CHEMICAL ENGINEERING TRANSACTIONS
VOL. 121, 2025
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Petar S. Varbanov

ISBN 979-12-81206-22-9; **ISSN** 2283-9216
DOI: 10.3303/CET25121007

Temporal and Spatial Effects of COVID-19 Pandemic on Food Waste Generation in the European Union

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The COVID-19 pandemic has had significant socioeconomic and environmental impacts, substantially altering food production, consumption, and waste generation trends across the European Union. This study examines the temporal and spatial fluctuations in food waste generation among European Union member states during the COVID-19 pandemic, focusing on six key food waste parameters. The data analysis revealed that the total amount of food waste did not undergo significant changes during the 2020-2022 period. The proportion of food waste generated by household activities was the highest in 2021, which aligns with the increased time spent at home by the population. The proportion of food waste from retail and other food distribution channels, as well as restaurants and food services, exhibited a steadily increasing trend over the study period. The detailed results highlight differences in food waste generation dynamics, with varying degrees of impact across European Union countries. This suggests not only differential policy effectiveness, but also the influence of diverse socio-economic factors, individual and community habits.

1. Introduction

The COVID-19 pandemic has constituted one of the most disruptive global crises to food systems in recent decades, with effects that extended far beyond public health and into the structural and behavioural dimensions of food production, distribution, and consumption (Kumareswaran and Jayasinghe, 2022). The intricate relationship between food waste and the COVID-19 pandemic reveals a complex interplay of altered consumption patterns (Fabiano et al., 2024), supply chain disruptions, and evolving household behaviours (Luo et al., 2021). Among these effects, changes in the generation and patterns of food waste have emerged as a particularly complex phenomenon, exhibiting considerable variation across sectors, regions, and timeframes (Dora et al., 2021).

International literature (Rivera-Ferre et al., 2021) broadly agrees that the early stages of the pandemic triggered acute disruptions across multiple levels of the food supply chain (Mishra and Sahoo, 2021). From primary agricultural production to processing and distribution, the system experienced breakdowns due to border closures, labour shortages, and the volatility of market demand (Indah et al., 2021). These disruptions translated into significant volumes of food loss, particularly of highly perishable commodities such as dairy products, fruits, and vegetables. In many instances, producers reported being unable to channel their output into downstream markets (Bándy and Élő, 2023), resulting in the destruction or disposal of large quantities of food that could not be stored or redirected (Ababulgu et al., 2022).

The pandemic exerted heterogeneous effects on household-level food waste (Everitt et al., 2023). In some developing countries, it led to low food stocks in households (Ortiz et al., 2023), while in Europe, the initial phase was marked by widespread panic buying and stockpiling, resulting in a sudden increase in domestic food reserves (Pappalardo et al., 2020). These reserves were often not planned in accordance with the actual consumption needs but rather driven by uncertainty surrounding food security (Tabe-Ojong et al., 2022). Consequently, a substantial share of the hoarded food items expired before they could be used. However, research findings diverge regarding the net direction of food waste trends during the pandemic (Allahyari et al., 2022). Some studies emphasize that beyond the initial shock, many households began to adapt through more conscious planning, storage, and food preparation practices, partly as a result of reduced reliance on restaurants

Paper Received: 24 July 2025; Revised: 2 September 2025; Accepted: 1 November 2025
Please cite this article as: Zseni A., Horváth A., Macher G.Z., 2025, Temporal and Spatial Effects of COVID-19 Pandemic on Food Waste Generation in the European Union, Chemical Engineering Transactions, 121, 37-42 DOI:10.3303/CET25121007

and institutional food services (Filimonau et al., 2022a). The closure of the hospitality sector (Bódizs, 2022) and institutional food services created another locus of food waste accumulation (Filimonau, 2021). These entities typically operate with high volumes of rapidly perishable stock, much of which cannot be reallocated when demand plummets (Skawińska and Zalewski, 2022). Despite these structural losses, several countries experienced a rise in food donation initiatives and civil society engagement, wherein surplus food was redistributed to vulnerable populations through non-profit networks (Marshall et al., 2024). Although these interventions could not entirely offset the losses, they played a significant role in mitigating the waste intensity of the affected sectors (Capodistrias et al., 2022). Rather than offering a unilinear outcome, the COVID-19 pandemic revealed both vulnerabilities and adaptive capacities in food systems with respect to food waste (Galanakis, 2023).

The novelty of this research lies in its quantitative investigation of food waste patterns across European Union member states during the COVID-19 pandemic period (2020–2022), focusing on six key food waste parameters. The paper presents how countries with differing historical and economic backgrounds experienced and responded to the crisis in terms of food waste generation. Due to length limitations, this paper presents only a selection of the statistical methods employed during data processing in our broad research. The findings carry significant practical relevance, as they can support EU member states in developing more resilient and sustainable food systems, while informing targeted waste-reduction strategies for the most affected sectors in future crises.

2. Methodology

2.1 Data

The research utilized food waste data from the Statistical Office of the European Union, published on the Eurostat website. Tabular data covering food waste datasets for the EU-27 Member States for the years from 2020 to 2022 were collected. As the Eurostat database provides data on food waste only for the years 2020, 2021, and 2022, our analysis was necessarily limited to this period. The total amount of food waste (TOTAL) is comprised of the sum of five distinct food waste parameters: food waste from primary production of food (FP), manufacture of food products and beverages (MFP), retail and other distribution of food (RDF), restaurants and food services (RFS), and the total activity of households (HHA).

To characterize average food waste per person in each country, the values were converted into units of kg/y/capita using population data from the same source. The “Stringency Index” dataset, sourced from the “Oxford COVID-19 Government Response Tracker,” provided a quantitative measure of pandemic-related interventions that could potentially alter population eating behaviours (Hale et al., 2021). This dataset encompasses daily data for each country, detailing containment and closure policies, economic measures, health system responses, and vaccination strategies. To represent these interventions, the sum of C1 (School closing), C2 (workplace closing), and C6 (stay at home policy) values were employed as an indicator of measures. Given that each of these parameters ranges from 0 to 3, their sum varies from 0 to 9. Annual averages of this sum were calculated for each EU member state for each year, and these values were subsequently utilized to quantify the impact of COVID-19 policies anticipated to substantially affect food waste.

2.2 Methods

Classical statistical calculations and data visualization were applied to investigate yearly changes and to find similarities between countries. The calculations were performed using a self-developed program written in Python language that utilized Scikit-Learn and Scientific Python modules.

To analyse temporal patterns in food waste data, the changes in parameters for each country were calculated between 2020-2021 and 2021-2022. The means and standard deviations of these yearly differences were computed to characterize general trends. The statistics on changes in signs were collected to describe trends during the pandemic, such as identifying the number of countries with a decreasing HHA parameter from 2020 to 2021 and from 2021 to 2022. Correlation coefficients were also determined between the changes in food waste values and COVID-19 Stringency Indices. To ensure well-established conclusions, p-values were calculated to determine the probability that the observed tendency is due to random variation. A significance level of $p<0.05$ was used as the criterion for statistical significance. P-values greater than 0.05 but less than 0.2 were also recorded, but are not regarded as confirmed correlations, rather as indicators for further research. Such "possible" correlations need to be verified in later work.

Stacked histograms were used to display food waste values. This method allows for the representation of the five-component data for each EU Member State across three years in a single figure. To analyse temporal changes, parameter shifts were plotted on a coordinate system, with changes from 2020 to 2021 on the horizontal axis and changes from 2021 to 2022 on the vertical axis. These plots facilitate the identification of countries exhibiting similar trends over time.

3. Results

3.1 Changes in food waste data between 2020 and 2022

Table 1 presents a summary of the intensity of pandemic-related restrictive measures in each EU Member State, which likely influenced food waste generation. For brevity, only the mean and standard deviation of the annual averages across countries are displayed here. These data suggest that restrictive policies (school, workplace, and stay-at-home regulations) in 2020 and 2021 were approximately at the same average level, with a notable decrease in 2022. However, the considerable standard deviations indicate substantial variations among countries within each year.

Table 1: Averages (AV) and standard deviations (STD) of yearly COVID-19 closure parameter averages of EU member states

	AV	STD
2020	3.72	0.71
2021	3.94	0.86

Figure 1 presents a visual depiction of the dataset. For comparative purposes, the population-weighted EU-27 average is displayed on the right side of the histogram. Countries exhibiting the highest total per capita food waste generation, reaching 200 kg annually, include Cyprus, Denmark, and Belgium. Additionally, Greece, Portugal, and Romania demonstrate elevated levels of food waste, ranging from 150 to 200 kg/cap/y. Conversely, Slovenia, Croatia, Spain, and Hungary report the lowest total food waste generation, below 100 kg/cap/y.

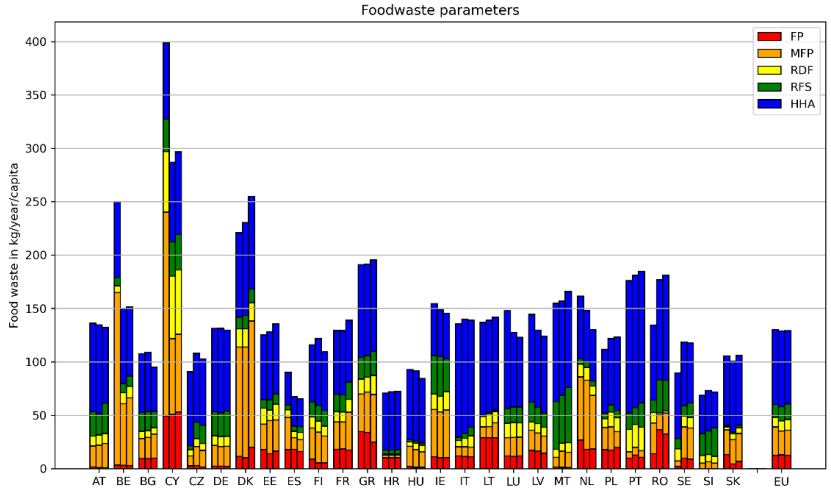

Figure 1: Sectoral distribution of food waste per capita, 2020-2022. First bar: year 2020, second bar: year 2021, third bar: year 2022 (Abbreviations: AT Austria, BE Belgium, BG Bulgaria, CY Cyprus, CZ Czech Republic, DE Germany, DK Denmark, EE Estonia, ES Spain, EU: EU-27, FI Finland, FR France, GR Greece, HR Croatia, HU Hungary, IE Ireland, IT Italy, LT Lithuania, LU Luxembourg, LV Latvia, MT Malta, NL Netherlands, PL Poland, PT Portugal, RO Romania, SE Sweden, SI Slovenia, SK Slovakia)

An analysis of temporal shifts in food waste data reveals that the EU-27 average exhibits no notable fluctuation in the aggregate volume or sectoral allocation of food waste production throughout the assessed 3 y period (Figure 1). Similarly, Germany, Greece, Croatia, and Slovakia demonstrated negligible changes in food waste quantities. A declining trend in food waste generation was observed in Austria, Belgium, Bulgaria, Cyprus, Spain, Finland, Hungary, Ireland, Luxembourg, Latvia, and the Netherlands. Conversely, the amount of total food waste increased in the Czech Republic, Denmark, Estonia, France, Italy, Lithuania, Malta, Poland, Portugal, Romania, Sweden, and Slovenia.

For most nations, the variations across the three years are minimal. However, notable inconsistencies exist in the parameters for Belgium, Cyprus, Spain, Romania, and Sweden, where the 2020 values diverge significantly from those of 2021 and 2022. Visual analysis of the histograms suggests that, for half of the countries, the difference between 2020 and 2021 is larger than between 2021 and 2022. This observation appears to contradict the data presented in Table 1, which indicates similar levels of pandemic regulations in 2020 and 2021, with a substantial decrease in 2022. We hypothesize that the 2020 values are indicative of an

unanticipated exposure of countries and individuals to a pandemic situation, leading to rapid, suboptimal decision-making. Consequently, numerous random elements influenced the 2020 values. Conversely, by 2021, the responses from countries and individuals were more refined. Therefore, the difference between 2021 and 2022 more accurately reflects the actual impact of closures, devoid of the bias introduced by initial panic reactions during the early pandemic years.
Food waste predominantly originates from household and food service sectors (Drofenik et al., 2022), as confirmed by the data presented in Figure 1. In terms of per capita household food waste, Italy and Portugal exhibit the highest quantities. Household activities account for over 60 % of food waste in Austria, Croatia, Czech Republic, Hungary, Italy, Lithuania, Portugal, and Slovakia.

3.2 Statistical analysis of annual changes in food waste parameters

To have well-established conclusions, a quantitative analysis of annual variations is essential. Initially, the differences in parameters were calculated for all 27 EU countries between 2 y transitions, adhering to the standard convention of subtracting the earlier value from the later one. Consequently, a positive sign denotes an increase in a parameter's value year-on-year. Table 2 presents the averages (AV) and standard deviations (STD) of food waste parameters across the 27 EU member states. In these tables, Δ(2021, 2020) and Δ(2022, 2021) represent the differences between years, AV signifies the average, and STD indicates the standard deviation of the EU member state values. The "p-value" represents the estimated probability that the deviation of the mean from 0 is a result of random chance.

Table 2: Statistical data of annual changes of food waste parameters. AV is the average, STD is the standard deviation of the EU member state values in kg/cap/y units, while "p-value" indicates the significance level of the average value.

	Δ(2021, 2020)			**Δ(2022, 2021)**		
	AV	**STD**	**p-value**	**AV**	**STD**	**p-value**
FP	0.15	5.41	0.44	-0.12	3.00	0.42
MFP	-7.50	31.08	0.11	0.82	5.26	0.21
RDF	0.28	2.53	0.28	0.43	1.72	0.10
RFS	**1.39**	4.36	0.05	**1.23**	3.18	0.02
HHA	-0.23	7.47	0.44	**-2.20**	4.63	0.01
TOTAL	-5.90	31.76	0.17	0.16	8.48	0.46

Based on the data presented in Table 2, several conclusions can be made.

- Standard deviations are consistently larger for Δ(2021, 2020) compared to Δ(2022, 2021). This supports the hypothesis that the differences in food waste characteristics were more pronounced between 2021 and 2020 than between 2022 and 2021.
- Shifts in EU average values are generally small relative to the standard deviations, suggesting substantial variations in food waste production changes across different countries. Applying a significance level of $p<0.05$, statistically significant observations for the EU average include an increase in food waste production in restaurants and food services (RFS) during both year transitions, and a substantial decrease in household food waste (HHA) production in 2022 compared to 2021.
- The average food waste production of the retail system (RDF) increased in both year transitions, with p-values of 0.10 and 0.28. This suggests that a continuous increase in RDF is a plausible hypothesis rather than a statistically confirmed statement.
- Another possible but low-significance level trend can be identified in the manufacturing of food product (MFP) parameter (decreasing in the first, increasing in the second year transition) and in the total food waste production change from 2020 to 2021.
- Primary food production (FP) appears to be constant within the accuracy of our data.

The aforementioned findings support the initial hypothesis, suggesting that the responses of countries and individuals during the first year of the pandemic were largely characterized by improvisation. By 2021, sufficient experience had been gained to identify near-optimal procedures and policies. However, pandemic-related closures had an important impact on food processing and eating habits. Consequently, differences between 2020 and 2021 encompass notable stochastic elements, while parameter changes between 2021 and 2022 reflect progressively relaxed pandemic mitigation strategies. Data indicate substantial and divergent trends in food waste generation within households and restaurants, which could be a logical inference. There were no appreciable changes in food waste originating from primary food production and food processing parameters in most of the countries. Simultaneously, the retail sector generated increasing quantities of food waste throughout this period.

3.3 Two-variable diagrams and statistics on direction of parameter changes

The previous subsection presented independent statistics for changes occurring across two-year transitions. To investigate potential relationships between these transitions, two-dimensional diagrams were plotted using Δ(2021, 2020) on horizontal and Δ(2022, 2021) values on the vertical axis, and two-variable statistics were computed, focusing on the signs of food waste parameter changes. The diagrams give an overview of the EU member states' tendencies in food waste parameter changes, while statistics can be used for significance level calculations to determine scientifically well-established statements about trends. Due to the limited size of this manuscript, these results are presented as supplementary material (Zseni et al., 2025).

4. Conclusions

This study analysed the temporal and spatial variations in food waste production across European Union member states during the COVID-19 pandemic, with a specific focus on six key parameters related to food waste. The research explored the temporal and spatial dynamics of food waste generation and shifts in food waste trends throughout the 2020-2022 period. The statistical analysis revealed the following key findings:

- Food waste parameters exhibited notable shifts between 2020 and 2022, and differences observed between 2020 and 2021 are much larger than between 2021 and 2022.
- Variations in national responses were considerable, and the presented graphs were provided to aid in identifying countries deviating from broader patterns.
- Statistically significant trends indicate a continuous increase in food waste generation from restaurants and food services during the COVID-19 pandemic. Conversely, household food waste production decreased from 2021 to 2022.
- The data suggest a potential declining trend in food waste originating from primary food production.

The observed results appear to contradict the fact that 2020 and 2021 were roughly similar in terms of COVID-19 lockdowns, while by 2022, restrictions had eased considerably. A probable explanation suggests that the initial epidemic period caught countries off guard, leading to numerous improvised measures and rendering 2020 an exceptional year. By 2021, sufficient experience had been gained to manage the situation more methodically, facilitating a smoother transition from 2021 to 2022. Similar patterns have been documented in recent literature, which highlight a significant increase in waste generated by RFS during the pandemic (Xiang et al., 2023). Studies attribute this rise primarily to the widespread adoption of food delivery and takeaway services, which resulted in increased packaging waste (Iimuro and Tabata, 2024) and operational inefficiencies (Massoud and Zoghi, 2024). These findings confirm the observed shift in waste distribution patterns between households and the RFS sector across Europe (Filimonau et al., 2022b). On average across the EU, the food waste parameter associated with restaurants and their services increased from 2020 to 2021, driven by the surge in food delivery companies. This trend continued from 2021 to 2022 as guests returned to dining establishments following the relaxation of restrictions. The latter phenomenon may also account for the decrease in waste generation by households.

Although many processes have not fully returned to their pre-pandemic state, our future research will replicate these studies once the post-COVID (2023 and beyond) data series is released. This will allow for a more robust and reliable assessment of COVID-19's impact on food waste production.

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