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INVESTIGATION OF WASTE KUZNETS CURVE HYPOTHESIS IN SELECTED OECD MEMBER EU COUNTRIES: PANEL DATA ANALYSIS

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Abstract

Waste generation and composition are crucial aspects of environmental sustainability. Recently, they have gained attention from researchers due to their close association with social and environmental issues. The objective of this study is to assess the validity of the Waste Kuznets Curve (WKC) hypothesis about urban solid waste production in the top ten countries with the highest urban solid waste generation among the OECD member EU countries. The study analyses the impact of socio-economic control variables on per capita urban solid waste generation. A panel regression model was used for the sample group of countries from 1995 to 2019, and predictions were made. WKC hypothesis, which suggests a negative relationship between per capita urban solid waste generation and per capita real income, was invalid based on the results. Furthermore, the inclusion of control variables such as the Human Development Index, population density, and unemployment rate had a significant impact on the generation of urban solid waste per capita. When the relevant literature is evaluated, it is envisaged that the study will contribute to the very limited literature in which the WKC hypothesis is tested in the model, in which socioeconomic variables are also taken into account, due to the specificity of the current period and the selected country group.

Keywords: Municipal Solid Waste Generation, Economic Growth, Waste Kuznets Curve, Panel Regression.

Jel Codes: O44, Q01, Q53

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1. Introduction

Solid waste production and composition are crucial factors in achieving environmental sustainability, as they can lead to economic, social, and environmental issues. Global industrialization, urbanization, rapid population growth, and changes in consumption patterns driven by economic growth dynamics have resulted in various changes in urban solid waste production and composition (Ozcan et al., 2016; Namlis and Komilis, 2019; Cheng et al., 2020; Gardiner and Hajek, 2020). The rise in population and urbanization has led to a significant increase in the production of solid waste in urban areas. As a result, effective waste management has become increasingly vital. crucial. The focus point of waste management has shifted from prioritizing waste prevention, storage, and incineration to prioritizing the environmental impacts of waste collection, segregation, recycling, and recovery. Circular processes, such as zero waste, reuse, resource efficiency, and productivity, are highlighted as essential indicators of circularity (Hollins et al., 2017).

All the around world, 2.01 billion tons of municipal waste is generated annually and at least 33% of this waste poses environmental safety concerns. The average daily waste generation per capita is 0.74 kilograms. Waste generation per capita varies greatly across countries, ranging from 0.11 kg to 4.54 kg globally, and is influenced by the country's level of national income. For instance, high-income countries, which account for only 16% of the world's population, produce around 34% of the world's waste, equivalent to 683 million tons. It is estimated that global waste will reach 3.40 billion tons by 2050, with a population increase of more than double. In general, there is a positive correlation between waste production and income levels. It is projected that per capita daily waste generation in high-income countries will increase up to 19% by 2050, which is approximately 40% more than in low- and middle-income countries (Kaza et al., 2018). Currently, per capita urban waste generation is still increasing in about one-third of all European Union (EU) member countries. As a result, these member countries are developing various environmental policies to prevent waste production and to control waste management. In the 1990s, waste reduction became the primary purpose of waste management policy in the EU, following the Community Waste Management Strategy (COM (96)399). The Waste Prevention and Management theme in the European Commission's 6th Environmental Action Programme aims to separate waste generation from economic growth and significantly reduce the amount of waste produced (Sokka et al., 2007). To reduce waste production in the EU and ensure its separation from economic growth, the EU Waste Framework Directives (2008) outline a five-step waste hierarchy. This serves as a guiding principle for EU and national waste policies. The hierarchy prioritizes waste prevention, followed by preparation for reuse, then recycling, and finally other recovery and disposal. The waste hierarchy prioritizes waste prevention, followed by reuse, recycling, energy recovery, and disposal, including landfilling (Smol et al., 2020). In 2019, the average daily urban waste generation per capita in the EU was 1.38 kilograms, which is only 0.03 kg lower than the 2000 figure. While the EU has not significantly reduced urban waste generation, it has shifted towards increased recycling. The 2030 Agenda for Sustainable Development (New York, September 2015) highlights the importance of waste prevention and management for sustainable cities through the Sustainable Development Goals (SDG11, SDG12) (European Environment Agency (EEA), 2021). The goals aim to reduce the adverse environmental effects of cities on individuals by promoting waste prevention, reduction, recycling, and reuse by 2030. According to the waste hierarchy, the European Union aims to recycle a minimum of 60% of urban waste by 2030 (UNDP, 2015).

Solid waste quantities and compositions vary not only between countries but also within cities, regions, and households. It is important to note that these variations are not only due to geographical location but also to other factors such as population density and economic status. These variations in waste generation are dependent on key determinants such as individuals' demographic structure, socioeconomic status, income levels, consumption expenditures, lifestyle habits, and development indicators (Beigl et al., 2008; Ozcan et al., 2016; Namlis and Komilis, 2019; Gardiner and Hajek, 2020; Flores et al., 2022). The main driving force behind the increasing waste generation is indicated to be the rise in economic growth. Over the last decade, it has been observed that the amount of solid waste generated is closely associated with economic growth (Sjöström and Östblom, 2010). In the EU, it has been reported that the amount of urban solid waste has steadily increased over the past twenty years (Gardiner and Hajek, 2020: 124). To address the issue of rising waste production, it is recommended that solid waste generation be decomposed from economic growth in the EU (Mazzanti, 2008; Sjöström and Östblom, 2010; Ozcan et al., 2016). Environmental adaptation policies and sustainable development goals also incorporate specific thematic strategies. Although policies have been implemented to decouple solid waste production from economic growth, waste generation continues to increase in most countries. Only a few countries, such as France, Hungary, Japan, and Spain, have managed to separate total waste production from socio-economic developments such as population and economic growth (Sjöström and Östblom, 2010; EEA, 2021).

The Waste Kuznets Curve (WKC) hypothesis attracts great attention in studies examining how economic growth affects the increase in waste quantities and its impact on environmental quality. It provides information on how waste generation may decouple from economic growth after a certain period. The Waste Kuznets Curve hypothesis is based on studies related to the Environmental Kuznets Curve (EKC). The EKC proposes an inverted U-shaped relationship between environmental quality degradation and per capita income (Grossman and Krueger, 1991; Shafik, 1994). The Waste Kuznets Curve tests the existence of an appropriate turning point or balancing point for urban solid waste quantities in selected economies. According to Abrate and Ferraris (2010), Ercolano et al. (2018), and Huang et al. (2021), urban solid waste production will remain stable at its maximum point for a while if there is a turning point and will start decreasing as economic growth continues to increase. The EKC hypothesis explains a non-linear inverted U-shaped pattern where environmental pollution increases at low-income levels but decreases at high-income levels. The assumption is that ongoing economic growth will solve environmental problems in the end (Raymond, 2004; Lieb, 2004). The mechanism behind this non-linear trend in the EKC is explained by several determinants. Firstly, it provides information about the scale effect of the increasing part of the curve. It is assumed that higher inputs used in production lead to a larger output from an economy. However, this assumption may have a negative impact on environmental degradation. Secondly, there can be non-linearity due to the connection between economic development and the structure of an economy. Economies that specialize in advanced production are considered more resource-intensive and polluting compared to those based on subsistence farming. This situation implies a parallel and positive relationship between development and environmental degradation. Population growth, which directly affects the supply of human resources, is a fundamental factor in production. As per Fendoğlu (2021), population growth and economic development have a generally positive relationship, which encourages economic development. This, in turn, leads to an increase in living standards, which may increase solid waste generation. Additionally, when economies shift from the manufacturing sector to services after reaching a certain stage of development, it may contribute a decrease in environmental degradation. This section of the curve describes the decreasing part of the EKC (Ercolano et al., 2018). Consistent with research on the EKC and empirical studies that test the Waste Kuznets Curve (WKC) hypothesis, this study examines the extent to which an increase in economic activity reduces negative environmental impacts and how waste generation responds to changes in income. Empirical research was conducted on the intersection of the Organization for Economic Co-Operation and Development (OECD) and EU member countries that have reached a certain standard. The study focused on the top 10 countries[1] with the highest solid waste production among OECD member EU countries during the examined period (1995–2019). The validity of the WKC based on the EKC was tested, and additional socio-economic control variables were included in the empirical research. The results obtained were used to present findings and policy recommendations.

2. Literature Review

Solid waste generation differentiates among countries in terms of quantity and composition. Empirical studies have been conducted at macro and micro levels to examine global, regional, and urban trends in solid waste production. The following studies do not consider the validity of the Kuznets Curve Hypothesis but do include in explanatory variables that may affect urban solid waste production.

Keser et al. (2012) conducted spatial data analyses on Turkish provinces and found that the unemployment rate and asphalt road ratio in rural areas are important variables influencing urban solid waste production rates in Turkey. Giannakitsidou et al. (2016) investigated the relationship between urban waste production and socio-economic indices for the EU-28 countries using the least squares estimator. The study conducted by Namlis and Komilis (2019) found a positive association between urban solid waste production and income (GDP), the Human Development Index (HDI), and the Social Progress Index (SPI) in 10 European countries from 2008 to 2015. The researchers used principal component analysis and a least squares estimator to determine solid waste generation rates based on gross domestic product, human development index, unemployment rate, and carbon dioxide emissions. The study conducted by Gardiner and Hajek (2020) for The Nomenclature of Territorial Units for Statistics (NUTS-2) EU countries from 2000–2018 found a causal relationship between gross domestic product, human development index, carbon dioxide emissions, and solid waste generation. The unemployment rate was identified as a weak variable. The panel Granger causality method was used separately for old and new EU member countries. Bidirectional causality was found between waste production and both economic growth and research and development intensity. Akay (2021) examined the NUTS-2 regions of Turkey from 2008 to 2016, taking into account the total amount of waste, municipal taxes received, per capita gross domestic product, population, and migration. Logit and probit model estimation methods were used. The study found that municipal taxes did not affect waste production. However, per capita gross domestic product and population size had a positive and significant impact on waste

[1] Luxembourg (692.5 kgs), Denmark (685.5 kgs), Germany (616.6 kgs), Ireland (573.2 kgs), Slovenia (550.9 kgs), Netherlands (527.0 kgs), France (516.0 kgs), Austria (509 kgs), Spain (490.5 kgs), Finland (488.2 kgs).

amount. Additionally, the number of migration received had a statistically significant and negative impact. Sinha et al. (2022) modeled urban solid waste production in the top ten OECD economies with the best recycling practices from 2000 to 2018. The model incorporated explanatory variables such as eco-innovation, environmental tax revenue, governance quality, structural transformation index of the economy, and capital-labor ratio to determine the impact of technological, regulatory, and institutional factors on waste production. The findings suggest that eco-innovation, environmental tax, governance quality, and capital-labor ratio variables are more effective in reducing waste production for the top ten recycling countries. Omekwe and Alagoa (2023) aimed to measure the impact of socio-economic factors such as income, family size, employment status, educational attainment, packaging, and disposal techniques on waste generation. As a result of the study, they found significant differences between regions in parameters such as income, educational attainment, family size, and employment status; the low region had higher income, employment level, and educational attainment, but family size was lower than the medium and high regions.

Studies have been investigated to test the WKC hypothesis at both the country and state/city levels. First, at the country level, Cole et al. (1997) used the panel generalized method of moments (GMM) and least squares estimator methods to examine the relationship between urban solid waste production and per capita income for 13 OECD countries from 1975 to 1990. Their findings indicate that the WKC hypothesis is not supported. In contrast, Baalbaki and Marrouch (2020) examined 33 OECD countries between 1995 and 2012 using the panel fixed effects estimator method. They concluded that the WKC hypothesis was not valid. Conversely, Yılmaz (2020) empirically investigated the existence of a Kuznets curve in terms of urban solid waste production, per capita urban solid waste, and consumption expenditures for 16 OECD countries between 2002 and 2017. Yılmaz (2020) used the panel Generalized Method of Moments (GMM) estimator and found evidence supporting the existence of a U-shaped relationship for OECD countries. Huang et al. (2021) analyzed the relationship between per capita waste generation and per capita income at the global level, examining 11 of the world's largest economies, representing half of the global population, using panel regression. They concluded that the hypothesis was valid in developed economies but not in developing economies. Mazzanti and Zoboli (2005) conducted a panel regression analysis of 15 EU countries for the period 1995–2000 and found no support for the WKC hypothesis. In contrast, Arbulú et al. (2015) used the Panel Generalized Least Squares estimator method to analyze 16 EU countries for the period 1997-2010 and found evidence supporting the validity of the WKC hypothesis. Studies at the state or city level include Mazzanti et al.'s (2009) panel regression model, which emphasized a non-linear U-shaped relationship between solid waste production and per capita value added for 103 Italian regions from 2000 to 2004. Abrate and Ferraris (2010) also used panel regression to investigate the relationship between household waste production and income through the WKC analysis from 2004 to 2006 year with a sample of 547 selected Italian regions. Ichinose, Yamamoto, and Yoshida (2015) tested the validity of the WKC hypothesis for Japan by categorizing urban solid waste using Ordinary Least Squares (OLS), GMM, and Bayesian estimators. Their findings support the validity of the WKC hypothesis for household urban solid waste but not for business waste production. Ercolano et al. (2018) demonstrated a U-shaped relationship between economic development and waste production in the Lombardy region of Italy from 2005 to 2011, providing evidence for the validity of the WKC. Cheng et al. (2020) tested the WKC hypothesis for 258 cities in China at the provincial level from 2003 to 2016 using the stochastic impact by regression on population, affluence, and technology (STIRPAT) model. However, they did not find conclusive evidence supporting the traditional WKC. Although the validity of WKC hypotheses is often undermined by heterogeneous characteristics across countries, studies have shown that the hypothesis is more valid in less heterogeneous state and city studies. This is because waste management laws and practices in states and cities may differ from those at the national level.

This approach differs from the works of Giannakitsidou et al. (2016) and Namlis and Komilis (2019), which did not test the EKC-based WKC hypothesis. This study aims to test the WKC hypothesis based on the Environmental Kuznets Curve (EKC) for the top ten OECD member EU countries with the highest per capita urban solid waste production. To our knowledge, this is the first study conducted on this topic. Examining the WKC hypothesis in these countries is crucial for understanding the relationship between the environment and the economy. Understanding the link between high waste production and economic growth in these countries is expected to provide a strategic perspective for achieving sustainable development goals and designing effective environmental policies. Furthermore, this study considers the potential contributions of evaluating waste management policies and shaping future environmental policies more efficiently.

3. Data Set and Method

The primary objective of this study is to assess the validity of the WKC hypothesis within the framework of the Environmental Kuznets Curve (EKC) for the top ten OECD member EU countries exhibiting the highest per capita urban solid waste production. The research requires conducting an empirical analysis to examine the correlation between per capita urban solid waste production (USWP), per capita real income (PCI) adjusted for inflation to constant prices in 2017, the Human Development Index (HDI), population density (POP) denoted as the number of individuals per square kilometer, and the unemployment rate (UR) for the specified group of countries. The natural logarithm of all variables considered in the model was used. The data selected for analysis are presented in Table 1.

Table 1.

Variables and Explanations

Variable	Indicator	Measurement	Source
Per Capita Municipal Solid Waste	USWP	Kg per person	OECD Environment Database
Per Capita Income (Constant)	PCI	US$ per person	World Bank Indicators
Human Development Index	HDI	Index	United Nations Development Program
Population Density	POP	Population per km²	World Bank Indicators
Unemployment Rate	UR	Annual % rate	World Bank Indicators

Source: Authors

Per capita municipal solid waste denotes the waste generated in urban areas through public, industrial, commercial, and municipal processes that necessitate management for environmental and public health considerations and is discarded by individuals without further use. By the OECD definition, municipal waste encompasses waste collected by municipalities from minor commercial activities, office buildings, schools, and government buildings. This waste is either processed by facilities or disposed of by small businesses. It is important to clarify that mineral waste originating from municipal sewerage networks and construction is excluded from this definition (OECD, 2020). The scope of urban solid waste encompasses waste collected from households, including paper and cardboard, glass, metals, plastics, biodegradable waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, bulky waste, and furniture, including mattresses (Eurostat, 2016). It serves as a robust summary indicator of economic well-being, illustrating the rate of increase in income per capita and measuring the overall economic output (Giannakitsidou et al., 2016). HDI is defined as a metric of average achievement in the fundamental dimensions of human development, encompassing leading a long and healthy life, acquiring education, and maintaining a decent standard of living. The three components of the index include life expectancy at birth, educational attainment based on expected and average years of schooling, and standard of living measured by income adjusted by gross national income per capita using purchasing power parity (UNDP, 2018: 22). This variable has been chosen as a determinant in waste production models by Giannakitsidou et al. (2016) and Namlis and Komilis (2019). The unemployment rate is defined by the World Bank as the proportion of the total labor force that is actively seeking employment but is unable to find it. Incorporating the unemployment rate as a factor influencing solid waste production, Keser et al. (2012) and Namlis and Komilis (2019) have integrated it into their models.

The study conducted a regression analysis, as outlined in Table 1, to examine the Environmental Kuznets Curve hypothesis regarding waste production. This approach follows previous models by Keser et al. (2012), Ercolano et al. (2018), Cheng et al. (2020), and Huang et al. (2021). Table 2 presents the regression equation and the indicators represented by the variables.

Table 2.

Regression Equation and Indicators

$$USWP_{i,t} = \beta_0 + \beta_1 PCI_{i,t} + \beta_2 PCI_{i,t}^2 + \beta_3 HDI_{i,t} + \beta_4 POP_{i,t} + \beta_5 UR_{i,t} + e_{i,t}$$

$USWP_{i,t}$	Dependent variable, representative of per capita municipal waste generation
$PCI_{i,t}$	Independent variable, representative of the economic growth indicator
$HDI_{i,t}$	Independent variable, representative of the indicator based on human development
$POP_{i,t}$	Independent variable, representative of the population density indicator
$UR_{i,t}$	Independent variable, representative of the unemployment rate indicator
β_0	Constant, the intercept term of the equation
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$	Parameters of the equation
$e_{i,t}$	Error term
i, t	Individual and time dimensions of the panel respectively

Source: Authors

The estimated coefficients are β_1 and β_2. If there is an inverted U-shaped relationship between per capita urban solid waste production and per capita real income, consistent with the WKC hypothesis, where $\beta_1 > 0$ and $\beta_2 < 0$, the hypothesis is valid. Conversely, if the situation is reversed, i.e., $\beta_1 < 0$ and $\beta_2 > 0$, the Kuznets Curve hypothesis is not valid, and a non-linear relationship in the form of a U-shape exists (Stern, 2004; Ercolano et al., 2018).

Table 3 demonstrates summary information for the variables examined in the study.

Table 3.

Descriptive Statistics

	USWP	*PCI*	*HDI*	*POP*	*UR*
Mean	6.355	10.773	-0.121	4.728	1.934
Median	6.354	10.743	-0.117	4.668	1.908
Maximum	6.757	11.652	-0.046	6.230	3.262
Minimum	5.890	9.975	-0.236	2.824	0.593
Std. Dev.	0.160	0.327	0.041	0.839	0.491
Skewness	0.277	0.882	-0.426	-0.518	0.288
Kurtosis	3.099	4.198	2.445	3.523	3.132
Jarque-Bera	3.305	47.324	10.771	14.038	3.639
Probability	0.192	0.000***	0.005***	0.001***	0.162

Note: ***, denotes significance at 1%.

Upon examination of the values presented in Table 3, it becomes apparent that the variable with the highest average value is per capita real income. This suggests a higher degree of economic prosperity in the region or a more equitable distribution of income compared to other variables. Conversely, the Human Development Index demonstrates the lowest average value, indicating lower levels of social and human development in the region. A closer look at the standard deviation values reveals that population density exhibits the highest variance. This implies that the distribution of population density in the region is generally heterogeneous and displays greater variability compared to other variables. Conversely, the Human Development Index displays the lowest standard deviation, suggesting that this variable generally maintains a more stable structure. Skewness values indicate that the income distribution in the region is skewed to the right, emphasizing a concentration of higher-income individuals. In contrast, population density is skewed to the left, suggesting a concentration of the population at lower values. Concerning kurtosis, the per capita real income variable demonstrates the highest kurtosis, while the Human Development Index exhibits the lowest kurtosis. The analysis suggests that the income distribution is generally more concentrated, and human development maintains a more stable structure. Furthermore, the results of the normal distribution test reveal that per capita urban waste and the unemployment rate variables exhibit a normal distribution.

Figure 1 *Presents The Correlations For These Variables.*

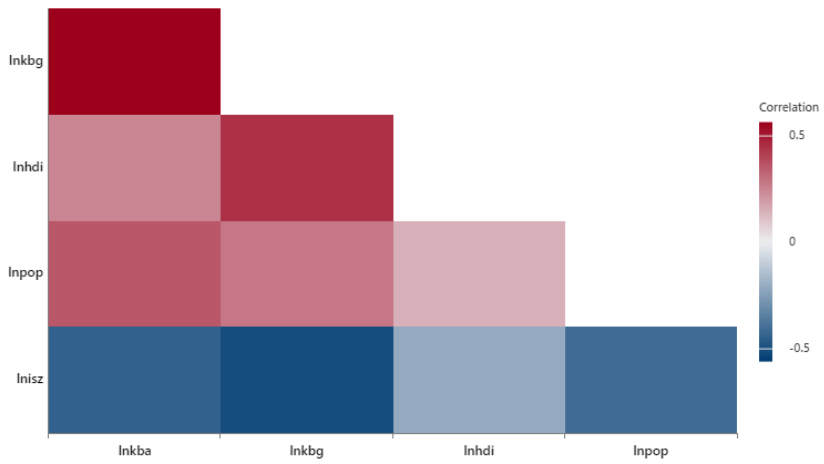

Figure 1.

Correlation Matrix

Upon analyzing Figure 1, a moderately positive correlation is evident between per capita municipal solid waste and per capita real income. This implies that as individuals' real income rises, there is a concurrent increase in the volume of municipal solid waste. In simpler terms, as economic prosperity escalates, there tends to be a corresponding rise in consumption and waste generation. Furthermore, a weak positive association is observed between per capita municipal solid waste and the Human Development Index. Regions with higher levels of municipal waste generally exhibit a somewhat elevated degree of human development. There exists a moderately positive correlation between per capita municipal solid waste and population density. Generally, areas characterized by higher population density tend to generate more municipal waste per capita. Additionally, a moderately negative correlation is identified between per capita municipal solid waste and the unemployment rate. Regions with higher unemployment rates typically experience a decline in per capita municipal waste.

3.1. Empirical Findings

The selection of methods for panel data analysis requires determining cross-sectional dependence and homogeneity as fundamental criteria. It is important to note that all tests for cross-sectional dependence should be marked as subjective evaluations. To test for cross-sectional dependence, the Breusch-Pagan (1980) LM test is used when $T > N$, the Pesaran (2004) scaled LM test is used when $T = N$ and the Pesaran (2004) CD test is used when $T < N$. The Bias-Adjusted test is used when $T > N$ or $N > T$. Technical term abbreviations should be explained when first used. This study focuses on the results of the Breusch-Pagan (1980)

LM test as $T > N$ in the sample. The homogeneity test applies the Delta test developed by Pesaran and Yagamata (2008). The delta (Δ) test is used for large samples, while the corrected delta (Δ_{adj}) test is used for small samples. Given the use of annual data from 1995 to 2020, it is more appropriate to use the corrected delta (Δ_{adj}) test for testing homogeneity. Table 4 presents the results of cross-sectional dependence and delta tests.

Table 4.

Cross-Section Dependence Test and Delta Test Results

		Statistic Value	**Probability**
$USWP$	Breusch-Pagan LM	275.0421	0.000***
	Pesaran scaled LM	23.19447	0.000***
	Bias-corrected scaled LM	22.98614	0.000***
	Pesaran CD	3.842071	0.000***
PCI	Breusch-Pagan LM	999.5213	0.000***
	Pesaran scaled LM	99.56129	0.000***
	Bias-corrected scaled LM	99.35295	0.000***
	Pesaran CD	31.58011	0.000***
HDI	Breusch-Pagan LM	1053.293	0.000***
	Pesaran scaled LM	105.2294	0.000***
	Bias-corrected scaled LM	105.021	0.000***
	Pesaran CD	32.44653	0.000***
POP	Breusch-Pagan LM	878.7548	0.000***
	Pesaran scaled LM	86.83138	0.000***
	Bias-corrected scaled LM	86.62304	0.000***
	Pesaran CD	28.78271	0.000***
UR	Breusch-Pagan LM	264.9336	0.000***
	Pesaran scaled LM	22.12895	0.000***
	Bias-corrected scaled LM	21.92062	0.000***
	Pesaran CD	9.764071	0.000***
	Δ	11.529	0.000***
	Δ_{adj}	13.588	0.000***

Note: ***, denotes significance at 1%.

Table 4 shows that there is cross-sectional dependence among variables in the model, which should not be ignored as it indicates an impact of variables on each other over time. The Delta test results also reveal a heterogeneous structure of the considered variables. Therefore, CIPS unit root tests were used to account for cross-sectional dependence, and the results are reported in Table 5.

Table 5.

CIPS Unit Root Test results

	Level	Difference
$USWP$	-2.56	-3.56***
PCI	-1.893	-2.889**
HDI	-2.127	-2.913**
POP	-1.229	-3.952***
UR	-1.872	-3.301***

Note: The critical values are -3.15, -2.88, and -2.74 at the 1%, 5%, and 10% significance levels, respectively. *** and ** denote significance at 1% and %5, respectively.

Based on the CIPS test results, it has been determined that the variables are stationary in the first difference. This indicates that an appropriate model can be established for the panel data analysis and that the analysis can produce reliable results.

In panel data analysis, the appropriate model selection is determined by various statistical tests. Firstly, the F-test is applied to determine whether to use the pooled ordinary least squares (POLS) or the fixed effects model. Secondly, the Likelihood Ratio (LR) test is used to choose between the classical model and the random effects model. Finally, the Hausman test is used to choose between random and fixed effects models, evaluating whether the model provides more reliable predictions based on a specific structure (Yerdelen Tatoğlu, 2018). These tests are critical tools for determining the appropriateness of the model used in the panel data analysis process and increasing the reliability of the obtained results.

The test results conducted to determine the most suitable panel model for the data are presented in Table 6.

Table 6.

Test Statistics for Model Selection

Models	Tests	Stats.	Results
Classical Model vs. Fixed Effect Model	F Test	34.19 (0.000)***	Fixed Effect Model Acceptance
Classical Model vs. Random Effect Model	LM Test	157.31 (0.000)***	Random Effect Model Acceptance
Random Effect Model vs. Fixed Effect Model	Hausman Test	8.45 (0.133)	Random Effect Model Acceptance

Note: ***, denotes significance at 1%.

Based on the results presented in Table 6, the random effects panel data model was selected as the preferred option. The statistical tests and probability values suggest that this model is a better fit than the others.

Panel data models make assumptions about heteroscedasticity, autocorrelation, and correlation between units for the error term (multicollinearity). Heteroscedasticity refers to the situation where error terms have different variances across units. If the error term variances are not homogeneous, meaning they alter across units, a heteroscedasticity problem arises. This situation can give rise to inefficient or misleading statistical estimates. In this study, we tested the assumption of heteroscedasticity using the Levene (1960) and Brown and Forsythe (1974) tests. Autocorrelation represents the correlation between error terms. If there is a significant correlation between error terms over time, an autocorrelation problem may occur. This can cause to inefficiencies in estimating regression coefficients and biased prediction errors. To test the autocorrelation assumption, statistical tests such as the Durbin-Watson test can be used. The study tested the autocorrelation assumption using the Durbin-Watson test by Bhargava et al. (1982) and the Baltagi-Wu (1999) test. Cross-sectional correlation takes places when there is a correlation between the error terms of different units in a panel data set. If this correlation exists, the model can be misleading if the relationship between units is ignored. To test the existence of cross-sectional correlation, the Pesaran (2004) test was used.

Table 7 shows the results of the tests conducted for different variances, cross-sectional dependence, and autocorrelation assumptions.

Table 7.

Testing of Assumptions

Assumptions	Tests	Stats.
	W0	11.377 (0.000)***
Heteroscedasticity	W50	9.331 (0.000)***
	W10	11.143 (0.000)***
Autocorrelation	Bhargava et al. (1982) Durbin Watson Test	0.3009
	Baltagi Wu (1999) Test	0.484
Cross-Section Dependence	Pesaran (2004) Test	2.316 (0.02)**

Note: *** and ** denote significance at 1% and %5, respectively.

Table 7 shows that assumptions related to heteroscedasticity, autocorrelation, and cross-sectional dependence have been detected. These issues, particularly in the presence of heteroscedasticity and autocorrelation, suggest that the estimates may be inconsistent. To address these issues, standard errors must be corrected. To correct standard errors, you can use robust standard errors or, if possible, correct the estimates with an appropriate method.

It is important to test the assumption that there is zero correlation between unit effects and explanatory variables ($H_0: corr(u_i, X) = 0$) in the random effects model. It is crucial to use precise technical terms and maintain a formal register throughout the text. If this assumption is not met, the estimator of random effects, β_{GEKK}, is neither unbiased nor consistent. Therefore, selecting the appropriate estimator is crucial when assuming that the effects are random. In random effects models, it is assumed that there is no relationship between the unobservable effect and the explanatory variables. The presence of β_0 in the random effect assumption leads to a correlation between the residuals of the same cross-sectional units (Hsiao, 2003). Thus, the Generalized Least Squares (GLS) method was chosen as the most appropriate estimator for this study.

Table 8 shows the results obtained using the GLS estimator:

Table 8.

Generalized Least Squares Estimation Results

Dependent Variable: $USWP$	**Coefficient**	**Standard Error**	**Z-Stat**	**Probability**
PCI	-11.476	1.618	-7.09	0.000***
PCI^2	0.533	0.073	7.26	0.000***
HDI	0.714	0.275	2.59	0.010**
POP	0.083	0.019	4.29	0.000***
UR	-0.09	0.021	-4.12	0.000***
$Constant$	0.0005	0.003	0.15	0.881
$Wald\ \chi^2$			157.250	0.000***
$corr(u_i, X) = 0$				

Note: ***, denotes significance at 1%.

The equation used to predict the amount of urban solid waste based on the obtained predictions is as follows:

$$USWP_{i,t} = 0.0005 - 11.476PCI_{i,t} + 0.533\ PCI_{i,t}^2 + 0.714\ HDI_{i,t} + 0.083\ POP_{i,t} - 0.09\ UR_{i,t} + e_{i,t} \quad (1)$$

Table 8 displays a substantial difference, namely the inclusion of the expression $corr(u_i, X) = 0$. This is a general assumption in the random effects model, indicating no correlation between unit effects and independent variables. Therefore, the model assumes no relationship between unit effects and the independent variables used. The 5-degree-of-freedom Wald test is preferred over the F-test and provides significant results. This test assesses whether the coefficients of the model are zero. The results show that the coefficients are statistically significant in the random effects model.

Based on the coefficient results, it can be observed that the variables PCI and PCI^2 have coefficients with opposite signs, with $\beta_1 < 0$ and $\beta_2 > 0$. This indicates a curvilinear relationship, which suggests that the WKC hypothesis is not valid. Similar results were obtained in parallel with the studies of Cole et al. (1997), Mazzanti and Zoboli (2005), Arbulu et al. (2015), Baalbaki and Marrouch (2020), Huang et al. (2021), and Cheng et al. (2020), which suggest that the WKC hypothesis is not valid. Conversely, studies such as Mazzanti et al. (2009), Abrate and Ferraris (2010), Ercolano et al. (2018), and Yılmaz (2020) have found results indicating the validity of the WKC hypothesis.

In addition to testing the WKC hypothesis, it is observed that the examined control variables ($HDI, POP,$ and UR) are significant. The positive coefficient of the HDI variable is explained by the tendency of individuals to consume more as economic growth, an increase in income levels, and higher living standards occur, resulting in higher urban solid waste production. These results parallel the findings of Giannakitsidou et al. (2016) and Namlis and Komilis (2019), who obtained evidence that solid waste production is high in countries with high human development. Since the POP variable has a positive coefficient, it implies that in countries with high population density (also with high immigration), there will be more urban solid waste production per capita. In line with this result, studies such as Daskalopoulos et al. (1998), Johnstone and Labonne (2004), Sokka et al. (2007), Mazzanti et al. (2009), Abrate and Ferraris (2010), Ichinose et al. (2015), Prades et al. (2015), and Huang et al. (2021) have found evidence that an increase in population and density positively affects urban solid waste production, while Ercolano et al. (2018) obtained a negative relationship in the opposite direction. The negative coefficient of the UR variable indicates that an increase in the unemployment rate will lead to a decrease in per capita urban solid waste production. The results are consistent with studies such as Keser et al. (2012), Arbulu et al. (2015), and Namlis and Komilis (2019), which have found evidence regarding the impact of the unemployment rate on urban solid waste production, suggesting that on account of unemployment, income decreases, causing to a decrease in consumption and, consequently, a lower urban solid waste production. This significance has been confirmed for the countries with the highest urban solid waste production as well.

Furthermore testing the WKC hypothesis, the study found that the examined control variables - HDI, POP, and UR - were significant. The positive coefficient of the HDI variable can be attributed to the tendency of individuals to consume more as economic growth, income levels, and living standards increase, leading to higher urban solid waste production. Giannakitsidou et al. (2016) and Namlis and Komilis (2019) found evidence that solid waste production is high in countries with high human development, which is consistent with these results. The positive coefficient of the POP variable suggests that countries with high population density, including those with high immigration, will produce more urban solid waste per capita. Consistent with this finding, studies such as Daskalopoulos et al. (1998), Johnstone and Labonne (2004), Sokka et al. (2007), Mazzanti et al. (2009), Abrate and Ferraris (2010), Ichinose et al. (2015), Prades et al. (2015), and Huang et al. (2021) have provided evidence that an increase in population and density has a positive effect on urban solid waste production.

However, Ercolano et al. (2018) found a negative relationship in the opposite direction. The coefficient for the variable UR is negative, indicating that an increase in the unemployment rate results in a decrease in per capita urban solid waste production. The findings align with previous studies such as Keser et al. (2012), Arbulu et al. (2015), and Namlis and Komilis (2019), which have betrayed the relationship between unemployment rates and urban solid waste production. Specifically, the studies suggest that unemployment gives rise to a diminish in income, resulting in reduced consumption and subsequently lower urban solid waste production. This relationship has been observed in countries with the highest levels of urban solid waste production.

4. Conclusion and Discussion

This study tests the WKC hypothesis, which is based on the EKC hypothesis, using a panel regression model for the top ten countries with the highest per capita urban solid waste production among the OECD member EU countries. The regression results did not confirm the presence of an 'inverse U' shape in the relationship between per capita urban solid waste production and per capita real income, as required by the EKC hypothesis, indicating that the WKC hypothesis was not valid. Significant findings were also obtained from the included socioeconomic control variables. The coefficients of population density and the HDI have a positive significance, indicating an increase in per capita urban solid waste production. Conversely, the negative significance of the unemployment rate suggests a decrease in per capita urban solid waste production. Based on the results, it is confirmed that economic growth does not reduce the amount of solid waste produced. The increase in urban solid waste production is a side effect of economic growth. The rapid urbanization and industrialization have led to a significant increase in population density, which poses a serious and inevitable threat. In response to this issue, the EU is formulating and renewing various environmental policies and creating thematic strategies to effectively reduce solid waste production. Although the EU has not yet succeeded in reducing urban solid waste, it is working towards this goal through waste management methods. These results highlight the complexity of the relationship between solid waste generation and economic growth. In terms of sustainability, these results show that economic growth does not have a direct effect on reducing waste generation. Therefore, to achieve sustainability goals, it is necessary to adopt environmental policies and practices that focus on a more efficient use of natural resources alongside economic growth. In addition, renewing and strengthening waste management policies is an important step towards sustainable waste management. These efforts can play an important role in reducing the amount of urban waste and minimizing its environmental impact.

In recent years, waste management policies have prioritized waste prevention as the first step, followed by waste reduction, reuse, recycling, energy recovery, and disposal, including landfilling. These steps are outlined in the waste hierarchy directives, which serve as a guide for waste policy. For instance, waste management in Australia, Belgium, Denmark, Germany, Latvia, South Korea, and Norway involves recycling over one-third of their municipal solid waste. The appropriate disposal of waste remains a fundamental challenge for policymakers in many industrialized countries, as they seek economically viable and environmentally acceptable solutions. Predicting current and future amounts and compositions of urban solid waste is a useful tool for designing the most appropriate treatment or disposal strategy. The EU waste policy has transitioned from a linear to a circular economy mechanism. It aims to extract high-quality resources from waste, support the transition to a modern, resource-efficient, and competitive economy with the European Green Deal, and promote green growth. However, the observed trends suggest that the EU is not on track to achieve its goal of reducing solid waste production. The data indicates that the EU has not fully implemented the waste prevention principle, which is the first step in the waste hierarchy outlined in the Waste Framework Directive. Despite urban solid waste accounting for only about 10% of total waste produced, it requires over one-third of the public sector's financial resources for pollution control. The need to separate population (tourists, migrants) and economic growth from waste production has become imperative. Managing complex solid waste structures, including organic, plastic, wood, glass, textiles, food, packaging, batteries, and electronic devices, requires a long-term approach. This involves determining both qualitative and quantitative dimensions at both micro and macro scales, adhering to waste laws, and implementing recycling campaigns. The effectiveness of public administration plays a crucial role in monitoring resource efficiency in production and consumption, preventing waste in waste management, and building zero-waste cities and communities. Future studies should investigate the effects of the composition and disposal methods of urban solid waste on socio-environmental aspects to diversify the field and inform new policies.

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