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Granger Causality and Kuznets Environmental Curve: An Analysis of the Relationship between Municipal Solid Waste Collection, Per Capita Income and GDP Per Capita in Brazil

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Abstract: *This study analyses the causation relationships between the daily collection of urban solid waste per capita and the GDP per capita of27 Brazilian states from 2008 to 2019. In this period, a two-way causation flow of Granger´s type was observed among the variables. In addition, the Kuznets Environmental Curve Hypothesis was also tested between the average monthly per capita income and the daily collection of solid waste per capita. The results suggest a relationship in the form of inverted N between the variables, denoting a non-linear relationship. It is also concluded that the generation of solid waste increases with the income of the Brazilian middle class (classes B and C, with average monthly revenue per capita between R$8,014.11 and R$ 16,474.51). From 2010, there was also a significant increase in the generation of solid waste per capita, when there was an increase in the average income of the Brazilian population. That year, the Brazilian middle class represented more than half the population.*

Keywords: *urban solid waste, GDP per capita, income per capita, EK Curve, Granger causality.*

1. Introduction

In recent decades society has witnessed numerous technological and economic advances. However, such advances are accompanied by increased consumerist behavior and, consequently, a greater municipal solid waste generation. In this case, Cheng, Shi & Fu(2020) comment that municipal solid waste (MSW) has received great attention at the international level due to its large production volume and enormous environmental threat.

The authors explain that the identification and analysis of the factors that affect the production of MSW have attracted the attention of scholars worldwide and are vital to its management. Emphasis has been given to the effect that the increase in income and economic development has on the production of urban solid waste. In this sense, a critical theory has been used to explain this relationship: the Kuznets Environmental Curve Hypothesis.

In his original study, Kuznets (1955) proposed a relationship that mainly discusses the unequal distribution of income and productivity in the form of an inverted U. From there came the original idea of the Kuznets Environmental Curve Hypothesis, in which the increase in income is related to environmental degradation. Cavalheiro et al. (2020) commented that the Kuznets environmental curve hypothesis aims explicitly for a dynamic change process in which environmental quality decreases as income or economic development increases. On the other hand, in a second moment, a country may present income growth and experience a decrease in environmental impacts after a turning point level (maximum point of the curve, in the shape of an inverted U) of income has been crossed (Liu et al.

(2017); Cuaresma et al. (2017); Ogundari et al. (2017); Murshed et al. (2020);Gentleman et al., (2020);Tenaw & Beyene (2021); Arnaut & Lidman (2021)).

From this point, it is possible to extend the concept of the Kuznets Environmental Curve to the form of N, in which, after a determined income linear (minimum point of the curve, in the form of N), the relationship between income increases and environmental degradation becomes positive (Torras & Boyce (1998); Joshi and Beck (2016)).In this sense, several empirical evidences, at the global level have pointed to the influence of economic growth and income growth causing an increase in the production of municipal solid waste (Berrens et al.(1998); Wang et al. (1998); Raymond (2004); Mazzanti & Zoboli (2008); Mazzanti et al. (2008); Mizzanti & Zoboli (2009); Abrate & Ferraris (2010); Ichinose et al.(2011); Trujillo et al. (2013); Arbulú et al. (2015); Ichinose et al. (2015); Kim et al. (2018); Ercolano et al. (2018); Jaligot & Chenal (2018); Su & Chen (2018); Madden et al.(2019); Barnes (2019); Cheng et al. (2020); Boubellouta & Kusch-Brandt (2020) and Wang, Zhu & Zhang (2021)).

On the other hand, few Brazilian studies investigate the Hypothesis of the Environmental Curve of Kuznets, especially using panel data. In this sense, Eviews (2017) comments that the current literature suggests that a panel-based approach has greater precision power when compared to an approach based on individual time series. Thus, this article seeks to establish a causal flow between solid waste generation in Brazilian states and their GDP (Gross Domestic Product). It is therefore investigated how GDP per capita and average monthly income per capita impact environmental quality and how environmental quality affects these variables, based on the theoretical hypothesis of the Kuznets Curve (EKC).

2. Theoretical Framework

2.1. Municipal Solid Waste and the Environmental Kuznets Curve (EKC)

According to Pacheco and Santos (2022), solid waste has been seen around the world as one of the main problems of today. Economically developed countries face increasingly complex waste in its origin and, therefore, in the problems related to its treatment.

Biage and Almeida (2015) comment that one of the main instruments for analyzing the impacts of economic growth on the environment is the EKC model, which has become a reference to explain the relationship between environmental pollution and economic growth. In its origin, Kuznets (1955) hypothesized that the relationship between GDPs per capita and income inequality occurs as an inverted U-shape. In other words, there is a turning point, i.e., the level of inequality will increase with the growth of GDP per capita to a certain level and then decrease with the further growth of GDP per capita. This hypothesis has been called the Kuznets Curve Hypothesis. It has been used in many fields, such as environmental economics (Grossman & Krueger, 1991), health economics (Costa-Font *et al*., 2018), and other fields of macroeconomics.

In environmental economics, Grossman and Krueger (1991) were the first to confirm the Kuznets Curve Hypothesis for environmental economics. The authors found an inverted U-shaped relationship between indicators of environmental air deterioration (sulfur oxide emissions –SO_2, fine smoke, and suspended particles) and GDP per capita. Avelino (2018) comments that this hypothesis assumes that environmental degradation increases in the early stages of economic growth (development) until it reaches a maximum point. From this inflection point, there is a decrease in degradation as income increases, reaching a more advanced level of economic development.

On the other hand, Panayotou (1993) was the first to use the Kuznets Environmental Curve (Boubellouta & Kusch-Brandt, 2020). The authors used cross-sectional data on deforestation and environmental pollution from 55 developing and developed countries to examine the relationship between environmental degradation and GDP per capita. The authors therefore confirmed the relationship in the inverted U-shape between the variables.

Since then, the environmental literature has used different countries, regions, and variables related to environmental degradation to test the EKC Hypothesis. According to Boubellouta & Kusch-Brandt (2020), international studies can be divided into three categories: air pollution studies, water pollution, and water foot print. To these three categories, we can also add the analysis of the Kuznets

Environmental Curve from the perspective of solid waste emission, especially urban solid waste (Berrens et al.(1998); Wang et al. (1998); Raymond (2004); Mazzanti & Zoboli (2008); Mazzanti et al. (2008); Mizzanti & Zoboli (2009); Abrate & Ferraris (2010); Ichinose et al.(2011); Trujillo et al. (2013); Arbulú et al. (2015); Ichinose et al. (2015); Kim et al. (2018); Ercolano et al. (2018); Jaligot & Chenal (2018); Su & Chen (2018); Madden et al.(2019); Barnes (2019); Cheng et al. (2020); Boubellouta & Kusch-Brandt (2020) and Wang, Zhu & Zhang (2021).

Table1.*EKC studies for Solid Waste.*

Author	Analysis Region	Method	Type of waste	Period	EKC?
Shafik (1994)	39 OECD countries	OLS	Municipal Solid Waste	1960-1990	No
Cole *et al.*, (1997)	13 OECD countries	GLS	Municipal Solid Waste	1975-1990	No
Berrens *et al.*, (1998)	United States	Generalized Range Model	Hazardous waste	1991	Yes
Wang *et al.*, (1998)	United States	Maximum likelihood model	Hazardous waste	1992	Yes
Seppälä *et al.*, (2001)	5 industrial countries	Cochrane-Orcutt Estimate	Municipal Solid Waste	1975-1994	No
Raymond (2004)	128 countries	OLS	Solid waste	2002	Yes
Mazzanti and Zoboli (2005)	15 European countries	Fixed effects and random effects	Municipal Solid Waste	1995-2000	No
Mazzanti (2008)	28 European countries	Fixed effects and random effects	Municipal Solid Waste	1995-2000	No
Mazzanti & Zoboli (2008)	25 European countries	Fixed effects	Municipal Solid Waste	1995-2005	Yes
Mazzanti *et al.*, (2008)	Italy	Pooled OLS	Municipal Solid Waste	1999-2005	Yes
Mizzanti & Zoboli (2009)	25 European countries	Fixed effects and random effects	Municipal Solid Waste	1995-2005	Yes
Managi & Kaneko (2009)	China	GMM Estimator	Solid waste	1992-2003	No
Abrate & Ferraris (2010)	Italy	OLS	Municipal Solid Waste	2004-2006	Yes
Ichinose *et al.*, (2011)	Japan	OLS	Municipal Solid Waste	2000-2006	Yes
Mazzanti *et al.*, (2012)	Italy	Fixed effects	Municipal Solid Waste	1999-2006	No
Trujillo *et al.*, (2013)	Colombia	Grouped OLS	Municipal Solid Waste	2008-2011	Yes
Arbulú *et al.*, (2015)	25 European countries	Grouped OLS	Municipal Solid Waste	1997-2010	Yes
Ichinose *et al.*, (2015)	Japan	GS2LS and GMM	Municipal Solid Waste	2005	Yes
Lee *et al.*, (2016)	United States	VAR model	Municipal Solid Waste	1990-2012	No
Kim *et al.*, (2018)	China	Geographically weighted regression	Industrial solid waste	1995-2010	Yes
Ercolano *et al.*, (2018)	Italy	Fixed effects and GMM	Municipal Solid Waste	2005-2011	Yes
Jaligot & Chenal (2018)	Switzerland	Generalized least squares	Municipal Solid Waste	1996-2015	Yes
Su & Chen (2018)	Taiwan	OLS	Medical waste	2001-2015	Yes
Madden *et al.*, (2019)	Australia	Bundled OLS and GTWR model	Municipal Solid Waste	2011-2015	Yes
Cui *et al.*, (2019)	China	Spatial panel template	Municipal Solid Waste	2006-2015	No

Barnes (2019)	151 countries	OLS	Plastic	2010	Yes
Cheng *et al*., (2020)	China	Difference-in-difference (DID)	Municipal Solid Waste	2003-2016	Yes
Boubellouta & Kusch-Brandt (2020)	28 European countries	Generalized Moments Method (GMM)	Electronic waste	2000-2016	Yes
Wang*et al*., (2021)	China	Tapio elastic decoupling analysis	Municipal Solid Waste	2002-2017	Yes
Bayer *et al*., (2022)	Brazilian municipalities	Fixed effects and random effects	Municipal Solid Waste	2011-2015	Yes

Source: *adapted from Boubellouta & Kusch-Brandt (2020).*

It is observed in Table 1anextensive list of studies in which the EKC Hypothesis is tested from 1994 to 2022.Most studies investigate the hypothesis by testing the relationship of GDP per capita, or per capita income, with municipal solid waste generation. For example, Shafik (1994) demonstrated that the generation of municipal solid waste and carbon emissions increases continuously as the population's income increases. Despite this, the author did not confirm the hypothesis.

In line with Shafik (1994), 9/30 of the studies indicated in Table 1also did not confirm the hypothesis(Shafik (1994);Cole et al. (1997); Seppälä et al.(2001); Mazzanti and Zoboli (2005); Mazzanti (2008); Managi & Kaneko (2009); Mazzanti et al. (2012); Lee et al.(2016); Cui et al. (2019)).Despite opposite evidence, 21/30 studies confirm the EKC Hypothesis. However, the evidence is inconclusive for validating the hypothesis. It is still lacking more evidence to support or refute it. Thus, more research is needed to clarify the possible relationship between solid waste generation and per capita income or GDP per capita in the form of an inverted U, as proposed in theory.

3. Methods

In this research, we used the variables average monthly income per capita obtained through IBGE (2015, 2016, 2017, 2018, 2019a, and 2020). The Gross Domestic Product (GDP) and the Brazilian population were obtained by IPEADATA (2022). The amount of solid waste was obtained through MDR (2022), and the state GDP per capita was obtained through IBGE (2019b). The analyzed period was chosen due to the limited available data about average monthly per capita income and state GDP per capita.

This study is quantitative, explanatory, and causal research with panel data. Zeileis *et al*., (2002) developed an algorithm to evidence the occurrence of structural breaks in the series. Therefore, it was necessary to follow some pre-defined steps to analyze and adjust the econometric models properly. The unit root test was initially performed to verify whether the series were stationary. After that, Pedroni's co-integration test was performed, and then Granger's Causality test was performed. Finally, to test the Hypothesis of the EKC, paired and balanced panels were used, in which the Haussmann test was used to verify the use of Fixed Effects or Random Effects regression between the analyzed variables. After performing the regression, the first and second derivatives were calculated to identify the inflection points in the models. Finally, the ordinary least squares method was used to test the EKC Hypothesis according to the theoretical model shown in equations 1 and 2.

$$WastePerCapita_{i,t} = \phi_{0,i,t} + \phi_{1,i} income_{i,t} + \phi_{2,i,t} income^2{}_{i,t} + \phi_{3,i,t} income^3{}_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$WastePerCapita_{i,t} = \gamma_{0,i,t} + \gamma_{1,i,t} gdp_{i,t} + \gamma_{2,i,t} gdp^2{}_{i,t} + \gamma_{3,i,t} gdp^3{}_{i,t} + \theta_{i,t} \quad (2)$$

Waste Per Capita is the amount of solid waste per capita generated daily in each state analyzed and is the parameter, *income* is the average monthly income per capita in each Brazilian state, and *GDP* is the GDP per capita of each of the states. $\phi_{1,i}$ e $\varepsilon_{i,t}$ are the errors of the models, which served to test the environmental Kuznets curve in the inverted U and N-shaped. The first and second derivatives were calculated to determine the inflection points, as shown in equations (3) and (4). Both results indicate inflection points (minimum and maximum points), which help to interpret the Environmental Kuznets Curve.

$$d_1 = \frac{\phi_1}{(-2 \times \phi_2)} \quad (3)$$

$$d_2 = \frac{\phi_2}{(-3 \times \phi_3)} \quad (4)$$

4. Results and Discussion

This research aimed to test the EKC Hypothesis against solid waste generation per capita and the average monthly income per capita. To this end, a descriptive analysis of the data was initially performed. Table 2 shows the total Brazilian population, the total volume of waste collected annually (in tons), the per capita volume collected daily, the average monthly income per capita, and the GDP per capita from 2003 to 2020.

In Table 2, both the average monthly income per capita and GDP per capita were updated by the IPCA (broad consumer price index), based on the year 2020.It can be observed in Table 2 that the Brazilian population grew by 16.94% in the period, while the total amount of waste collected grew by 187.29%. This result is partially explained by the increase in income that grew by 20.78%, as well as the increase of 41.86% in GDP per capita. In the same period, the percentage of the population assisted by waste collection increased from 88% to 92%.

Table2. *Brazilian population (in millions), total volume of waste collected annually (in tons), per capita volume of waste collected daily, monthly average per capita, and GDP per capita in the period from 2003 to 2020*

Year	Brazilian population (in millions)	Total waste collection (in tons)	Collected (kg/per capita/day)	Average per capita income(in R$)	GDP per capita (in R$)
2003	181,8000	32,276,392	0.4864	1,194.15	25,643.99
2004	184,0000	46,197,558	0.6879	1,179.84	26,435.04
2005	186,1000	38,261,517	0.5633	1,217.05	27,031.13
2006	188,2000	39,233,491	0.5711	1,280.94	27,971.04
2007	190,1000	38,993,837	0.5620	1,329.14	30,428.23
2008	192,0000	44,669,109	0.6374	1,421.00	32,870.05
2009	193,9000	43,264,826	0.6113	1,387.97	33,014.92
2010	195,7000	45,860,488	0.6420	1,373.01	36,539.18
2011	197,5000	59,718,820	0.8284	1,529.57	38,503.07
2012	199,3000	68,251,542	0.9382	1,635.56	39,433.85
2013	201,0000	73,799,426	1.0059	1,682.71	40,936.69
2014	202,8000	73,504,013	0.9930	1,743.31	41,471.76
2015	204,5000	77,997,025	1.0449	1,668.44	40,123.21
2016	206,2000	68,352,700	0.9082	1,517.48	37,576.63
2017	207,8000	73,335,190	0.9669	1,476.59	35,192.81
2018	209,5000	72,189,839	0.9441	1,553.04	38,010.37
2019	211,0000	75,343,227	0.9783	1,568.87	36,686.07
2020	212,6000	92,727,500	1.1950	1,442.38	36,380.43

Table 2 also disclosed a close relationship between the increase in income and economic development and, consequently, the increase in the generation and collection of solid waste in Brazil. There is particular emphasis on the significant increase in total waste generation, which was higher than the increase in population, indicating a significant increase in the generation and collection of waste per capita in Brazil. These results suggest a causal relationship in line with the EKC Hypothesis, as Bayer *et al*., (2022) pointed out. To better elucidate this relationship, we sought to evaluate the occurrence of structural breaks in the time series of the volume of waste per capita collected daily and the average monthly income per capita.

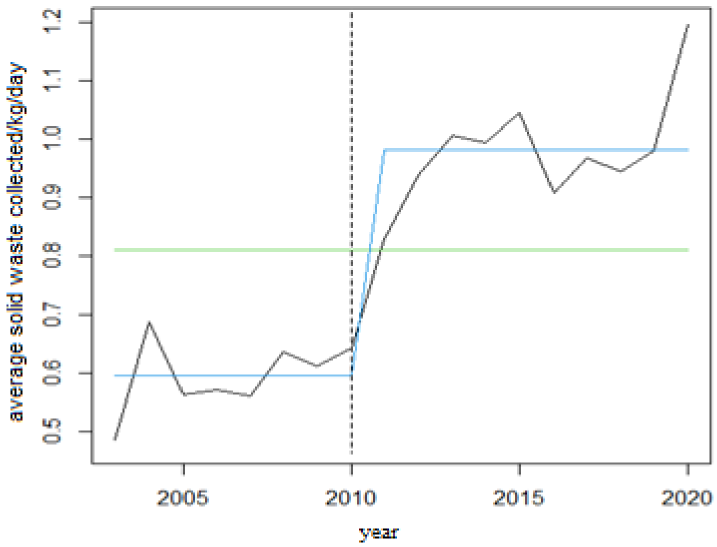

Figure1. S*tructural breaks in the volume of waste per capita collected daily.*

It is observed in the green line of Figure 1 that the *per capita* average of solid waste collected in Brazil throughout the period (2003 to 2020) was close to 0.8 kilograms. Similarly, there was also a structural break that occurred in 2010. Before this structural breakdown, the volume of waste *per capita* collected daily was 0.60 kilograms. After the break, the volume collected in the same period became close to 1.0 kilograms. This structural change dates to a significant increase in the generation and collection of waste after the year 2010. To elucidate the occurrence of this effect, we sought to analyze the structural breakdown of the time series of the average monthly per *capita* income in Brazil.

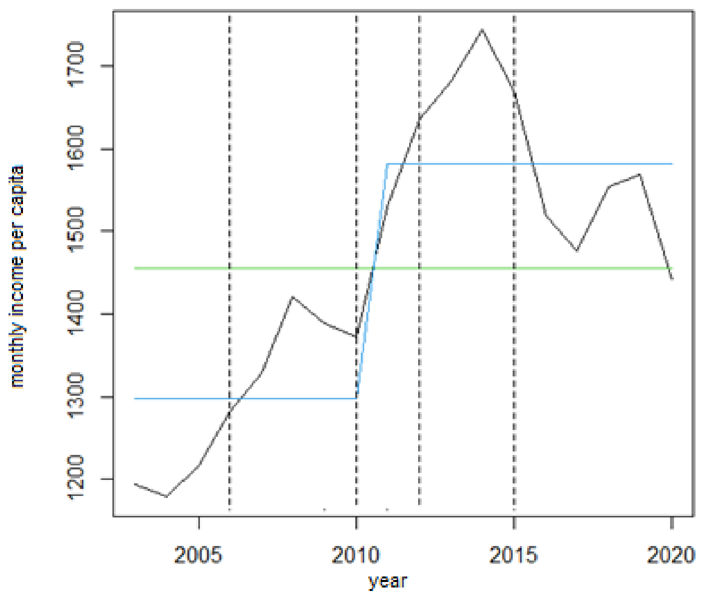

Figure2. *structural breaks in the average monthly income per capita in Brazil (in R$)*

For the elaboration of the structural breakdown test, per capita income updated by the IPCA (broad consumer price index) was used, having as a base period the end of 2020. Figure 2 shows that Brazil's average monthly per capita income throughout the analyzed period (2003 to 2020) was approximately R$ 1,450.00. Analogous to Figure 1, it is observed that the main structural break of the series occurred in 2010; before this break, the monthly income was approximately R$ 1,300.00.

After the main structural breakdown, the average monthly income increased to approximately R$ 1,600.00. From there, it is possible to propose the hypothesis of a possible causal relationship between the variables. To elucidate this eventual relationship, we used the data structure as a data panel, in which the 27 Brazilian federative units (26 states and the Federal District) were investigated from 2008 to 2019. The period was chosen due to the limitation of data availability, both the average monthly income per capita and the GDP per capita of the state.

Using panel data, initially, the Unit Root test was performed. After that, the Pedroni Co-integration test was performed, and finally, the Granger Causality test was performed. In this sense, Eviews (2017) highlights that the literature suggests that unit root tests performed in a data panel have greater power than unit root tests based on individual time series. This research used the unit root test of Levin *et al*., (2002).The results are shown in Table 3.

Table3.*Unit root test for the variables at the level (Lag 0) and in the first difference (Lag1) of the variables: State GDP per capita and volume of waste per capita collected per day (in Kg), from 2008 to 2019 (on an annual basis), 27 federative units, applying the deterministic model without trend and intercept, with intercept and with intercept and with a trend*

Variable	Lag	Trend	Const	None
GDP Per Capita	0	79.467***	65.878	4.384
	1	47.042 ***	97.364	145.113 ***
Volume of Waste per Capita Collected per Day(in Kg)	0	81.588 ***	67.372 ***	40.443 ***
	1	67.272 ***	101.088 ***	214.168 ***

*Legend: * significance of 10%; ** significance of 5%; significance of 1%; Δ variation. None: no trend and no intercept; Const: with intercept; Trend: with intercept and trend.*

It is observed in Table3 that the null hypothesis of the unit root was rejected for the first difference (lag 1) of GDP per capita and of the variable volume of waste collected per capita (in Kg), during the period from 2008 to 2019(on an annual basis), for the three tests of the deterministic models (no trend and no intercept, with intercept and with intercept and with trend).

Considering that the null hypothesis (H0) indicates the presence of a unit root, its rejection indicates that the data shows stationarity. Stationarity is an essential concept for econometrics, which indicates the absence of a trend, and that the variable behaves randomly around the same mean, which is often close to or equal to zero and with the same variance throughout the series. Furthermore, Gujarati & Porter (2011) highlight that the occurrence of stationarity is necessary to perform the co-integration and causality test. Thus, we proceeded with the Pedroni co-integration test using the data in the first difference, as shown in Table 4.

Table4..*Pedroni Co-integration Test for the deterministic model without trend and intercept (None), with intercept (Const) and with intercept and with a trend (Trend) applied to the variables: First D difference (variation) of the State GDP per capita and First Difference (variation) of the per capita Volume of Waste Collected per Day (in Kg), for the period from 2009 to 2019 (on an annual basis), 27 Federative Brazilian States.*

H0	Trend	Const	None
R≤4	-41.814	-12,320.580	-9.460
	***		***
R≤3	-0.212	-0.877	-1.912
			**
R≤2	3.084	-1.692	1.000
		***	
R≤1	-1.913	-6.648	-2.020
	***	***	***
R≤0	-1.870	-13.763	-6.017
	***	***	***

*Legend: * significance of 10%; ** significance of 5%; significance of 1%; None: no trend and no intercept; Const: with intercept; Trend: with intercept and trend*

In Table 4, it is shown that the null hypothesis of the non-existence of co-integration between the variables was rejected. This result denotes a close relationship between the short, medium, and long-term variables. This could suggest the existence of a causal flow of them, as Alexander (2001) proposed. However, according to the author, co-integration is not necessary for the existence of causality, although it is sufficient. Thus, co-integration vectors would denote that the variables are co integrated so that a Granger-type causal flow could occur in the system. To test this hypothesis, the Granger Causality test was calculated, as demonstrated:

Table5. *Granger's Causality Test, with panel data, applied to the variables: First Difference (variation) of State GDP per capita and First Difference (variation) of the per capita Volume of Waste Collected per Day (in Kg) for the period from 2009 to 2019 (on an annual basis) in the 27 Brazilian states.*

Lag	1st Difference (Δ) of GDP per capita of the Brazilian States	1° Difference (Δ) of the Volume per capita of Residues Collected per Day (in Kg)
	DOES NOT GRANGER CAUSE	DOES NOT GRANGER CAUSE
	1° Difference (Δ) of the Volume per capita of Residues Collected per Day (in Kg)	1st Difference (Δ) of GDP per capita from the States
1	11.996	0.049
2	5.579	3.742 ***
3	3.716 ***	4.481
4	2.754***	18.893 ***
5	6.744 ***	2.734 ***
6	3.969 ***	2.860 ***
7	2.962 ***	3.009***

*Legend: * significance of 10%; ** significance of 5%; significance of 1%; Δ% percentage change*

As observed in Table 5, the bi-directional causal relationship between the variables is verified, in which the null hypothesis of non-causality between them was rejected. In this sense, it was found that the null hypothesis that the First Difference (variation) of the State GDP per capita does not cause the First Difference (variation) of the per capita Volume of Waste Collected per Day (in Kg) was rejected. Furthermore, it is observed that the rejection of the null hypothesis occurred in all lags (1 to 7), indicating that the increase in GDP per capita at time t would cause a variation (increase) in the volume of waste produced and collected in the following periods (years 1 to 7).Notably, the impact is persistent and long-term. This result denotes that the increase in wealth and income of the Brazilian population promotes the impulse to consume and, consequently, generate waste.

Similarly, it is observed that the null hypothesis of non-causality between the First Difference (variation) of the per capita Volume of Waste Collected per day (in Kg) and the First Difference (variation) of the GDP per capita from the States (lags 2 to 7) was rejected. This result denotes that the increase in solid waste generation causes a variation (reduction) in GDP per capita. The high expenditure on the collection, treatment, and disposal of solid waste in Brazil partly explains these results. In this sense, Abelpre (2022) estimated that Brazil's collection, transportation, and destination costs were R$ 27.3 billion in 2020. Additionally, 51.49% of Brazilian municipalities have inadequate final disposal of solid waste. The organization explains that this harms 77.5 million people, generating an environmental and health system cost of billionaires of dollars per year.

To better elucidate the relationship between income, wealth, and solid waste generation in Brazil, we sought to test the EKC Hypothesis, as demonstrated in Equations (1 and 2). The results of the regression model with paired and balanced panels are shown in Table 6. The Hausman test was performed to determine the type of regression (with fixed or random effects) in which the null hypothesis was rejected (significance equal to $1.977x10^{-9}$).Rejecting the null hypothesis indicates a correlation between the effects and the regressors. Because of the latter, the estimators of the random effects model will not be consistent. Thus, the regression model with fixed effects was used.

Table6. *Standard error, z-value, p-value, and significance of the coefficients of the regression models with panel data (fixed effects) of the exogenous variable volume per capita of waste collected per day and endogenous variables: per capita income, per capita income square and per capita income cubed, in the period from 2008 to 2019*

Variable	coefficient	Standard error	z	p-value	Sig.
Constant	1.433	0,065	22.030	0.000	***
Monthly income per capita	$- 1.140x10^{-4}$	$1.390x10^{-5}$	-8.181	0.000	***
Monthly income per capita squared	$7.120x10^{-9}$	$9.160x10^{-10}$	- 7.775	0.000	***
Monthly income per capita per cube	$- 1.440x10^{-13}$	$0.001x10^{-20}$	-7.942	0.000	***

Constant	0.990	0.067	-14.850	0.000	***
GDP per capita	- $1.333x10^{-5}$	$6.020x10^{-6}$	-2.214	0.028	**
GDP per capita squared	$4.363x10^{-10}$	$1.520x10^{-10}$	2.860	0.005	***
GDP per capita to the cube	$-4.105x10^{-9}$	$1.58x10^{-9}$	-3.878	0.000	***

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

Table 6 shows the Environmental Kuznets Curve test. It is noteworthy that the inverted U-shaped test was inconsistent in this research. Thus, the EKC was tested in the shape of N, as shown in Equation 1. Table 6 shows that all regression parameters were significant. Furthermore, when observing the sign of the coefficients of both models, a relationship in the form of inverted N was observed in both regressions. That is, initially, as there was an increase in income or economic development, there was a reduction in the generation and collection of waste.

This effect was observed up to the turning point of the average monthly income of R$ 8,014.11 (calculated by the first derivative of the observed results, as shown in Equation 3).After overcoming this income level, the relationship between the variables became positive. Finally, a new inflection point was observed (average monthly income of R$ 16,474.51, calculated by the second derivative, as shown in Equation 4). From then on, the relationship between increased income and solid waste generation became negative again.

The results indicate that consumerist behavior and a greater propensity for solid waste generation occur mainly in the Brazilian middle class (classes B and C, with average monthly income per capita between R$ 8,014.11 and R$ 16,474.51). On the other hand, individuals with lower income (classes C, D, and E, according to the classification established by the Brazilian Institute of Geography and Statistics) are less likely to consume and generate less solid waste per capita. This behavior was also observed in high-income individuals (class A).

These results align with the structural breakdown observed in 2010, a golden year for the Brazilian middle class when they came to represent more than half of the Brazilian population. In this sense, Neri (2010) comments that between 2003 to 2009, more than 29 million Brazilians ascended to the middle class. But unfortunately, this ascension to the middle class harmed the environment, as it significantly boosted consumption and, consequently, the generation of solid waste per capita in Brazil

5. Final Considerations

This research aimed to test the hypothesis of the Kuznets Environmental Curve from the perspective of the average monthly per capita income of the 27 Brazilian states and the State's GDP *per capita*. The average daily collection per capita of municipal solid waste in each of the 27 Brazilian federative units was used as an environmental indicator. As a result, bidirectional causal flows were observed among the variables, indicating that the increase in economic development causes an increase in the generation and collection of waste in Brazil consistently in the short, medium, and long term.

Similarly, it was observed that the increase in the generation and collection of municipal solid waste causes a reduction in GDP *per capita* in the short, medium, and long term. This result is partially explained by the high cost of collection, transportation, and final disposal in Brazil (about R$ 27.3 billion per year) and the high proportion of municipalities (51.49%) with inadequate final disposal of solid waste. Furthermore, inadequate waste disposal exposes 77.5 million Brazilians to environmental and health risks, increasing costs for the public health system.

Although in this research, the hypothesis of the Kuznets Environmental Curve in the inverted U format was not evidenced, it was possible to observe the relations in the form of inverted N. These results imply that, as the income or economic development increased, the per capita generation of municipal solid waste also decreased. However, after a certain income minimum is exceeded (R$ 8,014.11), the relationship between the variables becomes positive; that is, to the extent that there is an increase in income, there is an increase in the generation of solid waste. Finally, overcoming another turning point of average monthly income per capita (R$ 16,474.51), the relationship between the variables becomes negative again. These results suggest that the Brazilian middle class determines the most significant impact on the generation and collection of waste in Brazil (classes B and C, according to the classification established by the Brazilian Institute of Geography and Statistics - IBGE).

In this sense, there was a significant increase in the generation and collection of solid waste in Brazil during the analysis period. Particular emphasis occurred after 2010, in which there was a significant increase from 0.60 kilograms per capita per day to a value close to 1.00 kilograms of solid waste per capita per day. As of this year, this significant increase was influenced primarily by the increase in the average Brazilian income and the insertion of millions of Brazilians in the middle class during the last decades. Therefore, this significant increase in waste generation is mainly related to the consumption pattern of the Brazilian middle class, with an average monthly per capita income between R$ 8,014.11 and R$ 16,474.51.

Besides confirming the non-linear relationship between per capita income and solid waste generation in Brazil, these results confirm the existence of the Kuznets Environmental Curve in the form of inverted N. This means that the generation of solid waste will increase more with the increase in the average income of the Brazilian middle class. This is potentially harmful, as it increases the adverse environmental effects and impacts the health of the Brazilian population. Unfortunately, the latter is not mitigated by Education because there is a lack of investment in this area as a strategy to promote greater environmental awareness, especially of the middle class of the Brazilian population.

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