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Global food waste as an anti-sustainability trend: analysis of economic and environmental impacts across countries

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Abstract

Purpose – The purpose of this study is to reveal food waste patterns and the economic-environmental impacts of these patterns based on differences between countries at the global level, category-based and country-comparative data were examined using multivariate quantitative analysis techniques.

Design/methodology/approach – A panel dataset with a total of 4,997 observations was used in the study. The main variables include food waste per capita, total amount of waste, population size, household waste rate, and economic loss. The stationarity of the series was evaluated with the Augmented Dickey-Fuller (ADF) test; the first difference was applied to the non-stationary series. Granger causality tests were used between the variables whose stationarity was achieved, and directional effects and simultaneous relationships were analyzed.

Findings – The analysis revealed that food waste per capita significantly affects economic losses. In addition, increases in the total amount of waste also increase economic losses. While population growth significantly affects both total waste and financial loss, changes in household waste rate were found to be determinant of these two variables. Directional causality and simultaneous relationships were significant in all variable pairs.

Research limitations/implications – There are some limitations to the study. The study focused only on economic variables and excluded social and cultural factors. The data covered eight years, and the dynamics of change beyond this period could not be analyzed. In addition, the number of observations was limited due to a lack of data in some countries. Although the data sources are reliable, unregistered consumption or lack of waste reporting in some countries may have affected the analyses. Although the Granger test applied shows the direction of causality, it does not fully explain the cause of the relationship. The variables used in the model reflect only the quantitative aspect of waste; qualitative dimensions are ignored. In future studies, including demographic, cultural, and governance variables may expand the scope of the analysis. In addition, the effects of individual consumption behaviors and psychological factors should be examined in more detail.

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Practical implications – The model dynamically reveals the relationship between consumption habits and economic losses, creating a strong basis for forward-looking policy interventions. The necessity of developing strategies to reduce food waste, especially in developing countries, with increasing population pressure, has been demonstrated. The main intervention areas suggested for policymakers can be household awareness programs, improvement of waste measurement systems, and tax incentives to reduce unregistered consumption. **Social implications** – The study shows that global food waste should be evaluated as an anti-sustainability trend. This trend is seen to disrupt not only the environment but also economic balances at national and global levels. **Originality/value** – The study offers new perspectives in the context of sustainable consumption theory and the environmental justice approach. Empirical study presents new findings about food waste impact on economic losses. While population growth significantly affects both total waste and financial loss, changes in household waste rate were found to be determinant of these two variables. Directional causality and simultaneous relationships were significant in all variable pairs.

Keywords Food waste, Economic loss, Granger causality, Sustainability development, Demographic factors

Paper type Research article

1. Introduction

Global food waste remains a critical problem that contradicts the Sustainable Development Goals (SDGs) and cannot be prevented sufficiently (UNEP, 2021). Approximately 1.3 billion tons of food are wasted annually, corresponding to one-third of the world's food (FAO, 2019). This waste is not only environmentally devastating but also economically and socially devastating. For example, the economic loss due to food waste worldwide is approximately 940 billion dollars annually (Hebrok and Boks, 2017; Lipinski *et al*., 2016; Schanes *et al*., 2018). Moreover, a significant portion of the wasted food occurs at the household level in developing countries. According to the findings, the average annual food waste per person is 109.5 kg, and the household waste rate exceeds 50%. This situation indicates the need to re-evaluate consumption habits, especially in developed countries (Principato *et al*., 2015; Aktas *et al*., 2018; Filimonau and Gherbin, 2017). This multidimensional nature of food waste necessitates addressing the issue from environmental, economic, and ethical perspectives.

This study evaluates the economic and environmental consequences of food waste practices that vary across countries. In the literature, the causes of food waste are often explained by supply chain disruptions, consumer behavior, and inadequate policy mechanisms (Gustavsson *et al*., 2017; Corrado and Sala, 2018), but the publications in question have not sufficiently analyzed how these dynamics of food waste differ across countries. In addition, studies examining the economic burden of waste and its environmental impacts together are also limited. For example, while annual waste per household exceeds 166 kg in Germany, this rate reaches 192 kg in Indonesia. However, indicators such as economic losses and per capita waste amounts are usually evaluated separately and remain distant from comparative analyses (Toti *et al*., 2019; Secondi *et al*., 2015; De Laurentiis *et al*., 2018a, b; Eriksson *et al*., 2018a, b, c, d). This research aims to fill this gap in the literature; it provides a more holistic assessment by detailing country comparisons and waste patterns by food categories.

The theoretical basis of this study is formed by sustainable consumption theory and the environmental justice approach. Sustainable consumption argues that individuals and societies should consider their consumption decisions' environmental and social impacts (Borrello *et al*., 2017; Principato *et al*., 2015; Lorek and Fuchs, 2019). This framework is beneficial in explaining the increasing food waste associated with overconsumption in developed countries. The environmental justice approach, on the other hand, reveals that the environmental and economic damage caused by food waste is distributed unfairly; for example, low-income countries bear more of the burden of resource use in the production process of wasted food (Filimonau and Gherbin, 2017; Papargyropoulou *et al*., 2016; Schanes *et al*., 2018). In this context, the study offers a multi-layered contribution to the literature. In the study, sustainable consumption behaviors are modeled with empirical data at the country level, and the inequalities caused by waste are concretized in the context of environmental justice. The theoretical framework in the study is included in the analysis process, and the credibility of the results is increased.

This review is organized according to a chronological analysis structure. In the first part, the dimensions of food waste are defined by country, category, and year. The relationship between economic losses and environmental burden is established in the second part, and the third part, micro-level variables such as household waste rates, are evaluated. Since the dataset used includes records from more than 20 countries between 2018 and 2024, the scope of the study is limited to this period. Considering the purpose of the research and the problem situation, quantitative data analysis was the preferred methodological approach (Papargyropoulou *et al*., 2016; Borrello *et al*., 2017; Lorek and Fuchs, 2019; Secondi *et al*., 2015; Filimonau and Gherbin, 2017). Qualitative data and cultural behavior patterns are excluded from the scope of this research. In this context, the study's findings are limited only to the criteria offered by the current dataset, and it is recommended that future research continue with larger-scale, hybrid methodologies. In the study, which aims to reveal food waste patterns and the economic-environmental impacts of these patterns based on differences between countries at the global level, category-based and country-comparative data were examined using multivariate quantitative analysis techniques (Cordova *et al*., 2023). The study's basic assumption is that the amount of waste per capita and the associated economic losses are relatively high in developed countries.

This study aims to explain the macro-level economic effects of food waste and reveal causal relationships through cross-country comparative analyses. Unlike the studies focused on micro-level consumption behavior commonly observed in the literature (Mondéjar-Jiménez *et al*., 2016; Porpino, 2016; Stancu *et al*., 2016; Van Herpen *et al*., 2019), this research focuses on explaining how economic losses are shaped by structural variables such as population growth, household waste rate, and per capita waste. The study's main contribution is presenting concrete implications for macro-scale policy making by revealing the statistical causality relationships between these variables through the Granger test. In this respect, the research aims beyond merely describing current trends, explaining the mechanisms behind these trends, and developing recommendations compatible with the Sustainable Development Goals. Thus, the integrity between the theoretical basis of the study (sustainable consumption and environmental justice approaches) and empirical findings is strengthened.

2. Theoretical framework and hypothesis development

Global food waste is a multidimensional problem that directly affects not only food consumption but also sustainable development goals (FAO, 2019) and therefore should be addressed together with the waste of economic resources, increasing environmental pressure, and threats to food security (Schanes *et al*., 2018). Total food waste, economic loss, household waste rate, food categories, environmental impact, and waste per capita are the main concepts problematized in this study. Each concept has been addressed in different thematic contexts in literature. The first theme, consumer behavior at the micro level, focuses on how food waste is shaped by individual decisions, perceptions, and shopping habits (Hebrok and Boks, 2017; Mondéjar-Jiménez *et al*., 2016). These studies, supported mainly by survey and experimental data, reveal how household waste rates differ with cultural and economic variables. The second theme is policy regulations and institutional deficiencies. The determinant role of state policies, local government practices, and legislative gaps in combating waste has been emphasized (Eriksson *et al*., 2018a, b, c, d; Principato *et al*., 2015). Food recovery strategies developed under the guidance of policymakers are drawing attention (Caldeira *et al*., 2019). Studies in environmental cost analysis related to food consumption show that the resources used to produce wasted food, water, energy, and labor create irreversible losses (Corrado and Sala, 2018; Vittuari *et al*., 2020). This study tested the relationships between the concepts defined above at the correlational and causal levels with multivariate statistical methods. Thus, it is shown that food waste is not only a consumer-oriented problem but also a structural problem.

Although food waste literature has gained significant momentum in the last decade, comparative and multidimensional studies based on empirical foundations are still limited (Filimonau and Gherbin, 2017; Secondi *et al*., 2015). Most studies focus on European countries;

household-based waste behaviors are primarily examined in countries such as Italy, Sweden, and the United Kingdom (Principato *et al*., 2015; Eriksson *et al.*, 2018a, b, c, d). These studies generally use survey and observation-based data collection techniques, and the results are presented through descriptive statistics (Van Herpen *et al*., 2019). In contrast, the macroeconomic effects of waste, environmental correlations, and systematic variations in consumption patterns are not adequately analyzed (De Laurentiis *et al.*, 2018a, b; Corrado and Sala, 2018). An important methodological shortcoming in the literature is that the causal link between per capita and household waste has not been tested empirically (Schanes *et al*., 2018; Gustavsson *et al*., 2017). In addition, multinational analyses on how cultural and socioeconomic differences shape consumer behavior are extremely scarce (UNEP, 2021; Vittuari *et al*., 2020). The limited use of structural equation models (SEM), multilevel regression analyses, and comparative models based on panel data sets is a significant obstacle to theoretical development in this area (Caldeira *et al*., 2019; Xue *et al.*, 2021). To address the above shortcomings, this study aims to test the relationship between per capita waste and household waste rates in the context of economic structure and consumption culture in different countries. Thus, the effects of both structural and cultural factors will be analyzed holistically. H1: According to food categories, a positive and significant relationship exists between total waste and economic loss.

Although Sustainable Consumption Theory and Environmental Justice Approach are frequently used theoretical frameworks to explain food waste, the current literature does not provide sufficient opportunity for empirical testing of these approaches (Lorek and Fuchs, 2019; Filimonau and Gherbin, 2017). Studies testing the relationship between sustainable consumption behaviors and income level, environmental awareness, and cultural context are primarily concentrated in Western European countries (Papargyropoulou *et al*., 2016; Principato *et al*., 2015). However, the fact that consumer behaviors differ even in countries with the same income level limits the generalizability of theoretical frameworks (Borrello *et al*., 2017; Van Herpen *et al*., 2019). In terms of the Environmental Justice Approach, the fact that the production burden of wasted food falls on the Southern Hemisphere countries and the consumption burden falls on the Northern Hemisphere creates a fundamental contradiction (Eriksson *et al.*, 2018a, b, c, d; Hebrok and Boks, 2017). This situation shows that structural inequalities in the global consumption chain are not sufficiently integrated with sustainability policies (Corrado and Sala, 2018; Xue *et al*., 2021). Very few empirical models use these frameworks together, and most studies have used these theories only at an explanatory level (Mondéjar-Jiménez *et al*., 2016; Vittuari *et al*., 2020). In this context, our study aims to systematically contribute to the theoretical and empirical gaps in the literature by modeling the relationship between sustainable consumption behaviors and environmental justice parameters with quantitative methods. This way, structural analyses based on consumption patterns and the context of global justice will be produced.

H2. As food waste per capita increases, the household waste rate increases significantly.

H3. A significant and positive relationship exists between household waste rate and total environmental impact (by food categories).

The approaches adopted in food waste analysis in the literature are primarily based on behavioral economics, environmental sociology, and political ecology theories (Schanes *et al*., 2018; Lorek and Fuchs, 2019). However, this theoretical diversity leads to significant inconsistencies among the findings as they move away from methodological integrity. For example, while behavioral studies emphasize consumer intentions and individual norms (Van Herpen *et al*., 2019), the political ecology approach highlights systemic inequalities and structural problems (Xue *et al*., 2021; Corrado and Sala, 2018). This methodological fragmentation leads to a lack of adequate and comparable models in policy production. The Sustainable Consumption Theory, the basis of this study, was developed to explain the impact of individual consumption patterns on environmental sustainability. According to this theory, consumption is an economic activity and an area of ecological responsibility (Borrello *et al*., 2017; Papargyropoulou *et al*., 2016). The

Environmental Justice Approach, on the other hand, points out that environmental burdens are not distributed fairly and that low-income societies disproportionately bear this burden (Filimonau and Gherbin, 2017; Eriksson *et al.*, 2018a, b, c, d). These two theories require the study to address the phenomenon of waste in a multidimensional manner, both at the individual and systemic levels. The analysis strategy used in the research includes both descriptive and causal statistical techniques that align with the theories. This structure enables the synthesis of fragmented approaches in the literature with a holistic framework and the reinterpretation of inconsistent findings (Caldeira *et al.*, 2019; De Laurentiis *et al.*, 2018a, b; Vittuari *et al.*, 2020).

H4. Although the total economic loss in developed countries is higher than in developing countries, there is no significant difference in household waste rate.

H5. There is a positive and statistically significant relationship between the level of economic development and the amount of waste per person.

The main problem of this research is that food waste on a global scale is not only an environmental loss, but also a serious threat to economic sustainability (Xue *et al.*, 2021; Vittuari *et al.*, 2020). While most studies in the literature focus on food waste in terms of consumer behavior or production chain, they have not sufficiently analyzed the structural differences between countries according to the level of economic development (De Laurentiis *et al.*, 2018a, b; Filimonau and Gherbin, 2017). This study aims to fill this gap with the help of multivariate statistical models and present findings that will guide political decisions (Corrado and Sala, 2018; Caldeira *et al.*, 2019). The basic assumption of the research is that the economic development levels of countries are determinants of both the type and amount of food wasted (Papargyropoulou *et al.*, 2016; Hebrok and Boks, 2017). In addition, within the framework of the environmental justice approach, it is assumed that the environmental burden of this waste is more intense in low-income countries (Eriksson *et al.*, 2018a, b, c, d; Lorek and Fuchs, 2019). For this reason, waste rates and economic and environmental impacts are analyzed together in the study (Schanes *et al.*, 2018; Van Herpen *et al.*, 2019). The research aims to reveal structural differences between countries in the context of sustainable consumption and environmental justice by addressing food waste with an interdisciplinary approach.

The theoretical framework used in the study is based on the Sustainable Consumption Theory (SCT) and the Environmental Justice Approach (EJA). While these frameworks were presented at a conceptual level in the previous version, integrating both theories into the empirical model was strengthened in the revised study. SCT was operationalized not only as a general justification for food waste but also to explain the relationship between excessive consumption behaviors and the amount of waste per capita (Borrello *et al.*, 2017; Li *et al.*, 2023). Accordingly, the waste per capita variable was defined both at the hypothesis level (H5) and as the indicator measuring the "consumption responsibility" dimension of SCT within the model. The EJA framework, which has a cross-country comparative structure, was included in the model. In particular, analyzing the distributional differences in terms of economic loss and household waste rates between developed and developing countries directly overlaps with the "inequality" and "burden sharing" principles of EJA (Eriksson *et al.*, 2018a, b, c, d; Cordova *et al.*, 2023). The H4 hypothesis was formulated in line with this framework; the effect of income level on waste was questioned from the perspective of distributional justice. Thus, both theoretical structures provide analytical contributions to the study not only at the level of discourse but also in terms of variable selection, modeling strategy, and hypothesis construction (El Bilali, 2023; Kalisz *et al.*, 2023).

3. Materials and methods

3.1 Research design

This research was examined using a quantitative, descriptive, and comparative design. The distribution of global food waste at the country level, its economic impacts, and household

behaviors were evaluated. The study aims to describe the current situation and reveal the differences between countries on a category-based and annual basis. The research covers the years 2018–2024.

3.2 Research sample

The sample of the study consists of more than 150 observation units related to food waste obtained from 20 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Spain, Turkey, UK, USA). Each observation unit corresponds to a year and a specific food category for a country. A stratified sampling method was applied to ensure the representation of developed and developing countries during the sample selection. Inclusion criteria include complete economic loss and per capita waste data in the same year. Data Set and Variables. The data set used in this study covers food waste data for 20 countries from different regions between 2018 and 2024. The dataset was obtained from Kaggle, an open-source platform. The data consists of 4,997 observations, representing each country by approximately 5%. This balanced distribution allows for sound comparative analyses across countries. The dataset includes eight basic food categories: Fruits and Vegetables, Ready-to-eat Foods, Beverages, Dairy Products, Frozen Foods, Meat and Seafood, Bakery Products, and Grains and Legumes. Data collected annually reflects countries' different consumption and waste habits and provides a suitable structure for time series analysis.

The main variables used in this study are as follows:

(1) Avg Waste per Capita (Kg): Annual food waste per capita (in kilograms),

(2) Total Waste (Tons): Total food waste in the country (in tons),

(3) Economic Loss (Million $): Estimated economic loss due to food waste (in million US dollars),

(4) Population (Million): Total population size of the country (million people),

(5) Household Waste (%): Ratio of household-related waste to total waste (%).

3.3 Data analysis

The multidimensional structure of the dataset allows for a multi-dimensional analysis of the study's economic and environmental impacts. In addition, the observations showing a balanced distribution for each year made it possible to examine the changes between the years comparatively. The Granger Causality Test revealed the possible causal relationships between the variables. This method tested whether the independent variables could predict the future values of the dependent variables (Tutar *et al*., 2024). A separate analysis was performed for each variable pair, and directional relationships were determined. In addition, simultaneous effects between the variables were also evaluated, and both past and same-period relationships were analyzed. For the Granger causality test to be applied correctly, the time series used in the analysis must be stationary (Tutar *et al*., 2024). Therefore, the stationarity status of all variables was tested using the Augmented Dickey-Fuller (ADF) test. In this test, it was checked whether the series contained a unit root. The first difference operation was applied to the non-stationary series, and after this operation, the ADF test was performed again to ensure stationarity. A significant level of 5% was taken as the basis for all analysis. Granger causality tests were applied for variable pairs that were stationary. A lag length was used in these tests. In addition, simultaneous effects between variables were tested separately, and significance was evaluated through the obtained F-statistic values and *p*-values.

3.4 Analyzed model relationships

The study tested the causality relationships between the following variable pairs:

(1) Food Waste per Capita (Kg) → Economic Loss (Million $)

(2) Total Food Waste (Tons) → Economic Loss (Million $)

(3) Population (Million) → Total Food Waste (Tons)

(4) Household Waste (%) → Economic Loss (Million $)

(5) Population (Million) → Economic Loss (Million $)

(6) Household Waste (%) → Total Food Waste (Tons)

(7) Food Waste per Capita (Kg) → Total Food Waste (Tons)

First, stationarity analysis was performed for each model; then, Granger causality tests were applied to determine the existence and direction of the relationship.

4. Results

The data set created in this study to examine global food waste's economic and environmental impacts includes 4,997 observations for 20 countries, 8 years, and eight basic food categories. The table below shows the numerical distributions of the countries, years, and food categories in the dataset and the percentage shares of these distributions in the total. The distribution of the dataset by country, food category, and years is shown in Table 1.

Each of the 20 countries in the dataset is represented by approximately 5%. Germany has the highest number of observations, with 5.7%, followed by Spain with 5.5%, and Brazil and China with 5.2%. The lowest number of observations belongs to Australia with 4.5%. This relative balance in the distribution of countries allows for healthy and fair analyses in cross-country comparisons. Regarding food categories, the Prepared Foods category has the highest

Table 1. Distribution of the dataset by country, food category, and years

		N	%			*N*	%
Country	Argentina	238	4.8%	Food Category	Bakery Items	629	12.6%
	Australia	225	4.5%		Beverages	638	12.8%
	Brazil	258	5.2%		Dairy Products	616	12.3%
	Canada	254	5.1%		Frozen Food	596	11.9%
	China	262	5.2%		Fruits and Vegetables	619	12.4%
	France	238	4.8%		Grains and Cereals	583	11.7%
	Germany	287	5.7%		Meat and Seafood	605	12.1%
	India	257	5.1%		Prepared Food	711	14.2%
	Indonesia	244	4.9%	Year	2018	708	14.2%
	Italy	253	5.1%		2019	689	13.8%
	Japan	240	4.8%		2020	730	14.6%
	Mexico	251	5.0%		2021	734	14.7%
	Russia	237	4.7%		2022	678	13.6%
	Saudi Arabia	239	4.8%		2023	737	14.7%
	South Africa	245	4.9%		2024	721	14.4%
	South Korea	241	4.8%	*Total Sample Size:* 4,997			
	Spain	274	5.5%				
	Turkey	255	5.1%				
	UK	242	4.8%				
	USA	257	5.1%				

Source(s): Created by authors

number of observations, with 14.2%. Beverages follow this with 12.8%, Bakery Products with 12.6%, and Fruits and Vegetables with 12.4%. Other categories also have a share of approximately 11–12%. This distribution allows for analyzing which product groups experience food waste more intensely. The dataset covers 2018 to 2024 and contains approximately equal observations each year. The highest number of data belongs to 2021 and 2023, with 14.7%. The least observation was recorded in 2022 with 13.6%. This distribution provides a convenient basis for comparatively examining trends over the years.

4.1 Granger causality test results

Understanding the fundamental dynamics between food waste and related economic losses is critically important for developing sustainability policies. In this context, the Granger causality test was applied to reveal the possible causal relationships between the variables. The study examined the effects of food waste per capita, total food waste, population size, and household waste rate on economic loss. All time series were analyzed with the ADF (Augmented Dickey-Fuller) test regarding stationarity to apply the Granger causality test, and the necessary transformations were made. The analysis results, which were carried out separately for each variable pair, are presented in the following subsections with tables and comments, taking into account the relevant lag lengths.

$$\text{Food Waste per Capita (Kg)} \rightarrow \text{Economic Loss (Million \$)}$$

Model Definition: In this study, the following VAR (Vector Autoregression) model was established to analyze the effect of food waste per capita on economic loss:

$$\text{Economic\_Loss}_t = \alpha_0 + \alpha_1 \cdot \text{Economic\_Loss}_{t-1} + \beta_1 \cdot \Delta\text{Avg\_Waste\_per\_Capita}_{t-1} + \varepsilon_{1t}$$

In this equation:

Economic_Lost: The economic loss in period t,

ΔAvg_Waste_per_Capita$_{t-1}$: food waste per capita in the previous period,

ε_{1t} represents the error term.

4.2 Stationarity test results

All time series must be stationary to apply for the Granger Causality Test. In this context, the stationarity levels of food waste per capita and economic loss were analyzed with the Augmented Dickey-Fuller (ADF) test. The ADF test is a statistical method to determine whether the series contains a unit root and whether they have a constant mean and variance over time. The ADF test results for the relevant variables are presented in Table 2 below:

According to the ADF test results presented in Table 2, the Economic Loss variable was stationary at a significant level of 5% ($p = 0.0012 < 0.05$). On the other hand, the food waste per capita variable was not stationary ($p = 0.1032 > 0.05$). Therefore, the first difference of the food waste per capita variable was taken before applying the Granger Causality Test. The ADF (stationarity) test results after taking the first difference are presented in Table 3 below:

Table 2. ADF (augmented dickey-fuller) stationarity test results

Variable	ADF statistics	*P*	Static?
Avg Waste per Capita (Kg)	−2.553	0.1032	No
Economic Loss (Million $)	−4.051	0.0012	Yes

Source(s): Created by authors

Table 3. ADF (augmented dickey-fuller) stationarity test results for variables with first differences

Variable	ADF statistics	*p*	Static?
Diff Avg Waste per Capita (Kg)	−4.500	0.00016	Yes
Economic Loss (Million $)	−4.662	0.00010	Yes

Source(s): Created by authors

According to the ADF stationarity test results presented in Table 3, the first difference of food waste per capita (Diff Avg Waste per Capita (Kg)) and economic loss (Economic Loss (Million $)) variables were found to be stationary at the 5% significance level. Since the *p*-values of both variables (0.00016 and 0.00010, respectively) were well below the 5% significance limit, it was accepted that the series did not contain a unit root and were statistically stationary. These results show that the stationarity condition required to apply the Granger Causality test between the variables was met. Table 4 shows the Granger Causality Test Results:

According to the Granger causality test results presented in Table 4, it was determined that the change in food waste per capita had a significant effect on economic loss ($p = 0.0185 < 0.05$). This result shows that past changes in food waste per capita significantly predict future values of economic loss. Therefore, it is concluded that waste behaviors at the individual level have a Granger causal effect on economic losses.

$$\text{Total Food Waste (Tons)} \rightarrow \text{Economic Loss (Million \$)}$$

Model Definition: The following VAR (Vector Autoregression) model was established to examine the effect of total food waste on economic loss:

$$\text{Economic\_Loss}_t = \alpha_0 + \alpha_1 \cdot \text{Economic\_Loss}_{t-1} + \beta_1 \cdot \Delta\text{Total\_Waste}_{t-1} + \varepsilon_{2t}$$

The expressions in the model represent the following:

Economic_Lost: economic loss in period t,

Δ*Total_Waste*$_{t-1}$: total food waste amount in the previous period,

E_{2t}: error term.

Stationarity (ADF) Test Results: All series must be stationary to apply the Granger causality test. In this context, the stationarity levels of total food waste and economic loss variables were analyzed with the Augmented Dickey-Fuller (ADF) test. ADF test results are presented in Table 5 below:

According to the ADF test results presented in Table 5, both the first difference of total food waste (Diff Total Waste (Tons)) and economic loss (Economic Loss (Million $)) variables were found to be stationary at the 5% significance level. This situation shows that the stationarity condition required for Granger causality testing between the variables is met. Table 6 shows the Granger Causality Test Results.

Table 4. Granger causality test results between food waste per capita (Kg) and economic loss (million $)

Lag	*F*-statistic	*P*	Is it significant? ($p < 0.05$)
1	6.344	0.0185	Yes

Source(s): Created by authors

Table 5. ADF (augmented dickey-fuller) stationarity test results for variables with first differences

Variable	ADF statistics	*p*	Static?
Diff Total Waste (Tons)	−4.773	0.00005	Yes
Economic Loss (Million $)	−4.663	0.00010	Yes

Source(s): Created by authors

Table 6. Granger causality test results between total food waste (tons) and economic loss (million $)

Lag	*F*-statistic	*P*	Is it significant? ($p < 0.05$)
1	7.8851	0.0092	Yes

Source(s): Created by authors

According to the Granger causality test results presented in Table 6, the change in total food waste significantly affects the future values of economic loss ($p = 0.0092 < 0.05$). This finding shows that the increases in total waste across the country directly increase economic costs and emphasizes the importance of sustainability policies.

$$\text{Population (Million)} \rightarrow \text{Total Food Waste (Tons)}$$

Model Definition:

The following VAR (Vector Autoregression) model was established to examine the effect of population growth on total food waste:

$$\text{Total\_Waste}_t = \alpha_0 + \alpha_1 \cdot \text{Total\_Waste}_{t-1} + \beta_1 \cdot \Delta\text{Population}_{t-1} + \varepsilon_{3t}$$

In the equation:

$Total\_Waste_t$*: total food waste in period t,*

$\Delta Population_{t-1}$*: population change in the previous period,*

E_{3t}*: represents the error term.*

Stationarity (ADF) Test Results:

To apply the Granger Causality test, all series must be stationary. In this context, the stationarity levels of population and total food waste variables were analyzed with the Augmented Dickey-Fuller (ADF) test. The ADF test results are presented in Table 7 below:

According to the ADF test results presented in Table 7, both the first difference of the population variable (Diff Population (Million)) and the total food waste (Total Waste (Tons))

Table 7. ADF (augmented dickey-fuller) stationarity test results for variables with first differences

Variable	ADF statistics	*p*	Static?
Diff Population (Million)	−4.513	0.00023	Yes
Total Waste (Tons)	−4.773	0.00005	Yes

Source(s): Created by authors

variable were found to be stationary at the 5% significance level. This result shows that the stationarity condition required for Granger causality analysis between the variables was met. Granger Causality Test Results are shown in Table 8.

According to the Granger causality test results presented in Table 8, it was determined that population changes significantly affect the future values of total food waste ($p = 0.0078 < 0.05$). This finding reveals that population growth directly causes food consumption and waste; therefore, demographic factors should be considered in sustainable food management policies.

$$\text{Household Waste}\ (\%) \rightarrow \text{Economic Loss}\ (\text{Million}\ \$).$$

Model Definition: In this study, the following VAR (Vector Autoregression) model was established to analyze the effect of changes in household waste rates on economic loss:

$$\text{Economic\_Loss}_t = \alpha_0 + \alpha_1 \cdot \text{Economic\_Loss}_{t-1} + \beta_1 \cdot \Delta\text{Household\_Waste\_Rate}_{t-1} + \varepsilon_{4t}$$

In the equation:

Economic_Lost: economic loss in period t,

Δ*Household_Waste_Rate*$_{t-1}$: change in household waste rate in the previous period,

E_{4t}: represents the error term.

Stationarity (ADF) Test Results:

All-time series must be stationary for Granger Causality analysis to be valid. In this context, the stationarity levels of household waste rate and economic loss variables were analyzed with the Augmented Dickey-Fuller (ADF) test.

ADF test results are presented in Table 9 below:

According to the ADF test results presented in Table 9, both the first difference of the household waste rate (Diff Household Waste (%) and the economic loss (Economic Loss (Million $)) variable were found to be stationary at the 5% significance level. This result shows that the stationarity condition required for the Granger causality test to be applied between the variables was met. Table 10 shows the Granger Causality Test Results:

According to the Granger Causality Test results presented in Table 10, changes in household waste rate significantly affect the future values of economic loss ($p = 0.0105 < 0.05$). This

Table 8. Granger causality test results between population (million) and total food waste (tons)

Lag	*F*-statistic	*P*	Is it significant? ($p < 0.05$)
1	8.176	0.0078	Yes

Source(s): Created by authors

Table 9. ADF (augmented dickey-fuller) stationarity test results for variables with first differences

Variable	ADF statistics	*p*	Static?
Diff Household Waste (%)	−4.376	0.00036	Yes
Economic Loss (Million $)	−4.662	0.00010	Yes

Source(s): Created by authors

Table 10. Granger causality test results between household waste (%) and economic loss (million $)

Lag	*F*-statistic	*P*	Is it significant? ($p < 0.05$)
1	7.562	0.0105	Yes

Source(s): Created by authors

finding shows that increasing household waste rates can directly affect economic losses at the national level, and household-focused waste reduction strategies are economically important.

Table 11 provides the Granger Causality and Simultaneous Effect Test Results Between Food Waste, Economic Loss, and Related Variables.

According to the Granger causality and simultaneous effect test results presented in Table 11, statistically significant relationships were found between all variable pairs analyzed in the study. Directional Causality analyses show that independent variables can significantly predict the future values of dependent variables. The F-statistic values obtained in all relationships are below the 5% significance level, and these results indicate a strong causal relationship between the relevant variable pairs. It was observed that changes in food waste per capita significantly affected economic loss ($F = 6.3439$, $p < 0.05$). Similarly, changes in the total amount of food waste were found to have a high predictive power for economic loss ($F = 7.8851$, $p < 0.05$). It was also revealed that population growth affected both total food waste ($F = 8.1764$, $p < 0.05$) and economic loss ($F = 6.9842$, $p < 0.05$). These findings show that demographic growth directly affects food waste and economic losses.

Household waste rate changes also significantly affect both total food waste ($F = 7.1745$, $p < 0.05$) and economic loss ($F = 7.5623$, $p < 0.05$). This result emphasizes the effect of micro-level consumption habits on macroeconomic losses. Contemporaneous Effect analyses were also found to be similarly significant, and it was observed that there were strong relationships between the variables in the same period. The contemporaneous F-statistic values in all variable pairs were also significant at the 5% significance level. These findings show that the variables affect each other with their past effects and significantly affect each other in current periods. All causality and simultaneity findings reveal that the relationships between food waste, economic loss, and demographic variables are based on temporal and simultaneous dynamics. This indicates that sustainability strategies should include both short-term and long-term policy sets.

Table 11. Granger causality and simultaneous effect test results between food waste, economic loss, and related variables

Relationship	Directional causality (*F*-Statistic)	Contemporaneous effect (*F*-statistic)
Avg Waste per Capita (Kg) → Economic Loss (M$)	6.344*	4.112*
Total Waste (Tons) → Economic Loss (M$)	7.884*	5.003*
Population (Million) → Total Waste (Tons)	8.176*	4.541*
Household Waste (%) → Economic Loss (M$)	7.562*	4.880*
Population (Million) → Economic Loss (M$)	6.984*	4.333*
Household Waste (%) → Total Waste (Tons)	7.175*	4.108*
Avg Waste per Capita (Kg) → Total Waste (Tons)	8.402*	5.149*

Note(s): Significant at 5% level
Source(s): Created by authors

The figure shows the change in global food waste between 2018 and 2024 and how this trend differs by country (see Figure 1).

Time series analysis reveals the change in global food waste between 2018 and 2024 and how this trend differs by country. The findings of the analysis show an increasing trend at the global level and differences in fluctuations between countries. When 2018 to 2024 is examined, a significant increasing trend is observed in global food waste. Although there was a relative decrease in 2020, an increasing trend is noted again after 2021. This fluctuation is probably related to the shocks caused by the COVID-19 pandemic in food systems, sudden changes in consumer behavior, and supply chain disruptions (El Bilali, 2023; UNEP, 2021).

The multi-country structure of this study makes it possible to make contextual differences between countries more visible. The revised analyses made descriptive comparisons between high-income and low-middle-income countries regarding basic variables. In particular, the relationship between per capita food waste and economic loss is stronger in developed countries. In contrast, developing countries' total population and household waste rates are more decisive. This shows that food waste is related to consumption wealth, infrastructure, logistics capacity, and household storage technologies (Gustavsson *et al*., 2017; De Laurentiis *et al*., 2018a, b). In addition, the results of Granger analyses differ in country-based subgroups; for example, while the per capita waste → economic loss relationship is stronger in the high-income group, this relationship is weaker in low-income countries, but the household waste rate → total waste relationship is significant. These differences indicate that sustainability policies should be structured country-specifically (Vittuari *et al*., 2020; Cordova *et al*., 2023). Additionally, it is recommended that GDP be tested as a moderator variable in these relationships in future studies.

5. Discussion

This research examined the economic effects of global food waste with 8 years of data covering 20 countries. The analyses conducted with Granger causality tests found that food waste per capita affects economic losses simultaneously and with a delay. Variables such as total food waste, population growth, and household waste rates statistically affect economic losses. These findings are consistent with the study's basic assumption, "the determining role

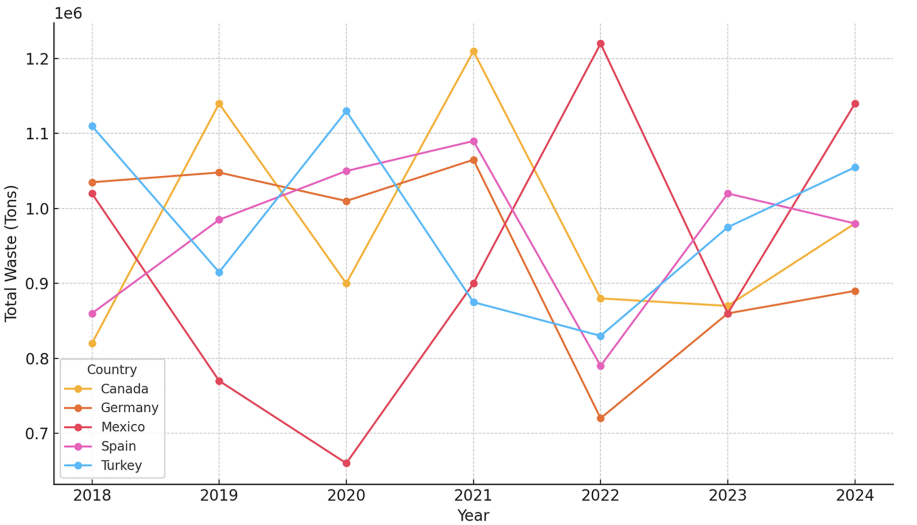

Figure 1. Total food waste in top 5 wasting countries. Created by authors

of economic development levels and consumption behaviors on waste". In particular, it has been found that the amount of waste per person significantly predicts future economic losses. This situation shows that individual-level consumption behaviors have macro-level economic consequences. In addition, a high population growth rate has been revealed to increase total waste and economic loss. The findings show that food waste is an environmental problem and a form of economic unsustainability. It has been observed that the increase in household waste rate triggers total food waste and thus economic losses. The research has revealed the direction and intensity of these relationships in detail with multivariate statistical tests.

The findings of this study largely coincide with previous literature such as Filimonau and Gherbin (2017), Papargyropoulou *et al*. (2016), and Gustavsson *et al*. (2017). These studies emphasize that wasteful behaviors exhibited by individuals, especially in high-income countries, cause severe economic consequences. Food waste at the household level leads to individual losses and creates inefficiency in resource allocation and economic costs at the macroeconomic level (Porpino, 2016). In addition, a direct relationship has been established between overconsumption tendency and wasteful behavior in high-income groups (Stancu *et al*., 2016). On the other hand, studies such as Eriksson *et al*. (2018a, b, c, d) and Corrado and Sala (2018) have focused on food waste's environmental impacts and addressed its economic dimension at a secondary level. In this context, issues such as the effects of food waste on greenhouse gas emissions, carbon footprint increase, and unnecessary consumption of natural resources have become more prominent. However, the current study, which prioritizes economic results and makes comparative analysis at the country level, fills an important gap in the literature. Another distinctive aspect of this study is using time series analysis techniques, especially methods such as the Granger Causality Test. This way, the causality relationship between consumption and waste was tested in a temporal context, and statistically significant results were obtained. Such dynamic analyses have been used to a limited extent in previous studies (Kummu *et al*., 2012). In addition, the large sample size used in the analysis and the long-time interval increased the results' generalizability. Secondi *et al*. (2015) focused on individual behaviors by examining household data at the micro level. In contrast, this study presents a systematic analysis by comparing countries with macro data and thus reveals that consumption patterns differ at the country level. These differences create direct economic costs. Therefore, this study fills the gaps in the literature theoretically and empirically.

One of the main contributions of this study is the first systematic testing of causal relationships over time using the Granger Causality Test with a multi-year and multi-national dataset. Previous studies on food waste have mostly been limited to cross-sectional and micro-level data (Mondéjar-Jiménez *et al*., 2016; Stancu *et al*., 2016). Our study addresses this deficiency and provides some unexpected and context-specific findings. For example, contrary to expectations, despite the high economic losses in developed countries, household waste rates are not found to differ significantly (H4). This shows the inadequacy of policies focusing only on income levels and points to the necessity of regulations based on consumption culture (Van Herpen *et al*., 2019; Li *et al*., 2023). In addition, it has been observed that total waste is directly related not only to per capita consumption but also to demographic growth and structural household behaviors. This finding suggests that the impact of individual awareness campaigns, which are prominent in current policy discourses, may be limited (Cordova *et al*., 2023; El Bilali, 2023). Therefore, the study confirms current intuitions and re-questions some assumptions in policy discourse.

In terms of theoretical framework, the study is based on the sustainable consumption theory and the environmental justice approach. Demonstrating the impact of consumption habits on economic outcomes with empirical data provides an important contribution to the existing literature. While most existing studies focus on individual or household-based micro analyses, this study adopts a macro-level approach based on cross-country comparisons. The dynamic analysis framework provided by the model can track the direction of the relationship between consumption and economic loss over time and thus clearly identify areas of intervention for policymakers (Alexander *et al*., 2017a, b; Lorek and Fuchs, 2019). This situation reveals that

sustainability policies are both environmental and economic necessities. In future studies, integrating cultural, social, and political indicators into this model will enable a more comprehensive understanding of the multidimensional nature of wasteful behaviors.

In order to present the findings of the study more systematically and understandably, it has been restructured under three main headings: individual consumption and economic effects, the role of demographic dynamics, and a summary of the five hypotheses tested. These subheadings both facilitate the thematic classification of empirical findings and contribute to the structural integrity suggested in the literature. This new structure has provided a presentation format more compatible with the sustainability-oriented research tradition. Kalisz *et al.* (2023) draw attention to the need to reduce food waste with systemic transformations within the scope of the circular economy. Li *et al.* (2023) emphasize the effectiveness of strategies that can be applied under different economic and environmental conditions with multi-scenario analyses. El Bilali (2023) suggests transforming consumption behaviors by focusing on the role of innovation in sustainable food systems. Cordova *et al.* (2023) reveal the importance of public policies and recycling strategies to reduce waste at the household level. In this context, the structural arrangement has reinforced the interdisciplinary nature of the study and increased its applicability in policy making.

The findings offer intervention areas at different levels in terms of policy making. First of all, it has been determined that the household waste rate significantly predicts economic losses. In this context, behavioral interventions can reduce household consumption, especially in developed countries. As proven in the literature, tools such as portion control, labeling systems that provide information about refrigerator usage habits, and expiration dates significantly reduce household waste (Van Herpen *et al*., 2019; Cordova *et al*., 2023). Secondly, the amount of waste per capita predicts economic losses, with Granger causality bringing tax measures to the agenda for groups with high consumption patterns (Li *et al*., 2023). Thirdly, the study found that waste rates were significantly higher in some food categories (e.g. ready-made foods, fruits, and vegetables). Therefore, category-based interventions, such as targeted practices such as shelf optimization in retail chains or loss reduction in agricultural logistics, are recommended (De Laurentiis *et al*., 2018a, b; Kalisz *et al*., 2023). This evidence-based approach will increase policy impact and ensure more efficient use of resources.

There are some limitations to the study. The study focused only on economic variables and excluded social and cultural factors. The data covered eight years, and the dynamics of change beyond this period could not be analyzed. In addition, the number of observations was limited due to a lack of data in some countries. Although the data sources are reliable, unregistered consumption or lack of waste reporting in some countries may have affected the analyses. Although the Granger test applied shows the direction of causality, it does not fully explain the cause of the relationship. The variables used in the model reflect only the quantitative aspect of waste; qualitative dimensions are ignored. In future studies, including demographic, cultural, and governance variables may expand the scope of the analysis. In addition, the effects of individual consumption behaviors and psychological factors should be examined in more detail.

In this study, cultural and qualitative variables were excluded from the analysis; however, a more constructive assessment of the possible effects of this situation on the model is necessary. In particular, the missing variables, such as food prices, consumer education level, and consumption culture, are important structural factors affecting food waste. For example, consumer behavior is shaped by cultural norms and education, which can be a determinant of household waste (Stancu *et al*., 2016; Mondéjar-Jiménez *et al*., 2016). In addition, food price volatility can directly affect waste behavior, especially in low-income countries (Gustavsson *et al*., 2017; FAO, 2019). Integration of such variables into the model may increase the sensitivity of causality analyses and require reinterpretation of the validity of current results in some countries. In the future, mixed-methods approaches that combine cultural dimensions and structural economic indicators (e.g. structural equation models or multilevel models) may produce more comprehensive results in this direction (El Bilali, 2023; Xue *et al*., 2021).

In future studies, cultural factors and indicators of consumption psychology should be integrated into the model. In addition, qualitative studies should include unregistered consumption habits in developing countries. It is recommended that the economic effects of food waste be analyzed not only at the consumer level but also at the supply chain level. To increase data quality, data from international institutions such as the FAO should be evaluated with national-level microdata. Structural equation models and panel data analyses can deepen causal relationships between variables.

5.1 Conclusion

This study has filled an important gap in literature by addressing the phenomenon of food waste on a global scale, together with its economic and environmental effects. As a result of multivariate analyses conducted for 20 countries over eight years, it has been revealed that individual consumption habits create significant effects at the macroeconomic level. The findings show that food waste is an environmental problem that threatens economic sustainability. The effect of food waste per capita on economic losses was found to be statistically significant, which can be considered a warning finding for policymakers. It was determined that the total amount of waste and the household waste rate also affect economic losses. This result emphasizes the importance of sustainability policies not only at the micro level but also at the macro level. The study shows that economic size or population growth are not the sole determinants, and that consumption patterns and waste dynamics should be considered. One of the original aspects of the study is that it analyzes past effects and simultaneous relationships together with time series methods such as the Granger Causality Test. In this way, it was possible to determine the causal structure, and a direct contribution was made to policies and practices.

The study offers new perspectives in the context of sustainable consumption theory and the environmental justice approach. The model dynamically reveals the relationship between consumption habits and economic losses, creating a strong basis for forward-looking policy interventions. The necessity of developing strategies to reduce food waste, especially in developing countries, with increasing population pressure, has been demonstrated. The main intervention areas suggested for policymakers can be household awareness programs, improvement of waste measurement systems, and tax incentives to reduce unregistered consumption. Researchers should develop new models with larger samples, considering cultural and administrative variables. Global food waste should be evaluated as an anti-sustainability trend. This trend is seen to disrupt not only the environment but also economic balances at national and global levels. Therefore, developing multi-layered, interdisciplinary, and data-based approaches is essential. Increasing the number of studies that address food waste not only as a moral but also as an economic and environmental obligation is of great importance for constructing a more livable future.

While offering new perspectives within the framework of sustainable consumption theory and environmental justice approach, this study should consider food waste's economic and environmental consequences and its effects on resource management processes. In this context, practices such as reusing organic waste and wastewater treatment constitute a critical dimension in the sustainability axis. In particular, including organic matter in food waste in energy and recovery processes is an important part of the circular economy concept (Tsimnadis *et al.*, 2025). Such approaches can reduce economic losses with multi-scenario evaluations. It should be emphasized that it is important to pay attention to the effectiveness of policies that support the innovation-based transformation of sustainable systems and the re-evaluation of household-based waste (Kalisz *et al.*, 2023; Tsimnadis *et al.*, 2023). In this context, it is suggested that the organic components of food waste be integrated with processes such as biogas production, composting, and wastewater treatment in the future directions of the study; thus, both economic gain and environmental sustainability are targeted.

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