Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2025, Volume 13, Issue 3, 1130579

Original Research Article

Using Multivariate Statistical Analysis for Examining the Relationship between Food Waste Generation and Socio-economic Factors

Anikó Zseni[1], András Horváth[1], Gergely Z. Macher[1], Dóra Sipos[1], Judit Pécsinger[1]

[1]Széchenyi István University, Hungary, Győr

e-mail: zseniani@sze.hu

Cite as: Zseni, A., Horváth, A., Macher, G. Z., Sipos, D., Pécsinger, J., Using Multivariate Statistical Analysis for Examining the Relationship between Food Waste Generation and Socio-economic Factors, J.sustain. dev. energy water environ. syst., 13(3), 1130579, 2025, DOI: https://doi.org/10.13044/j.sdewes.d13.0579

ABSTRACT

Food waste contributes to social inequalities and sustainability issues by worsening resource overuse and environmental harm. The United Nations Sustainable Development Goal 17 highlights the importance of reducing food waste to address hunger and promote a sustainable, economically viable global food system. This paper examines the geographic differences in food waste levels among European Union member nations and analyses the associations between food waste and diverse environmental, geographic, social and economic indicators, including Sustainable Development Goals and other sustainability metrics. Using dimensionality reduction methods, non-trivial multivariate connections between food waste and these parameters were identified, allowing for the characterization of countries based on a few significant factors. Principal Component Analysis (PCA) was applied to food waste data across European Union countries, which uncovered three distinct groups: (1) those with elevated food waste in primary production, manufacturing and distribution stages; (2) those with lower waste in these domains yet greater waste in restaurants and households; and (3) those with all of their food waste components are smaller than or equal to the average. The multivariate linear correlation between the PCA factors and socio-economic parameters is non-significant, but a few (non-linear) regularities could be identified: five of the six countries of the first group above are characterized by plains and an above-average supply of meat or fish. Another pattern observed is that former Eastern Block countries belong to the third group. The research findings offer valuable insights that can inform the efforts of environmental experts, professionals and policymakers working in the circular economy and waste management domains. This knowledge can facilitate the development of more effective strategies aimed at mitigating food waste and promoting sustainability.

KEYWORDS

Sustainable Development Goals, food waste, food consumption, socio-economic indicators, Principal Component Analysis, "multidimensional linear regression"

INTRODUCTION

Food waste is a complex issue influenced by various factors, including the perishable nature of food, unpredictable supply and demand dynamics, limited control over production factors, as well as social elements like household composition, lifestyle choices and eating habits. Both private and public stakeholders may prioritize other concerns, such as profit maximization or regulatory compliance, over addressing food waste. The inefficient use of technology in the supply chain, organizational weaknesses, inadequate legislation and lack of awareness about proper consumption further worsen the problem [1].

In the near future, food production will face numerous challenges as the world's population continues to grow, and per capita intake of calories, protein and cereals is expected to increase further. According to the World Resources Institute, feeding 9-10 billion people by 2050 will require a 70% increase in food calories compared to 2006 levels. Mitigating food waste is a potential approach to achieving a sustainable food supply, but it alone cannot completely solve the problem. According to UNEP, in 2016, a total of 931 Mt of food was wasted from households, retail establishments, and the food service industry, which suggests that 17% of total global food production may be wasted [2]. It is reported that 61%, nearly 570 Mt, of this waste comes from households, 26% from food service, and 13% from retail. The average global per capita food wastage stands at 74 kg, with minor difference between various income level countries (high-income countries: 79 kg/capita/y, upper middle-income countries 76 kg/capita/y, lower middle-income countries: 91 kg/capita/y). This indicates the necessity of improvement in most nations irrespective of their economic status [2].

The EU generates over 58 Mt of food waste annually [3], with a market value estimated at 132 billion euros [4]. According to Eurostat estimation, approximately 10% of food available to EU consumers may be wasted across retail, food services and households. At the same time, more than 37 million people cannot afford a quality meal every second day [5].

The total food waste data for EU-27 is 130 kg/capita in 2020, including 12.30 kg/capita (9.4%) for primary production, 26.85 kg/capita (20.6%) for manufacture of food products, 8.95 kg/capita (6.9%) for retail and other distribution, 11.86 kg/capita (9.1%) for restaurants and food services and 70.25 kg/capita (54%) for households [3].

The analysis of the reviewed literature clearly demonstrates that food waste is an extremely complex issue influenced by numerous factors, including the perishable nature of food, unpredictable supply and demand dynamics, and limited control over production factors [6]. Additionally, social elements such as household composition, lifestyle choices and eating habits play a significant role. Both private and public stakeholders often prioritize other concerns, such as profit maximization or regulatory compliance, which further exacerbates the problem of food waste. Previous research has shown that consumers' perceptions, behaviours, attitudes, beliefs, and values regarding food and waste are the primary factors driving food waste and loss [7].

Food waste has numerous environmental, economic and social consequences. Unnecessarily wasting resources used in food production, such as water and energy, places a significant burden on the environment. Food waste accounts for approximately 6% of total greenhouse gas emissions [8]. Economically, food waste represents a substantial loss for both producers and consumers. Socially, it deepens food insecurity and poverty in communities where it is a serious problem. Much of this wastage occurs at the point of consumption in the developed world [9]. These factors lead to the discarding of edible food that could have been consumed, resulting in unnecessary waste and its associated negative impacts [10].

The bioactive compounds present in food waste offer promising opportunities to convert this waste stream into value-added products across diverse fields [11], such as nutritional foods, bioplastics, biosurfactants, biofertilizers and single-cell proteins, which have identified food waste as a novel and promising source material [12]. Diverse food waste streams, such as fruit, vegetable and lipid-rich residues, can be utilized for the synthesis of various biopolymers, including polyhydroxyalkanoates, starch, cellulose, collagen and others [13]. Studies conducted in Malaysia have demonstrated the public's favourable reception of rice crackers produced from rice food waste [14]. Furthermore, the people's willingness to pay a specific amount to process their food waste suggests a high potential for the marketability of food waste recycling [14].

Repurposing food waste into energy also offers potential economic and environmental advantages within a circular economic framework. Food waste can be addressed through a range of treatment methods, encompassing thermochemical (incineration, pyrolysis, gasification, torrefaction and hydrothermal carbonization), biological (anaerobic digestion, composting, aerobic fermentation, dark fermentation and photofermentation) and chemical processes (transesterification) [15]. The environmental impacts of the various methods were thoroughly examined through life cycle assessment studies. Based on this comparative analysis, anaerobic digestion emerges as one of the most effective conventional approaches, while esterification, gasification and hydrothermal carbonization prove to be the superior thermochemical methods [16].

Reducing food waste is crucial not only for environmental sustainability, such as resource exploitation and greenhouse gas emissions [17] but also for economic and social reasons as well as addressing food insecurity [18]. Various methods can be used at the household level to reduce food waste, including meal planning and mindful shopping [19], proper food storage such as refrigeration or freezing, creative repurposing of leftovers into new meals, composting food scraps instead of discarding them, and donating excess food to local food banks or shelters [20]. Increasing the efficiency of food production and transport is also crucial in prevention efforts [21].

Community dining venues such as school canteens and university cafeterias can employ various strategies to mitigate food waste, including testing spoons, awareness campaigns, plate waste tracking, guest forecasting tools, reducing plate and utensil sites, offering menu options, adapting online prebooking meal system etc. [22]. According to research conducted in Swedish school canteens, awareness campaigns proved most effective in reducing plate waste (by 13 g per portion), while forecasting and plate waste tracking interventions were most successful in reducing serving waste (by 34 and 38 g/portion) [23].

The paper focuses on examining geographical variations in food waste quantities within EU-countries and its possible connection with various environmental, social and economic factors including selected indicators of Sustainable Development Goals. Our study recognizes that while prior research has examined the issue of food waste, the exploration of multivariate relationships and geographical differences across EU countries has been limited. Recent researches lack comparison of food waste behaviour across countries and regions [24].

In our previous work [25], correlation coefficient calculation was used to find the relationship between food wastage and predefined environmental, economic, and social indicators. However, the results did not reveal any non-trivial connections between food waste and social-economic parameters. It is assumed that there should be some connections, but a more sophisticated method is needed to uncover them because the effect of unknown parameters and measurement error bias them. Two methods were used to find non-trivial multivariate connections between food waste and other parameters: The K-means clustering method and the principal component analysis method. In our previous work, the K-means clustering method was applied to find the groups (clusters) of countries with similar food waste characteristics and collect the social parameters for every group [25]. It could be proven by cluster analysis that historical past has a significant role in food waste parameters, and several significant differences between socio-ecological parameters were found. In this paper, the results of the examination based on the Principal Component Analysis (PCA) method are introduced.

The novelty of this research lies in its introduction of a new methodology for uncovering the relationships between food waste and related parameters, as well as for conducting a more integrated, multidimensional analysis of food waste profiles across EU member states. These findings are not only relevant to the academic community but also hold practical significance for professionals and policymakers in the fields of circular economy and waste management, facilitating the development of more effective strategies.

DATA AND METHODS

Data

The research is based on the datasets of the Statistical Office of the European Union, which have been published on the Eurostat website. The quantitative assessment commenced by collecting relevant tabular data from Eurostat about food waste datasets for the EU-27 Member States for 2020, as well as thirty-three selected environmental, geographical, social, and economic indicators that are assumed to have connections with food waste generation. The basic year (2020) was selected due to the availability of comprehensive data-set at the time of manuscript preparation. Table 1 provides a summary of the indicators investigated during the research. Regarding the six types of food waste data, the total amount of food waste (TOTAL) consists of the sum of the following 5 food waste parameters (Eq. (1)): 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):

$$TOTAL = FP + MFP + RDF + RFS + HHA \tag{1}$$

Table 1. Selected indicators for the research

Abbreviation	Indicators	Reference
TOTAL	Total (aggregate changing according to the context) - Food Waste (t, kg/capita)	[26]
FP	Food waste from primary production of food - agriculture, fishing and aquaculture (t, kg/capita)	[26]
MFP	Food waste from manufacture of food products and beverages (t, kg/capita)	[26]
RDF	Food waste from retail and other distribution of food (t, kg/capita)	[26]
RFS	Food waste from restaurants and food services (t, kg/capita)	[26]
HHA	Food waste from total activities by households (t, kg/capita)	[26]
AOF	Area under organic farming (% of total utilized agricultural area)	[27]
COFP	Consumption footprint (per inhabitant)	[28]
CMR	Circular material use rate (%)	[29]
ELET	Early leavers from education and training by sex (%)	[30]
FECH	Final energy consumption in households per capita (kg of oil equivalent)	[31]
GDP	GDP and main components (output, expenditure, and income) (current prices, million euro and per capita)	[32]
GVAEGS	Gross value added in environmental goods and services sector, reference year 2010 (million euro and per capita, chain-linked volumes at 2010 exchange rates)	[33]
GWHP	Gross weight of goods handled in all ports by direction - annual data (kt)	[34]
HCOR	Housing cost overburden rate by poverty status (%)	[35]
IAF	Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day - EU-SILC survey (%)	[36]
MF	Material footprint (tonne/capita)	[37]
MSDR	Severe material and social deprivation rate (%)	[38]
MWG	Municipal waste by waste management operations (kt and per capita)	[39]
NSFT	Nights spent at tourist accommodation establishments by residents/non-residents (number)	[40]
POP2020	Population on 01.01. 2021 - total (number)	[41]
POPCHG	Difference between population 01.01. 2021 and 01.01. 2020 (%)	[41]
POPCHTOT	Crude rates of population change, total (%)	[42]
POPCHNAT	Crude rates of population change, natural (%)	[42]
POPCHMIG	Crude rates of population change, migration + statistical correction (%)	[42]
PPGDP	Purchasing power adjusted GDP per capita (GDP/capita in purchasing power standards)	[43]
PUKHW	Population unable to keep home adequately warm by poverty status (%)	[44]
REG_URB	Region type: Urban (% of the total area of the country)	[45]

REG_INT	Region type: Intermediate (% of the total area of the country)	[45]
REG_RUR	Region type: Rural (% of the total area of the country)	[45]
REG_COA	Region type: Coastal (% of the total area of the country)	[45]
REG_MOU	Region type: Mountain (% of the total area of the country)	[45]
REG_ISL	Region type: Island (% of the total area of the country)	[45]
REG_BOR	Region type: Border (% of the total area of the country)	[45]
RMRPG	Relative median at-risk-of-poverty gap (%)	[46]
RMW	Recycling rate of municipal waste (%)	[47]
RPS	People at risk of poverty or social exclusion (thousand persons and per capita)	[48]
TEA	Tertiary educational attainment by sex (%)	[49]
WGPC	Waste generation per capita (kg/capita)	[50]

According to the methodology of the EU database, geographical data such as REG_URB or REG_MOU are based on the population parameters of the regions. Therefore, REG_MOU can be zero if there are mountains in the country, but no region has a dominant mountain-dwelling population.

Investigation procedure

Every country has five food waste parameters of different types (food waste generated by the primary production of food (FP), the manufacture of food products and beverages (MFP), the retail and other distribution of food (RDF), restaurants and food services (RFS), and households (HHA) (see Table 1). Mathematical methods for analysing food waste characteristics handle these parameters as five-dimensional vectors. One possible approach to analyse this 5-dimensional data set is clustering, which was performed in our previous work [24]. Another method is reducing the dimension of the data set.

A classical method of dimensionality reduction is Principal Component Analysis (PCA) [51], which begins by calculating the average vector of the set and then determining the difference between each vector and the mean vector. The next step is finding the direction in which the set of these difference vectors is most elongated – representing the "most important" one – and characterising it with a unit-length vector. Then, the subsequent (second, third, etc.) most important directions that are orthogonal to the previous ones are calculated. In our case, it means that there are five 5-dimensional base vectors; however, the first ones are more important than the subsequent ones. In several applications, just the first two or three PCA components are enough to reproduce the many-dimensional data points with measurement accuracy. PCA for the dataset was performed using SciKit-Learn software.

After conducting PCA on the dataset, it could be determined that with only two components, the average reconstruction accuracy was 4.51 kg/capita/y for the country data. Although the data source does not provide numerical measurement error values, it can be estimated that the average error of the food waste components is approximately within this range. It is noteworthy that the main vector's components have an average distance from the table data of 13.13; however, with one PCA component, this error reduces to 7.44 and further decreases to 4.51 when utilising two components and then to 3.27 with three components - indicating only a small improvement upon adding a third component. The outcome of PCA resulted that instead of five components for each country, the mean vector and two base vectors (s_1 and s_2) were provided for the entire dataset (Eq. (2)) (see right-side diagram of Figure 1); thus, food waste of each country can be characterised by using only two components: P1 and P2:

$$foodwastecomponents \approx mean\ P1 \times s_1 + P2 \times s_2 \tag{2}$$

The P1 component encompasses food waste from primary production (FP), the manufacturing of food production (MFP), and the distribution of food production (RDF). These activities are less dependent on individual habits and are more reflective of the specificities of the economic sector (like agriculture, industry, and transportation). The P2 component includes food waste from restaurants and other food services (RFS) as well as from households (HHA), which are assumed to be much more strongly influenced by individual consumption, eating, and cooking habits than in the case of the previous three indicators.

One- and multidimensional linear regression between PCA factors and non-food waste indicators were applied to find possible linear connections. In the multivariate case, the Lasso method [52] with 2 to 10 variables was applied. This regression algorithm tries to use as few base functions as possible to avoid the artefact of overfitting.

Additionally, a visual analysis of plots was performed to find a nonlinear relation between PCA factors and socio-economic-geographical indicators.

RESULTS

The left diagram of Figure 1 shows the five food waste parameters of the 27 EU members.

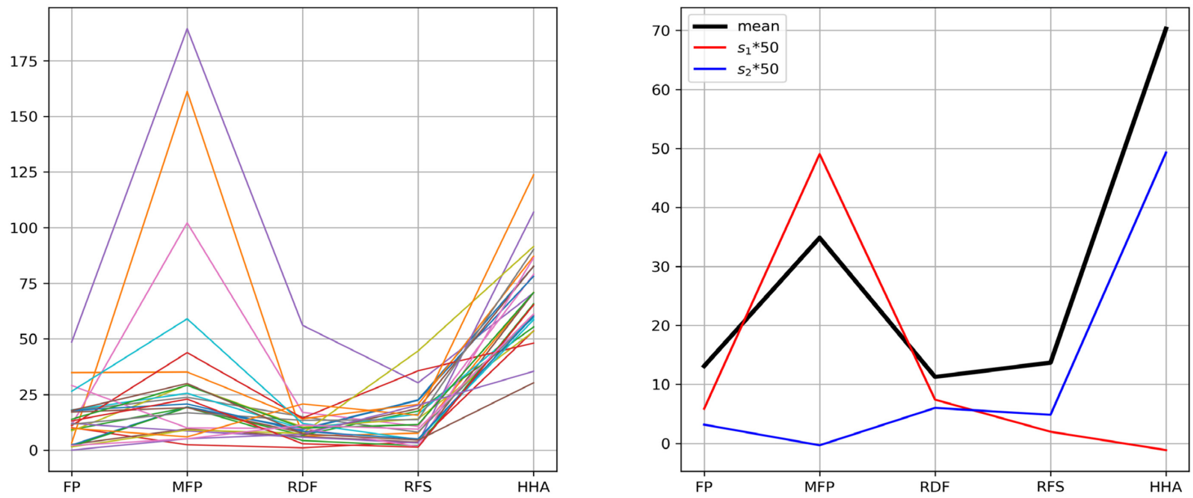

Figure 1. Food waste components of the 27 EU-members (left) and mean vector and base vectors (scaled) of PCA (right) (unit: kg/capita/y)

While there are noticeable variations in the quantity of various components, it is evident that different types of countries can be identified: some exhibit a high value of food waste from the manufacture of food products and beverages (MFP) but relatively low food waste from retail and other distribution of food (RFS), while others show values above the average for both parameters. Nevertheless, recognizing patterns in this diagram proves to be challenging.

Figure 2 shows EU members in the P1-P2 plane after conducting PCA on the dataset. The origin (0, 0 point) is near Romania because this country's food waste parameters are the closest to the EU average. Three countries (Denmark, Belgium, and Cyprus) have significant positive P1 values, which means that they are highly above the average in MFP (food waste from manufacturing of food production), FP (food waste from primary production), and RDF (food waste from distribution of food production), according to the s_1 base vector. Meanwhile, they have approximately zero P2 values, which includes food waste from restaurants and other food services (RFS) as well as from households (HHA). Three more countries (Greece, Ireland, and Netherlands) have positive P1, and all of them have moderate P2 values. This reveals a non-trivial connection between food waste components: if a country's first PCA component is over the average, the second component is close to the average. On the other hand, if P1 is negative, then P2 can be a significant negative or positive value. This special connection between PCA components results in large empty areas in Figure 2 over and under the green dotted lines. According to this, the countries can be divided into three groups:

1. P1>0: Cyprus, Belgium, Denmark, Netherlands, Ireland, and Greece. Their difference from the average food waste characteristics is mainly in s1 direction, which means high excess in food waste from manufacture of food products (MFP), and significant excess in food waste from primary production (FP) and food waste from distribution of food production (RDF) components.
2. P1<0 and P2>0: Portugal, Italy, Malta, Luxembourg, Lithuania, Latvia, Austria, Germany. They have below the average values in FP, MFP, and RDF, but excess in food waste from households (HHA) and food waste from restaurants and other food services (RFS) values.
3. P1<0 and P2<0: Romania, Czech Republic, Slovakia, Hungary, Sweden, Poland, Estonia, France, Croatia, Bulgaria, Finland, Slovenia, Spain. All of their food waste components are smaller than or equal to the average.

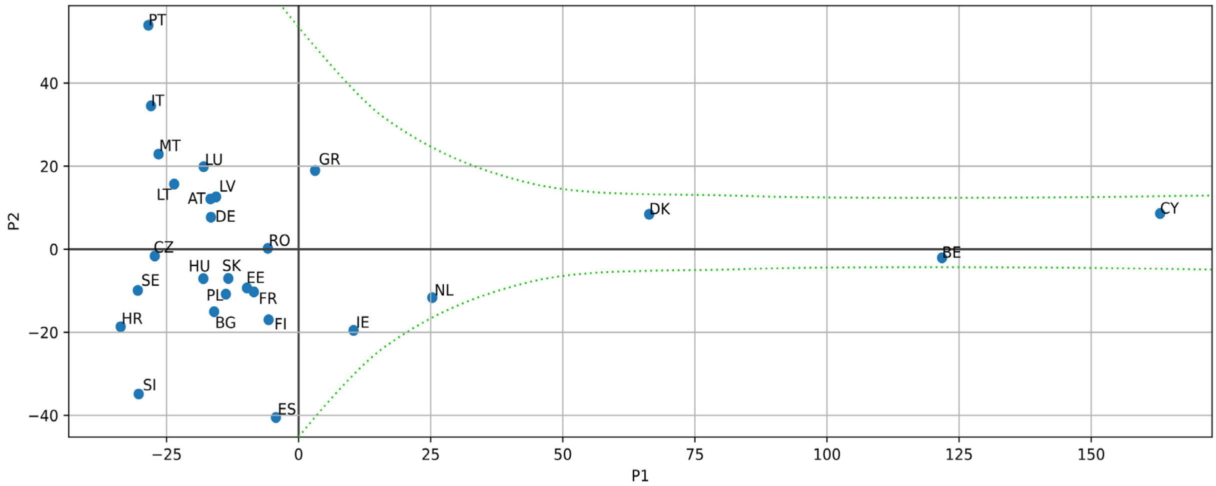

Figure 2. EU countries in P1-P2 plane. (Abbreviations: AT Austria, BE Belgium, BG Bulgaria, CY Cyprus, CZ Czech Republic, DE Germany, DK Denmark, EE Estonia, ES Spain, FI Finland, FR France, GR Greece, HR Croatia, HU Hungary, IE Ireland, IT Italy, LT Lithuania, LU Luxembourg, LV Latvia, MT Malta, NL Netherlands, PL Poland, PT Portugal, RO Romania, SE Sweden, SI Slovenia, SK Slovakia).

Uncovering the reasons behind these results is challenging, particularly because the correlation coefficients did not reveal a clear connection with the examined geographic, economic and social indicators.

Belgium, Denmark, Netherlands and Ireland are geographically close to each other and have similar geographical features such as seashores and weather conditions. The relief is similar in the case of Belgium, Denmark and Netherlands. These similarities may have a comparable impact on their agriculture systems, similar to the case of Greece and Cyprus. In these countries, the primary production, manufacturing and distribution of food result in more food waste compared to others. This raises intriguing but challenging questions that encourages further investigation. Economic factors associated with food waste on farms and throughout the supply chain, are encompassing price fluctuations, workforce insurance costs, supply chain constraints, commercial and client performance, agreement incentives and other existing policies [6]. Foregoing the harvesting of fields due to low market demand or low prices is one of the primary causes of food waste [7].

Geographically and culturally, Portugal, Italy and Malta share similar features. It is reasonable to assume that eating out is more common in these countries, which could be linked to a higher P2 value associated with a higher amount of food waste from restaurants and other food services (RFS). There is also a cultural and/or historical similarity due to the geographical proximity between Austria-Germany-Luxembourg and Lithuania-Latvia. In these eight countries, the amount of food waste from households (HHA) and food waste from restaurants and other food services (RFS) are higher compared to other countries, indicating more wasteful eating and cooking habits. This is particularly noteworthy in the case of the three Mediterranean countries.

The history of the countries must have a significant effect on food waste parameters, because most of the formal Eastern Bloc countries are in the third group. This is in good accordance with the results of our former cluster analysis results [25].

The connection between the PCA components (P1, P2) and the selected indicators was investigated. At first, the linear correlation coefficient was calculated for every possible pair of a socio-economical parameter and a PCA component. The result is negative: there was no case with at least 0.7 correlation coefficient. To extend the calculations in multi-dimension, the hypothesis that a linear combination of a few socio-economic parameters is suitable for reconstructing PCA components was investigated. Unfortunately, the result is negative: with ten or fewer components, the maximum correlation factor did not reach 0.7.

After the negative results of linear regression, plot pairs for all 33 geographical, social and economic parameters and the two PCA components were generated, and visually checked for any pattern. On a few of these plots, the members of the first group (P1>0) introduced above, formed a special set. Figure 3 shows the mountain type area percentage (REG_MOU) case as an example. Here 5 of the 6 members of the first group have almost 0 mountain-percentage value, which means that no region has a dominant mountain-dwelling population.

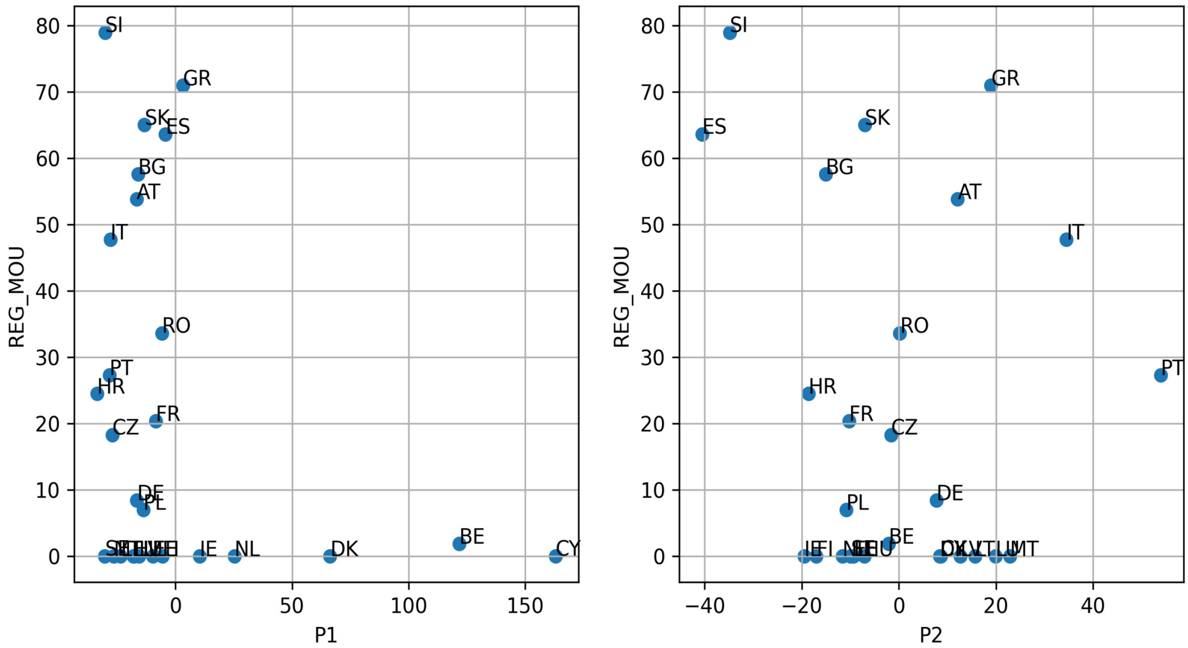

Figure 3. Plots of mountain area versus PCA components

Similar regularity is present in the IAF (Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day) plot (Figure 4). The only exception is Greece, which has the smallest P1 value in the first group. It can be established that the five countries with the largest P1-value (Ireland, Netherlands, Denmark, Belgium, and Cyprus) have a below-average percentage of mountain areas and a small percentage of persons who cannot afford meat or fish every second day. Moreover, these 5 countries have near to zero P2 values, which means average amount of food waste from household (HHA) and average amount of food waste from restaurants and other food services (RFS).

Despite the many uncertainties, the quantity of food waste, and especially its RFS (food waste from restaurants and other food services) and HHA (food waste from household) components that determine the P2 component, can be related to cultural and historical events affecting the countries. According to a study on the determinants and country differences of food consumption in the EU during the last decade of the 20th century, food consumption in European Union countries can be summarized by four major trends [53] (countries that joined later were not part of the study): a decrease in the proportion of expenditure allocated to food, already at very low levels; reaching maximum level in total food consumption; a shift in the structure of food consumption; and an increase in the proportion of food consumed outside home. This latter trend is common for all countries but varies widely in intensity based on labour circumstances and social aspects. Single-person households, younger individuals and families with young children may be more inclined to seek out various meal options outside the home [6], which can be related to the increased amount of food waste from restaurants and other services. Palatability, pricing, portion size, temporal limitations, dishware dimensions, suboptimal catering operations, fluctuating diner populations and caloric content can represent the prevailing originating factors of food waste in the case of restaurants and other food services [7].

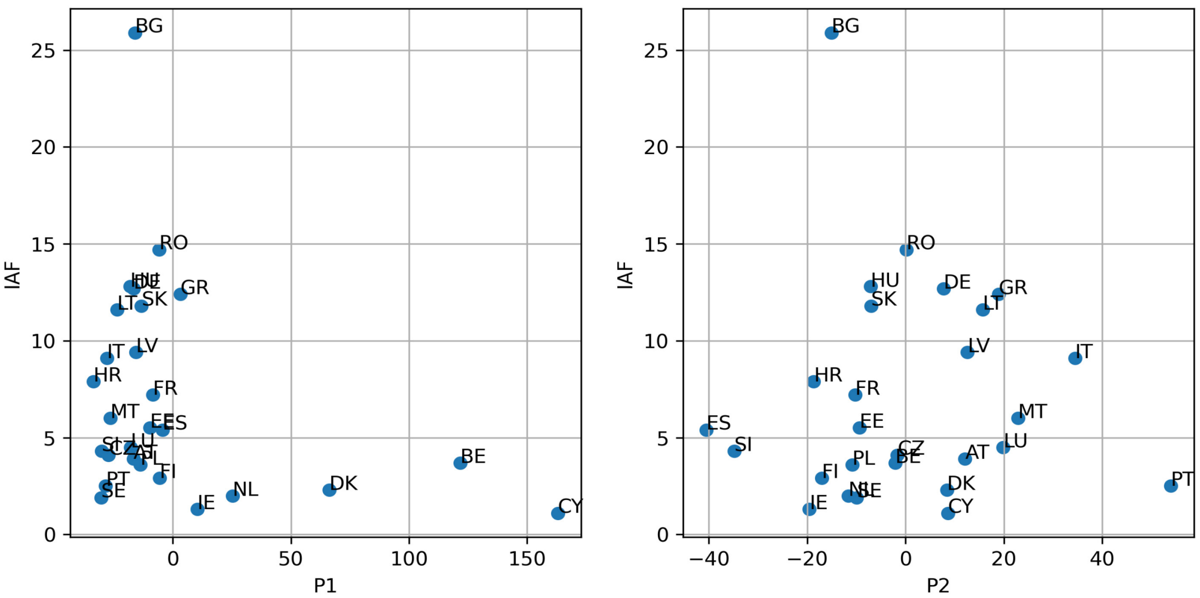

Figure 4. Plots of IAF (Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day) versus PCA components

According to previous studies, factors contributing to individual food waste include personal habits, interests, and perceptions regarding food appearance, quality, and the ability to consume large quantities and a diverse range of foods, regardless of geographic location or season [6, 7, 54]. Consumers' tendency to engage in excessive purchasing can be attributed largely to their impulsive buying behaviour and lack of mindfulness when shopping. Conversely, consumers' heightened disgust sensitivity may lead them to discard products beyond the recommended best before date without verifying their edibility [55, 56]. The main causes of food waste in private households are food overprovisioning, improper storage, transportation challenges, overcooking, large portions, difficulty managing leftovers, lack of knowledge about assessing food edibility and packaging issues [7].

In a previous study [57], the analysis focused on whether Europeans (including only member states at that time) were homogeneous or heterogeneous in terms of food behaviour and attitudes. The findings indicated that despite the globalization of food processes, Europe could not be conclusively seen as a uniform bloc with regard to food culture. The research suggests that national boundaries combined with language barriers remain strong indicators and best predictors of variations in food-related behaviours [58].

Research utilizing primary data from the United States, Canada, the United Kingdom and France examined and compared consumers' food waste behaviours. The findings indicate that age, dining outside the home, and using expiration dates and appearance to assess food spoilage are associated with increased frequency of food waste, and these trends are consistent across the studied countries. Furthermore, the researchers observed notable differences in food waste behaviour among the countries, suggesting that cultural factors play a significant role in shaping such practices [24].

Cultural values, acquired preferences, and ways of life all play a substantial role in shaping food consumption. The formation of habits influences attitudes and inclinations towards food products, which persist over time. Variations in dietary patterns across different countries can largely be attributed to historical factors such as local production and physical availability [59].

Governments can play a significant role by incorporating education campaigns to change consumer habits and preferences [60], implementing municipal composting programs, and providing tax credits to farmers who donate excess produce [61]. These actions help individuals and households reduce their food waste while contributing to national target of reducing food waste by 50% by 2030 aimed at improving overall food security and conserving natural resources. Collective action is required to tackle this pressing global problem [62].

Findings from our present study and previous research [24] also suggest that researchers and policymakers should account for cultural factors when developing strategies and policies to mitigate food waste within their respective countries. It is crucial to recognize that an effective food waste reduction policy requires country-specific tailoring, as consumers exhibit varying food waste behaviours across different nations. The successful approach implemented in one country or region may not necessarily be applicable to others. Consequently, research and policies should focus on addressing the unique circumstances of each individual country or region to ensure contextual relevance and efficacy.

CONCLUSIONS

The current research aims to explore the relationship between indicators of food waste and various environmental, geographical, social, and economic factors, using multivariate statistical methods to reveal their interdependencies. Due to the complexity of this field and the limited data availability, previous works could not find any measurable connection.

Our investigation produced both positive and negative results. The analysis presented in this paper indicates that food waste indicators do not exhibit a linear association with socio-economic factors. Univariate linear analysis revealed no significant correlation between any of the examined five food waste parameters and the 33 socio-economic parameters. This finding aligns with preceding studies. The Lasso method with 2 to 10 variables was applied, but the current multivariate linear regression investigations did not find statistically significant correlations.

Principal Component Analysis demonstrated that the five parameters characterizing food waste within the member states could be reduced to two PCA components. These two principal components summarize key food waste characteristics and enable cross-country comparisons. Furthermore, this result may be significant for further research as dimensional reduction can aid general visualization and understanding. The plane of these two components is not evenly covered by the countries, which indicates a hidden relationship behind these parameters. The recognized pattern was described in the article, but the exploration of the underlying reasons is the subject of further research.

The present study identified three distinct clusters in the PCA-based classification of countries. The first group, characterized by high food waste in the early stages of the supply chain, includes six countries where primary production, manufacturing, and distribution waste is predominant. In contrast, the second group (8 countries) experiences lower waste generation in these domains but more significant waste generation in restaurants and households. The third cluster, comprising 13 countries, can be characterized by reduced food waste across the studied sectors.

The analysis determined that these patterns are shaped by geographic, cultural, and historical factors rather than by direct socio-economic influences. The multivariate linear correlation between the PCA factors and socio-economic parameters remains weak, but a few non-linear regularities could be identified. For instance, five of the six countries in the first group above are characterized by plains and an above-average supply of meat or fish. Another pattern observed is that former Eastern Block countries belong to the third group. Additional research is necessary to investigate the underlying factors driving these trends.

These results provide important information for decision-makers, environmental specialists, and practitioners in the circular economy and waste management fields. Understanding these country-level patterns may contribute to developing more effective food waste mitigation strategies, tailored to regional characteristics.

REFERENCES

1. Canali, M., Östergren, K., Amani, P., Aramyan, L., Sijtsema, S., Korhonen, O., Silvennoinen, K., Moates, G., Waldron, K. and O'Connor, C. Drivers of current food waste generation, threats of future increase and opportunities for reduction, in: FUSIONS Reducing food waste through social innovation, (Technical) Report, Bologna, Italy, 2014, https://www.researchgate.net/publication/297001052_Drivers_of_current_food_waste_generation_threats_of_future_increase_and_opportunities_for_reduction, [Accessed: 24-March-2024].
2. United Nations Environment Programme, Food Waste Index Report 2021, Job No. ROW/2366/BA, UNEP, Nairobi, 2021, https://catalogue.unccd.int/1679_FoodWaste.pdf, [Accessed: 24-March-2024].
3. Eurostat dataset: Food waste [cei_pc035], https://ec.europa.eu/eurostat/databrowser/view/cei_pc035/default/table, [Accessed: 02-March-2024].
4. European Commission, Impact Assessment Report Accompanying the document Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste, SWD (2023) 421 final, Brussels, 2023, https://data.consilium.europa.eu/doc/document/ST-11624-2023-ADD-4/EN/pdf, [Accessed: 24-March-2024].
5. Eurostat dataset: Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day - EU-SILC survey [ilc_mdes03__custom_10189522], https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes03__custom_10189522/default/table, [Accessed: 02-March-2024].
6. Al-Obadi, M., Ayad, H., Pokharel, S. and Ayari, M.A., Perspectives on food waste management: Prevention and social innovations, *Sust. Prod. Cons.*, Vol. 31, pp 190-208, 2022, https://doi.org/10.1016/j.spc.2022.02.012.
7. Varese E. and Cesarani, M.C., Consumers' perception of suboptimal food: strategies to reduce food waste, *Brit. Food J.*, Vol. 125, No. 1, pp 361-378, 2023, https://doi.org/10.1108/bfj-07-2021-0809.
8. Economou, F., Voukkali, I., Papamichael, I., Phinikettou, V., Loizia, P., Naddeo, V., Sospiro, P., Liscio, M.C., Zoumides, C., Tirca, D.M. and Zorpas, A.A., Turning food loss and food waste into watts: a review of food waste as an energy source, *Energies*, Vol. 17, Article number 3191, 2024, https://doi.org/10.3390/en17133191.
9. Stöckli, S., Niklaus, E. and Dorn, M., Call for testing interventions to prevent consumer food waste. *Resour. Conserv. Recy.*, Vol. 136, pp 445-462, 2018, https://doi.org/10.1016/j.resconrec.2018.03.029.
10. Melikoğlu, M., Lin, C. and Webb C., Analysing global food waste problem: pinpointing the facts and estimating the energy content, *Cent. Eur. J. Eng.*, Vol. 3, No. 1, pp 157-164, 2013, https://doi.org/10.2478/s13531-012-0058-5.

11. Rakesh, B. and Mahendran R., Upcycling of food waste and food lost – A sustainable approach in the food sector, *Trends Food Sci. Tech.*, Vol. 143, Article number 104274, 2024, https://doi.org/10.1016/j.tifs.2023.104274.
12. Liu, Z., de Souza T.S.P., Holland, B., Dunshea, F., Barrow, C. and Suleria, H.A.R., Valorization of food waste to produce value-added products based on its bioactive compounds, *Processes*, Vol. 11., Article number 840, 2023, https://doi.org/10.3390/pr11030840.
13. Gautam, K., Vishvakarma, R., Sharma, P., Singh, A., Gaur, V.K., Varjani, S. and Srivastava, J.K., Production of biopolymers from food waste: Constrains and perspectives, *Bioresource Technol.*, Vol. 361, Article number 127650, 2022, https://doi.org/10.1016/j.biortech.2022.127650.
14. Jamaludin, H., Elmaky H.S.E. and Sulaiman, S., The future of food waste: Application of circular economy, *Energy Nexus*, Vol. 7, Article number 100098, 2022, https://doi.org/10.1016/j.nexus.2022.100098.
15. Singh, A., Singhania, R.R., Soam, S., Chen, C.W., Haldar, D., Varjani, S., Chang, J.S., Dong, C.D. and Patel, A.K., Production of bioethanol from food waste: Status and perspectives, *Bioresource Technol.*, Vol. 360, Article number 127651, 2022, https://doi.org/10.1016/j.biortech.2022.127651.
16. Batool, F., Kurniawan, T.A., Mohyuddin, A., Othmann M.H.D., Azaz, F., Al-Hazmi H.E., Goh, H.H. and Anouzla, A., Environmental impacts of food waste management technologies: A critical review of life cycle assessment (LCA) studies, *Trends Food Sci. Tech.*, Vol. 143, Article number 104287, 2024, https://doi.org/10.1016/j.tifs.2023.104287.
17. Hiç, C., Pradhan, P., Rybski, D. and Kropp, J.P., Food Surplus and Its Climate Burdens, *Environ. Sci. Technol.*, Vol. 50, No. 8, pp 4269–4277, 2016, https://doi.org/10.1021/acs.est.5b05088.
18. Mena C., Adenso-Diaz, B. and Yurt, O., The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resour., Conserv. Recy.*, Vol. 55, No. 6, pp 648-658, 2011, https://doi.org/10.1016/j.resconrec.2010.09.006.
19. Mozos, E.A., Badurdeen, F. and Dossou, P-E., Sustainable Consumption by Reducing Food Waste: A Review of the Current State and Directions for Future Research. *Procedia Manufact.*, Vol. 51, pp 1791-1798, 2020, https://doi.org/10.1016/j.promfg.2020.10.249.
20. Spang, E.S., Moreno, L.C., Pace, S.A., Achmon, Y., Donis-Gonzalez, I., Gosliner, W.A., Jablonski-Sheffield, M.P., Momin, M.A., Quested, T.E., Winans, K.S. and Tomich, T.P., Food loss and waste: measurement, drivers, and solutions. *Annu. Rev. Env. Resour.*, Vol. 44, pp 117-156, 2019, https://doi.org/10.1146/annurev-environ-101718-033228.
21. Lemaire, A. and Limbourg, S., How can food loss and waste management achieve sustainable development goals? *J. Clean. Prod.*, Vol. 234, pp 1221-1234, 2019, https://doi.org/10.1016/j.jclepro.2019.06.226.
22. Filho, W.L., Ribeiro, P.C.C., Setti, A.F.F., Azam, F.M.S., Abubakar, I.R., Castillo-Apraiz, J., Tamayo, U., Özuyar, P.G., Frizzo, K. and Borsari, B., Toward food waste reduction at universities, *Environ. Dev. Sustain.*, Vol. 26, pp 16585-16606, 2024, https://doi.org/10.1007/s10668-023-03300-2.
23. Malefors, C., Sundin, N., Tromp, M. and Eriksson, M., Testing interventions to reduce food waste in school catering, *Resour. Conserv. Recy.*, Vol. 177, Article number 105977, 2022, https://doi.org/10.1016/j.resconrec.2021.105997.
24. Heng, Y. and House, L., Consumers' perceptions and behavior toward food waste across countries. *Int Food Agribus Man Rev*, Vol. 25, No. 2, pp 197-209, 2022, https://doi.org/10.22434/IFAMR2020.0198.
25. Zseni, A., Horváth, A., Macher, G. Z., Pécsinger, J. and Sipos, D., Exploring disparities in the generation of food waste from a spatial and sustainability perspective, *BIO Web*

Conf, Vol. 125, Article number 02002, 2024, https://doi.org/10.1051/bioconf/202412502002.
26. Eurostat dataset: Food waste, https://ec.europa.eu/eurostat/databrowser/view/env_wasfw/default/table?lang=en, [Accessed: 02-March-2024].
27. Eurostat dataset: Area under organic farming, https://ec.europa.eu/eurostat/databrowser/view/sdg_02_40/default/table, [Accessed: 02-March-2024].
28. Eurostat dataset: Consumption footprint, https://ec.europa.eu/eurostat/databrowser/view/cei_gsr010/default/table?lang=en&category=cei.cei_gsr, [Accessed: 02-March-2024].
29. Eurostat dataset: Circular material use rate, https://ec.europa.eu/eurostat/databrowser/view/cei_srm030/default/table?lang=en&category=cei.cei_srm, [Accessed: 02-March-2024].
30. Eurostat dataset: Early leavers from education and training by sex and labour status, https://ec.europa.eu/eurostat/databrowser/view/edat_lfse_14/default/table?lang=en, [Accessed: 02-March-2024].
31. Eurostat dataset: Final energy consumption in households per capita, https://ec.europa.eu/eurostat/databrowser/view/sdg_07_20/default/table?lang=en, [Accessed: 02-March-2024].
32. Eurostat dataset: GDP and main components (output, expenditure and income), https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en, [Accessed: 02-March-2024].
33. Eurostat dataset: Gross value added in environmental goods and services sector, https://ec.europa.eu/eurostat/databrowser/view/sdg_12_61/default/table, [Accessed: 02-March-2024].
34. Eurostat dataset: Gross weight of goods handled in all ports by direction – annual data, https://ec.europa.eu/eurostat/databrowser/view/MAR_GO_AA/default/table?lang=en, [Accessed: 02-March-2024].
35. Eurostat dataset: Housing cost overburden rate by age, sex and poverty status, https://ec.europa.eu/eurostat/databrowser/view/ilc_lvho07a/default/table?lang=en, [Accessed: 02-March-2024].
36. Eurostat dataset: Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day, https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes03/default/table?lang=en, [Accessed: 02-March-2024].
37. Eurostat dataset: Material footprint, https://ec.europa.eu/eurostat/databrowser/view/CEI_PC020__custom_3026894/default/bar?lang=en, [Accessed: 02-March-2024].
38. Eurostat dataset: Severe material and social deprivation rate by age and sex, https://ec.europa.eu/eurostat/databrowser/view/ilc_mdsd11__custom_12755452/default/table, [Accessed: 02-March-2024].
39. Eurostat dataset: Municipal waste by waste management operations, https://ec.europa.eu/eurostat/databrowser/view/ENV_WASMUN__custom_2451701/default/table, [Accessed: 02-March-2024].
40. Eurostat dataset: Nights spent at tourist accommodation establishments, https://ec.europa.eu/eurostat/databrowser/view/tour_occ_ninat/default/table?lang=en, [Accessed: 02-March-2024].
41. Eurostat dataset: Population on 1 January, https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en, [Accessed: 02-March-2024].
42. Eurostat dataset: Population change - Crude rates of total change, natural change and net migration plus adjustment, https://ec.europa.eu/eurostat/databrowser/view/tps00019/default/table, [Accessed: 02-March-2024].

43. Eurostat dataset: Purchasing power adjusted GDP per capita, https://ec.europa.eu/eurostat/databrowser/view/sdg_10_10/default/table?lang=en, [Accessed: 02-March-2024].
44. Eurostat dataset: Population unable to keep home adequately warm by poverty status, https://ec.europa.eu/eurostat/databrowser/view/sdg_07_60/default/table, [Accessed: 02-March-2024].
45. Eurostat dataset: Area of the regions by other typologies, https://ec.europa.eu/eurostat/databrowser/view/urt_d3area/default/table?lang=en&category=reg_typ.urt.urt_demo, [Accessed: 02-March-2024].
46. Eurostat dataset: Relative median at-risk-of-poverty gap, https://ec.europa.eu/eurostat/databrowser/view/sdg_10_30/default/table?lang=en, [Accessed: 02-March-2024].
47. Eurostat dataset: Recycling rate of municipal waste, https://ec.europa.eu/eurostat/databrowser/view/cei_wm011/default/table?lang=en, [Accessed: 02-March-2024].
48. Eurostat dataset: Persons at risk of poverty or social exclusion by age and sex, https://ec.europa.eu/eurostat/databrowser/view/ilc_peps01n$dv_1944/default/table?lang=en&category=eq.eq_ilc.eq_pe, [Accessed: 02-March-2024].
49. Eurostat dataset: Tertiary educational attainment by sex, https://ec.europa.eu/eurostat/databrowser/view/sdg_04_20/default/table?lang=en, [Accessed: 02-March-2024].
50. Eurostat dataset: Waste generation per capita, https://ec.europa.eu/eurostat/databrowser/view/cei_pc034/default/table?lang=en&category=cei.cei_pc, [Accessed: 02-March-2024].
51. Jolliffe, I.T., Principal component analysis: A beginner's guide - I. Introduction and application, *Weather*, Vol. 45, No. 10, pp 375-382, 1990, https://doi.org/10.1002/j.1477-8696.1990.tb05558.x.
52. Tibshirani, R., Regression Shrinkage and Selection Via the Lasso, *J R Stat Soc Series B Stat Methodol*, Vol. 58, No. 1, pp 267-288, 1996, https://doi.org/10.1111/j.2517-6161.1996.tb02080.x.
53. Gracia A. and Albisu, L. M., Food consumption in the European Union: Main determinants and country differences, *Agribusiness*, Vol. 17, No. 4, pp 469-488, 2001, https://doi.org/10.1002/agr.1030.
54. Hebrok, M. and Boks, C., Household food waste: drivers and potential intervention points for design – an extensive review, *J. Clean. Prod.*, Vol. 151, pp 380-392, 2017, http://www.doi.org/10.1016/j.jclepro.2017.03.069.
55. Iyer, G.R., Blut, M., Xiao, S.H. and Grewal, D., Impulse buying: a meta-analytic review, J. Acad. Mark. Sci., Vol. 48, No. 3, pp 384–404, 2020, https://doi.org/10.1007/s11747-019-00670-w.
56. Stancu, V. and Lahteenmaki L., Consumer-related antecedents of food provisioning behaviors that promote food waste, *Food Policy*, Vol. 108, Article number 102236, 2022, https://doi.org/10.1016/j.foodpol.2022.102236.
57. Askegaard S. and Madsen, T. K., European food cultures: An exploratory analysis of food related preferences and behaviour in European regions, *MAPP Working Paper No. 26,* ISSN 0907 2101, 1995, https://pure.au.dk/ws/files/34302276/wp26.pdf, [Accessed: 22-Aug-2024].
58. Askegaard S. and Madsen, T. K., The local and the global: Exploring traits of homogeneity and heterogeneity in European food cultures, *Int Bus Rev*, Vol. 7, No. 6, pp 549-568, 1998, https://doi.org/10.1016/s0969-5931(98)00028-6.
59. Petrovici, D.A., Ritson, C. and Ness M., Exploring disparities and similarities in European food consumption patterns, *Cah. Econ. Soc. Rural.*, Vol. 75, pp 23-49, 2005, http://doi.org/10.3406/reae.2005.971.

60. Tagtow, A., Nguyen, J. and Johnson-Bailey, D., Food waste reduction efforts at the USDA. – Practice Applications. *J. Acad. Nutr. Diet.*, Vol. 115, No. 2, pp 1914-1918, 2015, https://doi.org/10.1016/j.jand.2015.10.008.
61. United States Environmental Protection Agency, United States 2030 Food Loss and Waste Reduction Goal, https://www.epa.gov/sustainable-management-food/united-states-2030-food-loss-and-waste-reduction-goal, [Accessed: 07-Jan-2024].
62. Neff, R.A., Kanter, R. and Vandevijvere, S., Reducing food loss and waste while improving the public's health. *Health Affair.*, Vol. 34, No. 11, 2015, https://doi.org/10.1377/hlthaff.2015.0647.