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Exploring disparities in the generation of food waste from a spatial and sustainability perspective

Anikó Zseni[1*], *András* Horváth[2], *Gergely Zoltán* Macher[1], *Judit* Pécsinger[1], and *Dóra* Sipos[1]

[1]Department of Applied Sustainability, Széchenyi István University, 9026 Egyetem tér 1., Győr, Hungary
[2]Department of Physics and Chemistry, Széchenyi István University, 9026 Egyetem tér 1., Győr, Hungary

Abstract. In the near future, food production will encounter numerous challenges. The world's population, per capita intake of calories, protein, and cereals is growing, and expected to continue increasing in the future. According to the World Resources Institute, feeding 9-10 billion people by 2050 will require a 70% increase in food calorie compared to 2006 levels. The expansion of crop and livestock production, the increasing use of fertilisers and pesticides at global level, and the growing adoption of precision farming methods may not be appropriate in the light of problems such as soil degradation, the impact of climate change on yields, the depletion of fish stocks and the reduction of arable land per capita in certain areas. Mitigation of food waste can be a possible way to sustainable food supply but it alone cannot solve the problem. The paper focuses on examining disparities in the generation of food waste from a spatial and sustainability perspective within EU-countries. Data related to food waste and various environmental, social and economic indicators are collected for EU countries. Correlation between these parameters is investigated to find possible connections. Cluster analysis is applied to food waste data to find the groups of countries with similar characteristics. The distribution of environmental, economical, and social parameters is calculated for these groups, and statistical methods are applied to investigate their differences.

1 Introduction

Food wastage is a major global problem with serious social, economic and environmental consequences. Food waste is present at all stages of the food chain, from production to consumption. It is estimated that more than 1.3 billion tonnes of food are thrown away worldwide every year, while millions of people suffer from hunger, which is a serious contradiction to the principle of sustainability [1]. This waste not only involves food, but also the associated resources, energy use and waste generation, causing significant environmental pressures.

* Corresponding author: zseniani@sze.hu

The 2030 Agenda for Sustainable Development has firmly brought international attention to the issue of food loss and waste [2]. Goal 12 aims to ensure sustainable consumption and production patterns. Within this goal, Target 12.3 specifically addresses food loss and waste, with the target of halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030 [2]. Reducing food loss and waste also has the potential to contribute to other SDGs, such as SDG 2 (Zero Hunger, including end hunger, food security, sustainable agriculture), SDG 6 (Clean Water and Sanitation, including sustainable water management), SDG 13 (Climate Action, including combat climate change impacts), SDG 14 (Life below Water, including sustainable use of marine resources), SDG 15 (Life on Land, including sustainable use of terrestrial ecosystems). Progress towards reducing food loss and waste can only be truly effective if efforts are informed by a solid understanding of the problem [3]. The extent and causes of food loss and waste, as well as the core reasons or objectives related to food security or the environment for reducing it have to be clarified. Additionally, we should comprehend how efforts to reduce food loss and waste impact our objectives being pursued.

According to FAO Food Loss Index, globally around 14 percent of the world's food is lost from production before reaching the retail level [3] and approximately a third of all food produced for human consumption is lost or wasted [1]. In high-income countries with low-level of food insecurity, efforts to reduce food waste are typically necessary in the downstream segments of the supply chain. This is especially true at the retail and consumption levels of the value chain, where higher levels of food waste are anticipated [4]. The average food waste in high-income countries is 118 kg/capita/year; 67% (79 kg/capita/year) of which came from household, 22% (26 kg/capita/year) from food service and 11% (13 kg/capita/year) from retail [5].

The EU generates over 58 million tonnes of food waste annually [6], with a market value estimated at 132 billion euros [7]. 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 [6].

Our research focuses on examining disparities in the generation of food waste from a spatial and sustainability perspective within EU-countries. Correlations between the quantity of food waste and selected environmental, social and economic indicators of Sustainable Development Goals are calculated and analysed to investigate which factors can be related to the increase or decrease in food waste. Similarities and differences between EU-countries are compared using cluster analysis.

2 Material and methods

2.1 Data

Our research is based on the datasets of the Statistical Office of the European Union, which have been published on Eurostat website [6]. 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 twenty-three selected environmental, 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 for this year. Table 1 provides a summary of the indicators investigated during our research. Regarding the six food waste data, TOTAL = FP+MFP+RDF+RFS+HHA.

Table 1. Selected indicators for the research.

abbr.	**indicator**
TOTAL	Total (aggregate changing according to the context) - Food Waste (tonne, kg/capita)
FP	Primary production of food - agriculture, fishing and aquaculture (tonne, kg/capita)
MFP	Manufacture of food products and beverages (tonne, kg/capita)
RDF	Retail and other distribution of food (tonne, kg/capita)
RFS	Restaurants and food services (tonne, kg/capita)
HHA	Total activities by households (tonne, kg/capita)
AOF	Area under organic farming (% of total utilised agricultural area)
CFP	Consumption footprint (per inhabitant)
CMR	Circular material use rate (%)
ELET	Early leavers from education and training by sex (%)
FECH	Final energy consumption in households per capita (kilogram of oil equivalent)
GDP	GDP and main components (output, expenditure and income) (current prices, million euro and per capita)
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)
GWHP	Gross weight of goods handled in all ports by direction - annual data (thousand tonnes)
HCOR	Housing cost overburden rate by poverty status (%)
IAF	Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day - EU-SILC survey (%)
MF	Material footprint (tonne/capita)
MSDR	Severe material and social deprivation rate (%)
MWG	Municipal waste by waste management operations (thousand tonnes and per capita)
NSFT	Nights spent at tourist accommodation establishments by residents/non-residents (number)
POP2020	Population on 01.01. 2021 - total (number)
POPCHG	Difference between population 01.01. 2021 and 01.01. 2020 (number)
PPGDP	Purchasing power adjusted GDP per capita (GDP/capita in purchasing power standards)
PUKHW	Population unable to keep home adequately warm by poverty status (%)
RMRPG	Relative median at-risk-of-poverty gap (%)
RMW	Recycling rate of municipal waste (%)
RPS	People at risk of poverty or social exclusion (thousand persons and per capita)
TEA	Tertiary educational attainment by sex (%)
WGPC	Waste generation per capita (kg/capita)

2.2 Methods

Based on data from specific sources on food wastage and predefined environmental, economic and social indicators, it is possible to identify connections between different factors. Our first method for finding the relationship between numeric parameters was the correlation coefficient calculation. This method can identify a nearly linear connection between two attributes. However, the results did not reveal any non-trivial connections (see details in section 3.1). One possible reason for this negative result could be that there are variables not included in this research, which may have distorted the result. In our perspective, these produce a "noise." Other limitation of simple correlation analysis is that it is not capable of finding multivariate and nonlinear connections.

In order to overcome these limitations, we did not investigate individual countries but found groups of similar countries and compared the group averages of social variables to find connections. We applied the K-means clustering method [8] to find the groups (clusters) of countries with similar food waste characteristics and collect the social parameters for every group. The results of clustering provide two types of interesting information:

- Can we identify the impact of different historical backgrounds? For instance, do the members of former Eastern Bloc countries tend to be in the same group?
- Can we identify significant differences in certain social parameters among the clusters? For example, if there is a statistically significant dissimilarity in GDP per

capita values between the two groups, we can state that there is a connection between "richness" and food waste parameters.

Due to measurement errors and unknown factors, we cannot expect apparent differences in social parameters between the clusters. Therefore, Welch's t-test [9] was applied to determine whether the difference in cluster averages is significant. The calculations were performed by a self-developed Python language program that used Scikit-Learn and Scientific Python modules.

3 Results and discussion

3.1 Correlation analysis

The correlation coefficient between two variables close to 1 indicates a linear connection. We calculated this coefficient for all the value pairs to find the possible simple relations. There were 15 pairs with a correlation coefficient over 0.7. Seven of them reflected well-known dependent cases, for example, between GDP and PPGDP or between total food waste production (TOTAL) and its components (like MFP and RDF). The other eight nearly linear connections were between social parameters. As they fall outside the main scope of our research, we only mention them briefly. Most connections were linked to GDP per capita, consumption footprint (CFP), the level of severe material and social deprivation (MSRD) and the volume of municipal waste produced per person (MWG) (correlation coefficient in bracket):

- GDP – GVAEGS (0.766); GDP – CFP (0.752); GDP – MWG (0.708);
- CFP – PPGDP (0.726); CFP – MWG (0.721);
- MSRD – RPS (0.863); MSRD – IAF (0.787);
- TEA – POPCHG (0.760).

Our calculations did not show any linear connection between a food waste and a social parameter. We assumed 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.

3.2 Country clustering based on food waste per capita data

Figure 1 shows the amount of food waste per capita in 2020, broken down by waste generation source. The chart also indicates that certain countries exhibit outliers in per capita value. These comprise Cyprus, Belgium, Denmark, and Greece. Meanwhile, Croatia, Hungary, Sweden, and Slovenia demonstrated consistently low levels of food waste. The highest levels were generally observed in overall household food waste, except in Belgium, Cyprus and Denmark, where the amount of food waste produced per person from food and beverage production is notably elevated.

The EU-27 total data is 130 kg/capita in 2020, including 12,30 kg/capita for primary production, 26.85 kg/capita for manufacture of food products, 8.95 kg/capita for retail and other distribution, 11.86 kg/capita for restaurants and food services and 70.25 kg/capita for households.

We applied K-means clustering on the 27 member, 5 dimensional (FP, MFP, RDF, RFS, HHA) dataset for N=3, 4, 5, 6 and 7 number of clusters. Here we present only the results of N=5 case, because for higher values the number of members in clusters became too low. Note that mathematical methods of selection optimal cluster number did not work, due to the low number of the whole set.

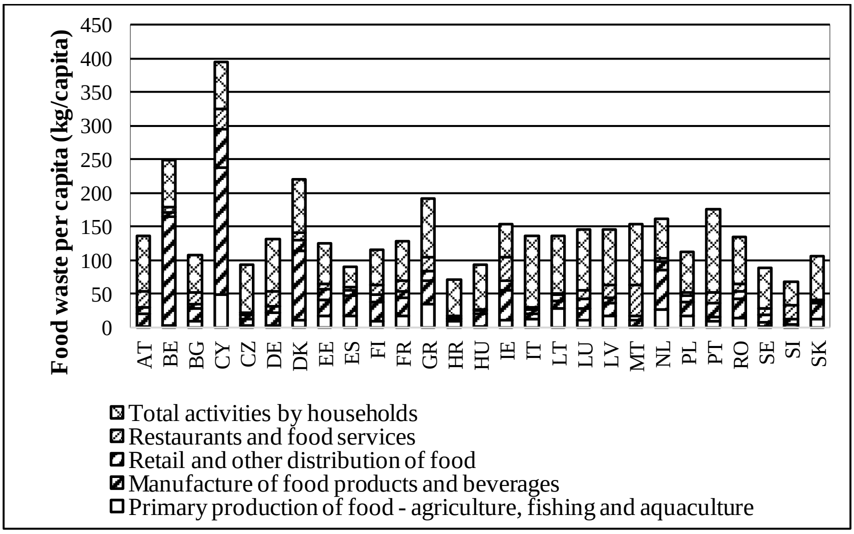

Fig. 1. Sectoral distribution of food waste per capita. (Abbreviations: AT Austria, BE Belgium, BG Bulgaria, CY Cyprus, CZ Czech Republic, DE Germany, DK Denmark, EE Estonia, ES Spain, FI Finland, FR France, GR Greece, HR Croatia, HU Hungary, IE Ireland, IT Italy, LT Lithuania, LU Luxembourg, LV Latvia, MT Malta, NL Netherlands, PL Poland, PT Portugal, RO Romania, SE Sweden, SI Slovenia, SK Slovakia). Data: https://doi.org/10.2908/ENV_WASFW, own editing.

The standard two-letter abbreviation of the clusters are the following:

- CL-1, 6 members: GR, IT, LT, LU, LV, PT
- CL-2, 4 members: AT, DE, IE, MT
- CL-3, 2 members: BE, DK
- CL-4, 14 members: BG, CZ, EE, ES, FI, FR, HR, HU, NL, PL, RO, SE, SI, SK
- CL-5, 1 member: CY

We can observe that the historical background correlates with the clustering. For instance, most of the former East Bloc countries are in CL-4. Cyprus is an unique case and forms its own cluster; therefore CL-5 will be omitted from the further analysis in this section.

Figure 2 illustrates the cluster centre values of clusters for each cluster across the distribution of food waste per capita in different sectors. These averages are multivariate indicators of differences in food waste processes.

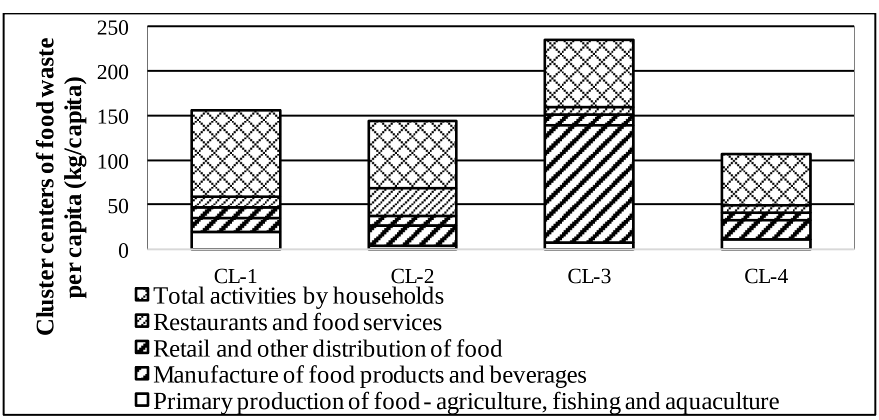

Fig. 2. Sectoral distribution of cluster centre values based on food waste per capita. Data: own calculation, own editing.

The CL-4 nations have the lowest average total food waste quantity, with the lowest amounts of food waste originating from households, restaurants, retail and other food distribution channels. Belgium and Denmark, as members of CL-3, exhibit the highest total food waste levels particularly stemming from the manufacture of food products and beverages. The countries in CL-1 are characterized by large amounts of household food waste, while those in CL-2 experience higher volumes of food waste originating from restaurants and related services. Greece, Italy and Portugal – members of CL-2 – attract numerous tourists, have remarkable gastro-cultures and eating out is very common.

We collected the chosen environmental, social and economic indicators for the groups formed by cluster analysis (similarity according to food waste) and examined which parameters have statistically significant differences between the clusters. The criteria of significance was that in Welch's t-test the p-value is less than 0.05. It means that if a difference of cluster-averages is marked as "significant", there is less than 5% probability that this just a statistical error.

Significant distinctions were identified across the groups based on the factors examined. Table 2 shows by "<" or ">" mark the indicators which have significant differences between clusters and indicates the direction of the difference between the two examined cluster groups. (For example in row CL-4 CL-3, "<" in column TEA means that for TEA indicator average for CL-4 is lower than for CL-3 cluster, while, ">" in column RMRPG means that for RMRPG indicator for CL-4 is higher than CL-3.)

Table 2. Indicators with significant differences between clusters, based on food waste per capita data. (Abbreviation of indicators: see Table 1.)

significant differences	CFP	FECH	IAF	MWG	POPCHG	PPGDP	PUKHW	RMRPG	RPS	TEA
CL-4 CL-3	<	<	>	<	<	<		>		<
CL-4 CL-2	<			<	<					
CL-4 CL-1	<									
CL-3 CL-2										
CL-3 CL-1		>	<	>			<	<		
CL-2 CL-1				>			<		<	

CL-4 and CL-3 clusters differ the most in terms of the examined parameters, with a distinction found between them across eight environmental, social, and economic factors. There is also a noticeable difference between CL-3 and CL-1 clusters in the case of five indicators.

Generally, CL-4 countries have a significantly lower consumption footprint (CFP) compared to all other food waste type clusters. The CL-4 cluster exhibits the lowest average food waste quantity, including the lowest average household food waste quantity as well (Figure 2). This suggests that a lower general consumption footprint is associated with lower food waste generation. Additionally, countries in CL-1 and CL-4 also produce less municipal waste (MWG) than countries in CL-3 and CL-2. Furthermore, households' final energy consumption (FECH) in CL-1 and CL-4 countries is lower than that of households in CL-3 countries. Notably, there are significant differences between CL-4 and CL-3 countries regarding tertiary educational attainment (TEA) and purchasing power adjusted GDP (PPGDP) as well, which are notably higher in Belgium and Denmark, countries of CL-3.

In the case of CL-3 nations Belgium and Denmark, the relative median at-risk-of-poverty gap (RMRPG) and the percentage of population unable to afford a meal with meat every other day (IAF) are significantly lower than in CL-1 and CL-4 countries. This is not surprising given the economic status of these countries. Additionally, in CL-3 and CL-2 countries percentage of population unable to keep home adequately warm (PUKHW) is lower compared to CL-1 countries.

We can only find one significant difference between countries for people at risk of poverty or social exclusion (RPS): the cluster average value of CL-2 (Austria, Germany, Ireland and Malta) is lower than CL-1 (Greece, Italy, Lithuania, Luxembourg, Latvia and Portugal).

3.3 Country clustering based on food waste relative data

Another approach to find similarities between countries in food waste data is to use the relative weight of the five parameters (FP, MFP, RDF, RFS, HHA), namely divide them with the country's total food waste production (TOTAL). The idea behind this method is that it is possible, that the distribution of different type of food waste sources is more significant than the total amount of food waste. Figure 3 shows the amount of these relative parameters in 2020, broken down by waste generation source. The chart also indicates that certain countries exhibit outliers in relative value. Food waste production from domestic sources is the predominant contributor in most nations, although there are exceptions such as Belgium, Cyprus, Denmark, Spain, Ireland and the Netherlands, where other sectors contribute a larger proportion of overall waste generation than household activities. Former Eastern Bloc nations tend to prioritize household activities as a significant factor. This is evident in Hungary, where households hold a relative value of over 70%. Similarly, Slovakia's value exceeds 60% and the Czech Republic's surpasses even higher at 76%. Croatia also demonstrates a similar trend with a relative value of 75% for households' importance. The EU-27 data are 9.4% for primary production, 20.6% for manufacture of food products, 6.9% for retail and other distribution, 9.1% for restaurants and food services and 54% for households.

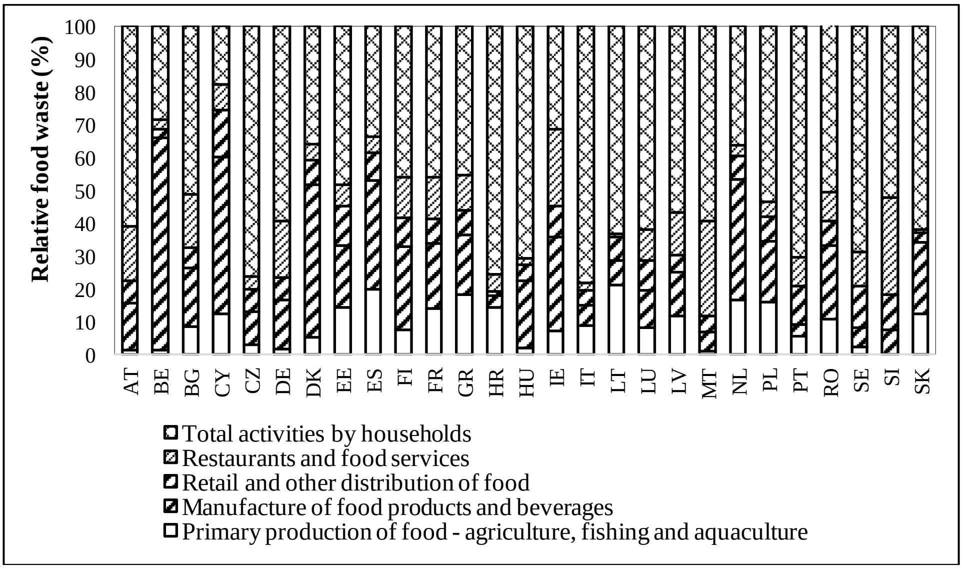

Fig. 3. Sectoral distribution of relative food waste values. (Abbreviations: see Figure 1). Data: https://doi.org/10.2908/ENV_WASFW, own editing.

Here we present the results for 4 clusters. It is comparable to the 5-cluster case above, because now Cyprus does not form a one-member group which was omitted.

- CL-1, 9 members: EE, ES, FR, GR, LT, LV, NL, PL, RO
- CL-2, 10 members: AT, BG, DE, FI, IE, LU, MT, PT, SE, SI
- CL-3, 3 members: BE, CY, DK
- CL-4, 5 members: CZ, HR, HU, IT, SK

It is interesting that the participants of the Visegrad Cooperation are all in the CL-4 cluster. Other correlations between group memberships and the historical past can be observed, but there is no strong correlation between them.

Figure 4 illustrates the cluster centre values of clusters for each cluster across the distribution of food waste relative values in different sectors.

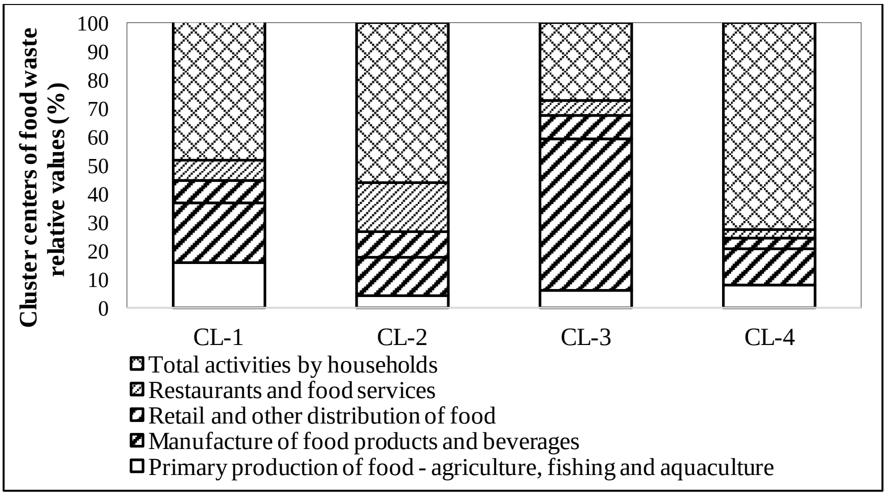

Fig. 4. Sectoral distribution of cluster centre values based on food waste relative values. Data: own calculation, own editing.

CL-1, CL-2 and CL-4 still have the majority of waste attributed to household activities. In contrast, manufacture of food and beverages make up the largest portion in CL-3. Household food waste generation alone represents almost three quarters of the total in CL-4. The greatest share of restaurant and service sector food waste is found in CL-2. Meanwhile, agricultural origin food waste is almost 16% in CL-1, which is the highest ratio compared to other clusters.

Significant distinctions were identified across the groups based on the factors examined. Table 3 shows by "<" or ">" mark the indicators which have significant differences between clusters and indicates the direction of the difference between the two examined cluster groups.

Table 3. Indicators with significant differences between clusters, based on food waste relative data.

significant differences	CFP	GDP	GVAEGS	IAF	MF	MWG	POP2020	POPCHG	PPGDP	RMRPG	RPS	TEA	WGPC
CL-4 CL-3	<			>		<		<	<	<		<	
CL-4 CL-2	<	<	<		<	<		<	<			<	<
CL-4 CL-1											<	<	<
CL-3 CL-2													<
CL-3 CL-1	>			<		>	<	>		<	<		
CL-2 CL-1		>	>			>		>	>	<			>

Cluster analysis reveals significant differences in social-economic parameters among the four clusters. The CL-4 and CL-2 clusters show the most significant differences in terms of the examined parameters, with distinctions found across nine environmental, social, and economic factors. Additionally, there is a noticeable contrast between the CL-4 – CL-3, CL-3 – CL-1, and CL-2 – CL-1 clusters in terms of 7-7 distinct indicators.

In CL-4 countries, the level of tertiary educational attainment (TEA) is notably lower compared to all other food waste type clusters. Similarly, CL-4 exhibits lower values for several other parameters such as consumption footprint (CFP), purchasing power adjusted GDP (PPGDP) and households' municipal waste production (MWG) when contrasted with

CL-2 and CL-3 countries. Additionally, gross value added in environmental goods and service sector (GVAEGS), GDP and material footprint (MF) have lower average values in CL-4 compared to CL-2 countries. Moreover, relative median at-risk-of-poverty gap's (RMRPG) average value is lower for CL-4 than it is for CL-3 countries.

The above indicators also reveal significant differences between the other cluster groups. The relative median at-risk-of-poverty gap (RMRPG) is notably lower in CL-2 and CL-3 countries compared to CL-1 countries, and even lower in CL-4 compared to CL-3. Purchasing power adjusted GDP (PPGDP) is lower in CL-1 than in CL-2 countries, along with indicators such as gross value added in the environmental goods and service sector (GVAEGS), households' municipal waste production (MWG) and GDP.

Indicators of waste production show significant differences between clusters. CL-1 and CL-4 have lower municipal household waste generation (MWG) values than CL-2 and CL-3. Waste generation per capita (WGPC) is lower in CL-4 compared to both CL-1 and CL-2, with the highest value seen in CL-2 countries.

Social parameters related to poverty also exhibit notable variations across cluster groups. The percentage of people at risk of poverty or social exclusion (RPS) is higher in CL-1 countries than in those belonging to CL-3 and CL-4, while the percentage of people unable to afford a meal with meat every second day (IAF) is lower in CL-3 as compared to CL-1 and CL-4.

4 Conclusions

Food waste is a significant global issue that poses economic, social, and environmental challenges. The issue of food waste is not only about wasted food, but also encompasses the resources, energy consumption, and waste production associated with its entire life cycle. Reducing food loss and waste is crucial in achieving the United Nations' Sustainable Development Goals and minimizing the associated negative impacts. 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.

The research aimed to explore the connections between indicators of food waste and several environmental, social and economic factors, illustrating their interrelationships. Although measurement data error and confounding factors limit accuracy, our most important findings are the following.

Significant differences exist among the EU member states in terms of the amount of food waste and its causes. In some cases, these differences can be linked to historical background, economic development, and social norms. The low correlation coefficients between food waste data and social-economical parameters indicate that a common large-scale relationship among the chosen measures cannot be discerned. This is similar to UNEP's claiming that household per capita food waste generation is found to be broadly similar across country income groups, suggesting that action on food waste is equally relevant in high, upper-middle and lower-middle income countries [8]. The absence of a simple correlation between parameter pairs suggests that the possible connections are multivariate and not linear. With cluster analysis we could prove that historical past has a significant role in food waste parameters and found several significant differences is socio-ecological parameters. For example, these results suggest that countries with lower quantities of food waste including lower quantities of household food waste tend to have a lower consumption footprint, less municipal waste, and reduced household energy consumption. Furthermore, countries with a higher relative weight of household waste tend to differ in more socio-economic factors from other countries, especially those related to poverty.

Our findings indicate that reducing food waste requires the mapping of EU-level policies and strategies at a local level, considering specific local conditions and differences. Effective measures should take into account consumer habits, the socio-economic environment, and the specificity of each local food supply chain. Food waste reduction is a complex challenge that demands a comprehensive approach.

Based on this study, it is important to emphasize that further research should not only focus on analysing the economic and environmental effects of consumer behaviour, technological innovations, and waste, but also on properly integrating EU measures. This proper integration is crucial for achieving objectives, and includes the effective implementation of EU-level policies and strategies at Member State level. As a result, Member States must actively participate in applying measures to make real and measurable progress in reducing food waste. These coordinated actions are essential for transitioning towards sustainable food systems.

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