per capita acima de US$ 82.786. Nesse segmento, surge novamente uma relação positiva entre a geração de resíduos sólidos e o PIB per capita.

**Palavras-chave:** resíduos sólidos, PIB per capita, curva ambiental de Kuznets.

**RESUMEN**
El objetivo de este estudio era analizar la relación entre la generación diaria de residuos sólidos per cápita y el PIB per cápita de 192 países. Se utilizó el método de los mínimos cuadrados ordinarios para comprobar la hipótesis de la Curva de Kuznets Medioambiental. Los resultados sugieren una relación en forma de N invertida entre las variables, revelando patrones distintos entre los países analizados. En la primera parte de la curva, que comprende 164 países con un PIB per cápita de hasta 36.191 dólares, existe una asociación positiva entre el PIB per cápita y la generación de residuos sólidos. A medida que aumenta el PIB per cápita, también lo hace la generación de residuos sólidos. En la segunda parte de la curva, 26 países se sitúan en la franja del PIB per cápita comprendida entre 36.191 y 82.786 dólares. En este segmento, existe una relación negativa entre las variables, lo que indica que a medida que aumenta el PIB per cápita, disminuye la generación de residuos sólidos. Por último, en la tercera parte de la curva medioambiental, dos países tienen un PIB per cápita superior a 82.786 dólares. En este segmento, vuelve a haber una relación positiva entre la generación de residuos sólidos y el PIB per cápita.

**Palabras clave:** residuos sólidos, PIB per cápita, curva medioambiental de Kuznets.
1 INTRODUCTION

According to the What a Waste 2.0 report, approximately 2.01 billion metric tons of urban solid waste (USW) are generated annually worldwide, and it is projected to reach 3.40 billion metric tons by 2050, representing an alarming increase of nearly 70%. The majority of solid waste is currently disposed of in landfills or dumped in open spaces. Globally, open dumping accounts for about 33% of waste, while 19% is recycled or composted, and an additional 11% is incinerated for final disposal (Kaza, Bhada-Tata & Van Woerden, 2018).

In this context, Godecke (2012) highlights that economic development, population growth, urbanization, and technological advancements, accompanied by changes in lifestyle and consumption patterns, directly contribute to a surge in solid waste production. Seara and Gonçalves (2013) emphasize that contemporary society's inclination toward increased use of products with shorter lifecycles and disposable packaging further exacerbates the challenges in solid waste management.

Conversely, Domingues (2021) underscores the role of consumerism in fostering waste generation. Over the past 30 years, global waste production has outpaced population growth by a factor of three, attributed to rising disposable incomes and evolving consumer habits. Additionally, the accelerated pace of technological advancement leads to products designed with planned obsolescence.

Leleux and Kaaij (2018) argue that effectively addressing excessive waste generation and ensuring proper disposal of urban solid waste (USW) pose significant challenges to modern society. Reports from the United Nations and the World Bank reveal that approximately half of all waste is generated by only 30 countries, which coincidentally exhibit high levels of economic development and income.

Given these circumstances, it becomes imperative to examine the relationship between economic development and the generation of urban solid waste on a global scale. Consequently, this study aims to analyze the correlation between economic development and solid waste generation worldwide. The study employs the Environmental Kuznets Curve hypothesis, which suggests an inverted U-shaped or N-shaped relationship between economic development and environmental quality.
LITERATURE REVIEW

2.1 URBAN SOLID WASTE

Urban Solid Waste (USW) primarily consists of waste generated in human settlements in urban areas. It encompasses various types of waste, including commercial, industrial, healthcare, residential, construction, and public cleaning waste.

According to Kaza, Bhada-Tata & Van Woerden (2018), urban waste management is a costly endeavor. In low-income countries, waste management often constitutes the largest portion of local government budgets, accounting for approximately 20%. In middle-income countries, it typically exceeds 10% of municipal budgets, while in high-income countries, it amounts to around 4%. In certain cases, budgetary allocations for waste management can be even higher.

Countries such as the United States, Japan, and those in the European Union possess some of the most intricate waste management systems globally. De Andrade and Ferreira (2011) highlight that these nations employ diverse treatment modalities before resorting to final disposal methods. Recognizing their substantial per capita waste generation, these countries adhere to stringent criteria for final disposal to safeguard their populations from the detrimental effects of pollution. The authors further explain that developed countries adopt a hierarchical approach to urban solid waste management, focusing on waste minimization, promoting reuse, followed by recycling, energy recovery through incineration, and ultimately resorting to sanitary landfill disposal.

Capitalism relies on the consumption of products, goods, and services to drive economic development. However, excessive consumerism can ensnare society. Therefore, it is crucial to differentiate between consumption and consumerism. Consumption refers to the act of purchasing goods aligned with essential needs for survival and well-being, such as water, food, and energy. Consumerism, in contrast, denotes the acquisition of non-essential items.

Due to consumerist tendencies, individuals allocate financial resources to purchase the "advantages" propagated by the media. The cycle of consumption and disposal has become increasingly rapid and repetitive. This phenomenon arises from the constant pursuit of newer products promising ultimate happiness and well-being, as portrayed by advertisements (Kremer, 2007).

According to the author, certain behaviors prevalent in capitalist societies exacerbate environmental problems. Negative actions stemming from unrestrained consumerism and the
consequent generation of waste contribute to detrimental environmental impacts. The production of goods, which increases each year, is driven by society's anthropogenic actions and often fails to acknowledge the potential scarcity of natural resources due to the influence of capital.

Dias (2015) asserts that the exponential growth in production, consumption, and disposal, facilitated by planned obsolescence and the continuous release of new product models, has resulted in an uncontrollable surge in waste generation. Among various waste types, USW stands out due to its close connection to consumption patterns and waste generation, influenced by planned and perceived obsolescence. Efforts aimed at reuse and recycling are implemented as alternatives. Additionally, Pascuas and Rengifo (2021) note that the use and consumption of mobile devices have escalated over time, contributing to the mounting electronic waste issue.

Moreover, according to Dias (2015), consumerism and wastefulness exacerbate USW generation. Magrinho, Didelet, and Semião (2006) observe a significant rise in waste generation linked to per capita material consumption. Unfortunately, this behavior, as indicated by the Intergovernmental Panel on Climate Change (IPCC), portends a pessimistic outlook for the next century. Therefore, comprehending waste generation, modifying consumption levels and behaviors, and implementing effective waste management strategies, in conjunction with basic sanitation policies, assume utmost importance.

2.2 RELATIONSHIP BETWEEN GDP AND URBAN SOLID WASTE GENERATION

The relationship between urban solid waste (USW) generation and Gross Domestic Product (GDP) has been extensively explored in various studies. Godecke (2012) argues that economic and cultural factors, in conjunction with demography, contribute to accelerated environmental degradation. Dantas (2015) suggests that the quantity of urban solid waste produced is not solely determined by the level of economic development or wealth, but also by the values and lifestyle habits of individuals.

Similarly, Khatib (2011) states that solid waste generation increases linearly with GDP, examining countries across low, middle, and high-income levels. Waste compositions also tend to display a prevalent organic component in less developed regions, whereas more developed regions exhibit a lower proportion of organic waste, primarily consisting of materials such as paper, plastic, metal, glass, etc.
Gardiner and Hajek (2017) conducted an analysis of 217 regions in the European Union from 2000 to 2013, utilizing tools such as cointegrated panels and the Granger causality test. Their study aimed to identify the relationship between solid waste generation and GDP. The findings indicated a long-term relationship between the variables.

Similarly, in a study conducted in Medellin between 2000 and 2017, Gonzales, Fernández & Ceballos (2020) observed cointegration between GDP and solid waste generation. The authors demonstrated a certain elasticity between the variables, with waste generation increasing by 0.66% for every 1% increase in GDP. Additionally, the study revealed that Colombia is currently in the growth phase of the Environmental Kuznets Curve.

Senzige et al. (2018) analyzed the city of Dar es Salaam in Tanzania and found that the rate of solid waste generation decreases with a decrease in economic status. The authors also identified a positive correlation between increased solid waste generation and higher GDP. Similarly, Gui, Zhao & Zhang (2019) analyzed 285 Chinese cities between 2006 and 2015, establishing a clear relationship between solid waste generation and GDP.

Troschinetz and Mihelcic (2008) studied 23 developing countries and discovered that factors such as GDP, per capita purchasing power, and the stage of economic development positively influence solid waste generation. As countries progress in their development, the rate of waste generation tends to increase. However, there is a weak correlation between income and waste generation in middle- and high-income countries, with waste generation actually decreasing in wealthier nations.

Likewise, Marder et al. (2018) analyzed 25 regions in the state of Rio Grande do Sul, Brazil, over a one-year period. They found a positive relationship between waste generation and per capita GDP. In the Brazilian state of Minas Gerais, Almeira et al. (2019) also observed a positive correlation between GDP and waste generation in the construction sector.

2.3 KUZNETS ENVIRONMENTAL CURVE

Kuznets (1955) established a relationship primarily addressing the unequal distribution of income and productivity in the form of an inverted U-shaped curve. This concept forms the basis of the original Kuznets Environmental Curve (EKC). Subsequent studies, including Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Panayotou (1993), introduced a revised framework for the Environmental Kuznets Curve (EKC), which employs an
inverted U-shaped curve to depict the theoretical relationship between environmental degradation and income levels. The consistent finding across these studies is that environmental degradation tends to increase in the early stages of economic growth but begins to decline once a certain income threshold is reached, forming the inverted U-shaped curve.

Figure 1 - Kuznets environmental curve

Source: Adapted from Maneejuk et al. (2020)

In Figure 1, it can be observed that during the early stages of economic development, there is an increase in environmental degradation. This is because, in the initial phase of economic growth, the primary focus is on economic expansion, often at the expense of environmental quality, with little consideration for environmental awareness. Concern for the environment becomes more prominent at higher levels of development, driven by structural changes in the industrial and service sectors, increased awareness and implementation of environmental policies, higher technological advancements, and greater environmental investments. Consequently, this leads to a gradual decline in environmental degradation (Dinda, 2004).

Cuaresma et al. (2017) analyzed low-income and middle-income countries to examine the relationship between environmental quality loss and income growth, employing the Environmental Kuznets Curve hypothesis to test this connection. The authors observed that the effect of increasing per capita income significantly impacts environmental quality, particularly during the early stages of economic development. They further explained that the marginal effect of per capita income growth on environmental quality loss is more pronounced in the initial phases of economic development and weakens as economies become more advanced.
Similarly, Liu et al. (2017) established an inverted U-shaped relationship between economic development and environmental quality loss. According to the authors, economic development, measured by per capita GDP, stands as one of the most influential drivers of changes in environmental quality and, consequently, contributes to an increase in environmental degradation.

Despite the Environmental Kuznets Curve hypothesis typically illustrating an inverted U-shaped curve when analyzing the interplay between environmental degradation and economic development, Joshi and Beck (2016) examined the environmental curve in the shape of an "N." The authors discovered that, initially, increased economic development led to a rise in environmental quality loss. However, after reaching a certain threshold of environmental quality loss, a subsequent reduction in the degradation occurred. Additionally, the authors observed a positive relationship reemerging in a third stage after surpassing a specific threshold or inflection point.

3 METHOD

This study is characterized as quantitative, descriptive, and explanatory research. The data were obtained from the World Data Bank (2021a) and World Data Bank (2021b) and analyzed for 217 countries.

Initially, descriptive analysis of the data was conducted, grouping the countries into macro-regions and categorizing them based on income levels (high-income countries, low-income countries, below-average income countries, and above-average income countries), as proposed by the World Bank (2021).

To test the hypothesis of the Environmental Kuznets Curve, the ordinary least squares method was used, following the theoretical model presented in equations 1 and 2.

\[ \text{ResPerCapita}_i = \phi_{0i} + \phi_{1i} \text{GDP}_i + \phi_{2i} \text{GDP}^2_i + \epsilon_i \]  

\[ \text{ResPerCapita}_i = \gamma_{0i} + \gamma_{1i} \text{GDP}_i + \gamma_{2i} \text{GDP}^2_i + \gamma_{3i} \text{GDP}^3_i + \theta_i \]  

Where:
ResPerCapita represents the quantity of solid waste per capita generated daily in each of the analyzed countries. \( y \) and \( \varphi \) are the parameters, GDP is the per capita GDP of each country \( i \), and \( \theta_i \) and \( \varepsilon_i \) are the error terms of the models used to test the inverted U-shaped and N-shaped Environmental Kuznets Curve, respectively (equations 1 and 2). To determine the inflection points, the first derivative and second derivative were calculated as shown in equations (3 and 4).

\[
d_1 = \frac{y_1}{(-2 \times y_2)} \quad 3)
\]

\[
d_2 = \frac{y_2}{(-3 \times y_3)} \quad 4)
\]

Where \( d_1 \) represents the first derivative and \( d_2 \) represents the second derivative of the observed results from equation 2. Both results indicate inflection points (points of minimum and maximum), which aid in the interpretation of the Environmental Kuznets Curve.

4 OBSERVED RESULTS

The generation of urban solid waste is a global problem that affects people worldwide. Inadequate waste management has significant implications for public health and the environment. Mismanaged waste leads to pollution and contamination of oceans, blockage of drainage systems, and increased risk of flooding. Improper disposal of solid waste can also contribute to the spread of diseases through vector breeding and exacerbate respiratory issues caused by airborne particles (Kaza, Bhada-Tata & Van Woerden, 2018). Given the global nature of this problem, its analysis becomes essential.

Table 1: Annual waste production, per capita production, and per capita GDP in the leading waste-producing countries in the world.

<table>
<thead>
<tr>
<th>Country</th>
<th>Population</th>
<th>GDP Per Capita</th>
<th>Waste (tonnes)</th>
<th>Waste Per Capita generated daily (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>205,962,108</td>
<td>10,957.87</td>
<td>79,889,010</td>
<td>1.063</td>
</tr>
<tr>
<td>China</td>
<td>1,371,220,000</td>
<td>6,931.90</td>
<td>210,000,000</td>
<td>0.420</td>
</tr>
<tr>
<td>Germany</td>
<td>81,686,611</td>
<td>46,295.21</td>
<td>51,046,000</td>
<td>1.712</td>
</tr>
<tr>
<td>Indonesia</td>
<td>261,115,456</td>
<td>3,974.73</td>
<td>65,200,000</td>
<td>0.684</td>
</tr>
<tr>
<td>India</td>
<td>1,071,477,855</td>
<td>2,301.66</td>
<td>168,403,240</td>
<td>0.431</td>
</tr>
<tr>
<td>Mexico</td>
<td>125,890,949</td>
<td>10,001.01</td>
<td>53,100,000</td>
<td>1.156</td>
</tr>
<tr>
<td>Russia</td>
<td>143,201,676</td>
<td>11,553.17</td>
<td>60,000,000</td>
<td>1.148</td>
</tr>
<tr>
<td>USA</td>
<td>318,563,456</td>
<td>53,114.47</td>
<td>258,000,000</td>
<td>2.219</td>
</tr>
</tbody>
</table>

Kg = Kilogram; USA: United States of America; Source: Own elaboration
In Table 1, we observe the per capita waste production and per capita GDP of the major solid waste-producing countries in the world. These eight countries (Brazil, China, Germany, Indonesia, India, Mexico, Russia, and the United States) account for 51% of the globally produced solid waste. The table also highlights that highly populous countries like China and India generate less than 0.5 kilograms of waste per capita daily. Conversely, when examining countries with higher per capita GDP values such as the United States and Germany, a greater amount of waste generation per capita is observed (2.2189 and 1.7121 kilograms, respectively), indicating a correlation between income level and solid waste generation.

<table>
<thead>
<tr>
<th>Country</th>
<th>Organic</th>
<th>Glass</th>
<th>Metal</th>
<th>Other</th>
<th>Paper</th>
<th>Plastic</th>
<th>Rubber</th>
<th>Wood</th>
<th>Garden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>51.4</td>
<td>2.4</td>
<td>2.9</td>
<td>16.7</td>
<td>13.1</td>
<td>13.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>China</td>
<td>61.2</td>
<td>2.1</td>
<td>1.1</td>
<td>13.1</td>
<td>9.6</td>
<td>9.8</td>
<td>1.3</td>
<td>1.8</td>
<td>-</td>
</tr>
<tr>
<td>Germany</td>
<td>30.0</td>
<td>10.0</td>
<td>1.4</td>
<td>17.6</td>
<td>24.0</td>
<td>13.0</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Indonesia</td>
<td>53.8</td>
<td>2.5</td>
<td>1.8</td>
<td>13.0</td>
<td>14.9</td>
<td>14.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>India</td>
<td>NA*</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mexico</td>
<td>52.4</td>
<td>5.9</td>
<td>3.4</td>
<td>13.6</td>
<td>13.8</td>
<td>10.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Russia</td>
<td>28.4</td>
<td>16.8</td>
<td>1.8</td>
<td>19.0</td>
<td>19.7</td>
<td>14.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>USA</td>
<td>14.9</td>
<td>4.4</td>
<td>9.0</td>
<td>3.2</td>
<td>26.6</td>
<td>12.9</td>
<td>9.5</td>
<td>6.2</td>
<td>13.3</td>
</tr>
</tbody>
</table>

USA: United States of America; NA = data not available.
Source: own elaboration.

The table 2 highlights the proportion of waste types generated in the eight largest producers of solid urban waste. It can be observed that in countries like Brazil, China, Indonesia, and Mexico, over half of their waste is of organic origin. On the other hand, Germany, Russia, and the United States have less than 30% of this type of waste, but a higher generation of paper waste is observed. However, the analyzed countries show a certain parity in the proportion of plastic disposal, indicating that this type of material is common in the consumption patterns of the populations analyzed.

<table>
<thead>
<tr>
<th>Group of Countries</th>
<th>Total Production (in tons)</th>
<th>Total Population</th>
<th>Per Capita Production generated daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Income Country</td>
<td>693,132,080</td>
<td>1,229,079,077</td>
<td>1.5451</td>
</tr>
<tr>
<td>Low Income Country</td>
<td>94,516,389</td>
<td>632,141,814</td>
<td>0.4096</td>
</tr>
<tr>
<td>Low Meadle Country</td>
<td>437,017,216</td>
<td>2,581,948,080</td>
<td>0.4637</td>
</tr>
<tr>
<td>Upper Meadle Country</td>
<td>620,579,043</td>
<td>2,526,506,151</td>
<td>0.6730</td>
</tr>
</tbody>
</table>

Source: own elaboration.
In Table 3, the daily per capita generation of solid waste is observed, with countries segregated according to their income level. It is noteworthy that the highest amount of solid waste production is found in high-income countries (HIC), driven by the high consumption patterns of their populations, resulting in a daily per capita production of 1.545 kilograms. Conversely, countries with above-average income exhibit a daily per capita production of 0.673 kilograms. In the case of low-income countries (LIC) and below-average income countries (LMC), their daily per capita production is comparable, at 0.409 and 0.463 kilograms, respectively.

### Table 4: Percentage of waste collection and recycling by country, segregated by income level.

<table>
<thead>
<tr>
<th>Group of Countries</th>
<th>% of waste collection</th>
<th>% of recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Income Country</td>
<td>94.56</td>
<td>51.1</td>
</tr>
<tr>
<td>Low Income Country</td>
<td>30.16</td>
<td>14.4</td>
</tr>
<tr>
<td>Low Middle Country</td>
<td>50.93</td>
<td>10.21</td>
</tr>
<tr>
<td>Upper Middle Country</td>
<td>77.94</td>
<td>9.09</td>
</tr>
</tbody>
</table>

Source: own elaboration.

In Table 4, it is evident that there is a significant disparity in the percentage of waste collection between high-income countries (94.56% collection rate) and low-income countries (30.16% collection rate). Likewise, a notable difference can be observed in the percentage of solid waste recycling, with high-income countries leading the way (51.10% recycling rate) compared to the other groups of countries.

### Table 5: Total Waste Production per Year, Per Capita Waste Generation, Percentage of Population Served by Waste Collection, Waste Collection Percentage, and Recycling Percentage in Major Regions Worldwide.

<table>
<thead>
<tr>
<th>Region</th>
<th>Total Annual Waste Production (tons)</th>
<th>Daily Per Capita Waste Generation (kg)</th>
<th>% of Population Served by Collection</th>
<th>Recycling Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin America and the Caribbean</td>
<td>225,712,555</td>
<td>0.99</td>
<td>94.51</td>
<td>4.8</td>
</tr>
<tr>
<td>South Asia</td>
<td>224,293,710</td>
<td>0.41</td>
<td>38.2</td>
<td>5.56</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>149,000,010</td>
<td>0.45</td>
<td>30.69</td>
<td>12.12</td>
</tr>
<tr>
<td>Europe and Central Asia</td>
<td>388,288,037</td>
<td>1.18</td>
<td>78.3</td>
<td>22.5</td>
</tr>
<tr>
<td>Middle East and North Africa</td>
<td>124,158,123</td>
<td>0.8</td>
<td>85.38</td>
<td>10.44</td>
</tr>
<tr>
<td>East Asia and the Pacific</td>
<td>450,607,260</td>
<td>0.55</td>
<td>85.51</td>
<td>19.73</td>
</tr>
<tr>
<td>North America</td>
<td>283,185,034</td>
<td>2.19</td>
<td>99.91</td>
<td>33.35</td>
</tr>
<tr>
<td>World</td>
<td>1,845,244,728</td>
<td>0.73</td>
<td>77.12</td>
<td>17.62</td>
</tr>
</tbody>
</table>

Source: own elaboration.

Observations in Table 5 reveal a significant disparity between North America and other regions concerning per capita solid waste production. The daily per capita waste generation in North America stands at 2.19 kg, surpassing all other regions. In contrast, the macro-regions of
South Asia, Sub-Saharan Africa, and East Asia and the Pacific demonstrate the lowest daily per capita waste production.

Regarding the percentage of the population served by selective solid waste collection, North America exhibits a high collection rate of 99.91%, followed closely by Latin America and the Caribbean with 94.51% coverage. Conversely, South Asia and Sub-Saharan Africa lag behind with percentages of 38.2% and 30.69%, respectively, indicating a lower proportion of the population with access to waste collection.

This research aims to test the Hypothesis of the Environmental Kuznets Curve (EKC) on a global scale. To assess the EKC hypothesis, regression models were employed with the exogenous variable of daily per capita waste generation in each country, along with the endogenous variables of per capita Gross Domestic Product (GDP), per capita GDP squared, and per capita GDP cubed.

Table 6: Standard Error, p-value, and significance of the coefficients in the Ordinary Least Squares regression model for the exogenous variable of daily per capita waste generation in each country and the endogenous variables: GDP per capita, GDP per capita squared, and GDP per capita cubed.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.4247</td>
<td>0.0568</td>
<td>0.0000</td>
<td>***</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>6.3072x10-5</td>
<td>0.0000</td>
<td>0.0000</td>
<td>***</td>
</tr>
<tr>
<td>GDP per capita squared</td>
<td>-8.7137x10-10</td>
<td>0.0000</td>
<td>0.0012</td>
<td>***</td>
</tr>
<tr>
<td>GDP per capita cubed</td>
<td>3.5085x10-15</td>
<td>0.0000</td>
<td>0.0614</td>
<td>*</td>
</tr>
</tbody>
</table>

Legend: * significance at 10%; ** significance at 5%; *** significance at 1%

Source: own elaboration.

Initially, a total of 217 countries were analyzed based on data obtained from the World Data Bank (2021a). However, due to data limitations, 25 countries were excluded from the analysis. As a result, the Hypothesis of the Environmental Kuznets Curve was tested in 192 countries. The inverted U-shaped Environmental Kuznets Curve did not provide consistent results in this study. Instead, the N-shaped Environmental Kuznets Curve was examined, as demonstrated in Equation 2.

Table 6 displays the significance of all regression parameters. The coefficients’ signs indicate an N-shaped relationship. Initially, as economic development increased, per capita waste generation also increased. This trend persisted until reaching the threshold of $36,191 GDP per capita (calculated from the first derivative of the observed results, as shown in Equation 3).

During the first phase of the Kuznets environmental curve, 164 countries were observed, representing 85.41% of the investigated countries and 87.91% of the examined population (6.023
billion people). Collectively, these countries generate 1.29 billion tons of solid waste annually, which translates to an average daily per capita waste production of 0.586 kg.

The research findings suggest that the majority of countries exhibit a consumerist behavior driven by economic growth and increased income. This finding is particularly significant as the increased generation of solid waste contributes to greater environmental degradation. Such degradation has wide-ranging implications, including public health concerns, alterations to ecosystems, and climate change resulting from increased greenhouse gas emissions, particularly methane emissions.

Once the threshold of $36,191 GDP per capita is surpassed, the relationship between the variables becomes negative. As economic development increases, per capita solid waste generation decreases until a certain threshold is reached again ($82,786 GDP per capita, calculated from the second derivative of the observed results, as shown in Equation 4). Beyond this threshold, the relationship becomes positive once more, indicating that as GDP per capita increases, so does per capita solid waste generation.

The second part of the Kuznets Environmental Curve was observed in 26 countries during this study (Andorra, United Arab Emirates, Australia, Austria, Belgium, Canada, Switzerland, Germany, Denmark, Finland, France, United Kingdom, Greenland, Hong Kong, Ireland, Iceland, Japan, Kuwait, Macau, Netherlands, New Zealand, Qatar, Singapore, San Marino, Sweden, and the United States). These countries represent 12.0% of the investigated population (822.3 million people) and account for 28.24% of global waste generation, approximately 521.1 million tons per year. This corresponds to a daily per capita solid waste production of 1.73 kg.

It is important to highlight that, despite the decrease in per capita solid waste generation with increased economic development, it remains significantly higher than the average observed in countries during the first phase of the Environmental Kuznets Curve. In fact, per capita waste generation increases by 196.27% (from 0.586 kg per capita to 1.736 kg per capita generated daily). This result underscores the need for public policies that encourage conscious consumption and reduce solid waste generation in developed countries.

In summary, the results indicate that countries with low or very low income and low or very low economic development, as well as countries with very high income and very high economic development (such as Luxembourg and Norway in this study), exhibit a positive relationship between increased GDP per capita and per capita solid waste generation. This
signifies lower environmental awareness and higher levels of consumerism, contributing to increased environmental degradation.

Conversely, in countries with high GDP per capita (ranging from $36,191 to $82,786), the relationship between increased economic development and income reflects greater environmental awareness and reduced solid waste generation, albeit at higher levels compared to countries with lower income.

The obtained results highlight the importance of economic development and the investment in fostering a culture of conscious consumption, primarily aimed at reducing waste generation and minimizing environmental degradation. Therefore, economic growth is not inherently problematic but rather a potential solution, as long as it is accompanied by conscious consumption and sustainable practices for specific levels of economic development.

5 FINAL REMARKS

This study aimed to investigate the global relationship between urban solid waste generation and development (measured by GDP), using the Environmental Kuznets Curve (EKC) hypothesis as the basis. The findings revealed an N-shaped relationship between environmental degradation (measured by daily per capita solid waste generation) and GDP per capita. The majority of the countries examined (164 countries) were situated in the first phase of the curve (with GDP per capita up to $36,191), indicating that economic growth is associated with an increase in solid waste generation. These countries collectively produce 1.29 billion tons of solid waste annually, equivalent to a daily per capita generation of 0.586 kg.

On the other hand, this study also identified 26 countries (13.54% of the sample) in the second phase of the curve. In these countries, an increase in economic development leads to a decrease in per capita solid waste generation. However, it is important to note that these countries still exhibit a significant production of municipal solid waste, amounting to 521.1 million tons annually, equivalent to a daily per capita generation of 1.73 kg. Lastly, only two countries (Luxembourg and Norway) fall into the third phase of the Environmental Kuznets Curve (with GDP per capita exceeding $82,786), indicating that as GDP per capita increases, so does the generation of municipal solid waste in these countries.

The study highlights the global increase in urban solid waste generation over time, driven by consumerism. Additionally, it sheds light on the waste generation patterns of eight countries.
accounting for approximately half of the total municipal solid waste generation among the 217 regions analyzed. Furthermore, significant disparities in waste collection were observed, with 94.56% of the population in high-income countries having access to waste collection services compared to only 30.16% in low-income countries. These findings underscore the importance of investing in public policies that promote conscious consumption and waste reduction. Moreover, there is a pressing need to invest in waste collection and recycling infrastructure for municipal solid waste on a global scale.
REFERENCES


