



## RESEARCH ARTICLE

### A statistical analysis of municipal waste treatment types in European countries

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## ABSTRACT

In today's world, the municipal waste management is becoming a main concern for every country and city. In environmental problems, how to collect and eliminate the municipal waste is extremely important. Different countries take different approaches towards the elimination of municipal waste and try to create policies. In this study, municipal waste treatment types for European Union (EU) and EU candidate countries is investigated. The data is taken from a report of EUROSTAT about municipal waste treated in European Union (EU) and EU candidate countries for 2012. There are 4 variables which form how municipal waste is treated in these countries. These variables are called as Recycled, Composted, Landfilled and Incinerated. Using correspondence analysis as a main statistical technique with the help of cluster analysis, a classification of the countries according to municipal waste treatment types is created.

**Keywords:** Correspondence analysis, cluster analysis, EUROSTAT, waste treatment

## 1. INTRODUCTION

According to a EUROSTAT news release on 26 March 2015, each person in the European Union generated 481 kg of municipal waste in 2013. There is a decreasing trend in the generation of municipal waste per person in EU. Amount of municipal waste generated per person differs significantly among EU member countries. In 2013, the lowest waste generated per person was in Romania and the highest was in Denmark.

Every country uses a different method to eliminate waste generated by households. The most important part of the waste disposal is to use a method which will have the minimum negative impact on the environment. Even though countries try to employ different methods to eliminate municipal waste, these methods can be classified into 4 main groups. These groups are called Recycled, Composted, Landfilled and Incinerated.

Eurostat publishes statistics about the waste treatment of the European countries [1]. In this study, the data set is obtained from Eurostat reports. Specifically, the report used is created for 2012 where most of the data

points are finalized. According to Eurostat report, 492 kg of municipal waste was generated per person in 2012 and 480 kg of municipal waste was treated per person. Also, the report states that the municipal waste was treated in different ways and the overall percentages of waste treatment by treatment types are as follows: 34% was landfilled, 24% was incinerated, 27% was recycled and 15% was composted.

There are a few studies related with solid waste management. Henry et al. [2] investigates the municipal solid waste management in developing countries using Kenya as an example. The paper deals with approaches of possible solutions that can be undertaken to improve municipal solid waste services. Sharholly et al. [3] investigates Municipal solid waste management (MSWM) identified as one of the major environmental problems of Indian cities. The study pertaining to MSWM for Indian cities has been carried out to evaluate the current status and identify the major problems. Various adopted treatment technologies for municipal solid waste (MSW) have been critically reviewed, along with their advantages and limitations. Del Mundo et al. [4] analyze the correlation of socio-economic status, environmental awareness, knowledge, and perception with solid

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waste management practices in the coastal barangays of Talisay and Balibago, Calatagan, Batangas Philippines. The study shows that total family monthly income and environmental awareness are negatively correlated with solid waste management practices. However, environmental knowledge and perception are positively correlated with solid waste management practices. Chamizo-Gonzalez et al. [5] studies the waste management problem in Spain. Their paper examines traditional forms of levying charges for Waste-collection-treatment-disposal under the coverage of the Polluter-Pays-Principle in The Organization for Economic Co-operation and Development (OECD) countries and Spanish provincial capitals, finding a prevalence of flat fee systems in Spain. Regarding Madrid specifically, the paper analyses the relationship between its Waste - collection - treatment - disposal charges and some possibly independent variables. Relationships between MSW generated and some potentially-linked variables are identified. Analysis rejected that Madrid waste generation-treatment-disposal charges based on dwelling values had a positive relationship with waste generated (more value of the properties in a district does not imply more waste generated), and reveals/- confirms other significant correlations between some variables; it being remarkable that neither age, gender, nationality nor education were found relevant.

Waste management is also important for companies. Maranan et al. [6] investigates operations and waste management of Slaughterhouses in the province of Laguna. In their study, authors try to provide an overview of environmental and public health concerns in relation to the operations and waste management practices of slaughterhouses in the Laguna Province. Results revealed that only four (36.4%) of the eleven slaughterhouses in the province were accredited with the National Meat Inspection Service (NMIS), which implies that that the majority of the slaughterhouses in Laguna do not comply with the set standards for abattoir operations. Moreover, the non-accredited establishments operate with substandard and outdated facilities and equipment.

Pires et al. [7] studies the solid waste management in European countries. Authors make a review of systems analysis techniques. The authors put their focus on waste management strategies in terms of how systems analysis, a discipline that harmonizes these integrated solid waste management strategies, has been uniquely providing interdisciplinary support for decision making in this area.

Alzamora et al. [8] reviews of municipal waste management charging methods in different countries. Their main focus is on the charges bought by city officials to disseminate the waste. They suggest that public debates should be carried out in order to get a more organized charging systems in the cities.

In this study, using correspondence analysis and cluster analysis, groups of countries are created to form similar countries in terms of their municipal waste treatment types for European Union data set. Some results and comparisons are provided by looking at the similar studies.

## 2. MATERIALS AND METHODS

### 2.1. Data collection process

Correspondence analysis (CA) is a method which is used for dimension reduction and visualization of a multivariate data set similar to principal components analysis (PCA) [7]. Both of the mentioned methods are based on singular value decomposition (SVD) providing the dimension reduction property and the lower dimensionality visualization. Therefore, CA and PCA are similar methods while the differences of these two rely on the type of the distance matrices used, the applied data type and weighting of the data. CA is a method mainly applied to contingency tables (cross tabulation of two categorical variable); however, it is not only restricted to contingency tables. It can also be applied to ratio-scaled data, binary data, preferences and fuzzy-coded continuous data [9]. Correspondence analysis has found a place in many areas of social sciences such as: sociology, linguistics, psychology (survey data), in ecological sciences in biology and, in environmental sciences. Reference [10] indicates that ecological data can be represented in nature as abundances or positive amounts like biomasses on a set of species at different sampling sites.

In correspondence analysis, a row (column) point of a data matrix is called row (column) profile. The row (column) profiles are the ratios of the row elements to their row (column) sums. Weights of these profiles are called masses which are the ratio of marginal sum of row or columns. Euclidean distances are employed in PCA method; on the other hand, chi-square distances are the subject of the SVD in CA. Chi square distance between rows  $i$  and  $i'$  can be given as following in Eq. 1:

$$\chi_{i,i'} = \sum_{j=1}^J \left( \frac{X_{ij} - X_{i'j}}{c_j} \right)^2 \quad (1)$$

Here  $c_j$  is the  $j$ .th average column profile. The algorithm for CA application is given as follows: [7]

- Divide the original data table  $\mathbf{N}$  by its grand total  $n = \sum_i \sum_j n_{ij}$ :  $\mathbf{P} = (1/n)\mathbf{N}$
- Denote by  $\mathbf{r}$  and  $\mathbf{c}$  the marginal sums of  $\mathbf{P}$  (rows and column sums respectively);  
 $\mathbf{r} = \mathbf{P}\mathbf{1}$ ,  $\mathbf{c} = \mathbf{P}^T\mathbf{1}$
- Calculate the matrix of standardized residuals  $\frac{p_{ij} - r_i c_j}{\sqrt{r_i c_j}}$  and its SVD:

$$\mathbf{S} = \mathbf{D}_r^{-\frac{1}{2}} (\mathbf{P} - \mathbf{r}\mathbf{c}^T) \mathbf{D}_c^{-\frac{1}{2}} = \mathbf{U}\mathbf{D}_\alpha \mathbf{V}^T$$

- Calculate the coordinates:

Principal coordinates of rows:  $= \mathbf{D}_r^{-\frac{1}{2}} \mathbf{U}\mathbf{D}_\alpha$ , of columns:

$$\mathbf{G} = \mathbf{D}_c^{-\frac{1}{2}} \mathbf{V}\mathbf{D}_\alpha$$

Standard coordinates of rows:  $\Phi = \mathbf{D}_r^{-\frac{1}{2}} \mathbf{U}$ , of columns

$$\mathbf{\Gamma} = \mathbf{D}_c^{-\frac{1}{2}} \mathbf{V}$$

An exploratory graph can be drawn to examine both the columns (variables) and rows (individuals or objects) together. These graphs are called biplots, that is, a generalization of scatterplots, and they have the possibility of containing more than two axes [9].

The variance of the CA analysis is called total inertia and it is indeed related to chi-square statistics. The explained variances for each dimension can be calculated through the ratio of the eigenvalue of the concerned dimension to the sum of the all eigenvalues. A scree plot can be an assistance to choose the number of dimensions containing the maximum variance of the CA solution.

The most preferred visualization of the CA solution is called symmetric map and is described as an approximation to the true biplots. It provides a better use of plotting area because of the property of having the same column and row point inertias along the dimensions [9].

The interpretation of the proposed visualization is that the individuals who have higher variable values than average tend to situate close to the corresponding axis which are the variables of the analysis. In addition, it can be an assistance as a visual clustering of multivariate data sets through this aggregation of the same kind in the same location feature. Contributions to CA solutions can also be calculated and can be shown in the biplots as the lighter shades of a specified color indicate low level contribution while the darker shades indicate high level contribution.

The second statistical analysis, which is used in this study, is the hierarchical cluster analysis. Biplot visualization may only be considered as a visual assistant for hierarchical clustering methods. Clustering is a process for grouping objects or individuals into a cluster by a distance measure. The goal in this process is to achieve the grouping of clusters such that objects in the same clusters have small distances from each other while others have not [12].

Hierarchical clustering can be agglomerative or divisive. Respectively, each object can be thought as a cluster to be merged into more than one or the objects can be thought whole as a cluster to be divided into more than once. It has an iterative algorithm that in each step distance matrix will be upgraded and merging or dividing can be done via a linkage method after the first cluster is formed. A single linkage is based on minimum distance between clusters and objects. A complete linkage is the merging of two clusters that are far apart. Average linkage is the method that uses average distances for merging. In order to show the clusters, a graph called dendrogram can be used. A dendrogram, which resembles a tree with branches, shows the hierarchical relation of the objects subjected to clustering. The algorithm ends when optimum clusters are found. Dendrogram can be cut through at a certain distance or through a cluster number given before the analysis. In most social studies, analysis clusters can be formed according to average linkage rule and the cluster numbers are given before the analysis by an expert view. One major drawback of the analysis is when the number of objects

is high, the algorithm takes longer time to find optimum clusters.

In this study, the data is taken from a report of EUROSTAT about municipal waste treated in European Union (EU) and EU candidate countries for 2012. Data includes values for 35 countries and EU averages. There are 4 variables which define how municipal waste is treated in these countries. These variables or municipal waste treatment types are named as Recycled, Composted, Landfilled and Incinerated. The Data set published in 2012 was the most collect set as the article was written, but as the EUROSTAT publishes new data, the authors have an intention to repeat the analysis in order to changing trends in waste treatment types. The values are given as the ratios of each treatment type that adds up to 100%. As noted in the report, data of some countries are estimated values. Furthermore, some values indicate real zeros so the data we will examine is a ratio-scale data. Zeros in the data indicate percentages lower than 0.5%. Municipal waste treated and generated per person was also included in the data for each country. Our initial aim is to visualize the data in lower dimensions and to form clusters of similar countries having similar pattern of waste management. Then, an examination of the differences of clusters by means of treatment type is shown.

### 3. RESULTS AND DISCUSSION

In order to create the statistical results, R software is used for the calculations [13]. CA is a package of R which is used for correspondence analysis [9]. Using correspondence analysis, a biplot of the data is obtained and shown in Figure 1. In Figure 1., there are five unlabeled countries located close to the landfilled axis in the far-right corner of the graph. These countries are Bosnia and Herzegovina, Former Yug. Rep of Macedonia, Romania, Serbia and Turkey. These countries' common approach towards the municipal waste treatment is mostly to landfill it. Additionally, Former Yug. Rep of Macedonia and Bosnia and Herzegovina have the same profiles. Countries with higher than average incinerated waste are located in the top left of the Figure 1. and these countries are identified as Austria, Belgium, Denmark, Germany, Netherlands, Norway, Sweden and Switzerland. Biplot indicates that Iceland, Ireland and Slovenia are countries of having higher amounts of Recycled municipal waste than others. In the middle and through the middle right of the Figure 1, it can be seen that there are countries with lower landfilled municipal waste when they are compared to the far right located countries like Turkey and Romania. Portugal and Czech Republic is recognized as lower contributor countries to Correspondence Analysis solution of the data set.

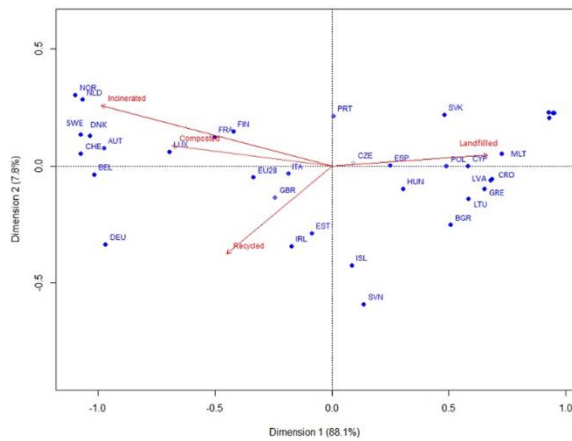


Fig 1. Correspondence analysis biplot of waste management data

The results of hierarchical cluster analysis are given in Table 1. A slight modification is used (0.1%) to represent a value for a treatment type if the value equals absolute zero. Therefore, it was possible to make a comparison of countries that do not apply the specific treatment type with the countries that apply the type in small amounts. This modification of the data does not change the course of CA and clustering because the row sums values are not changed. As a result of hierarchical clustering, countries are clustered into 6 homogenous groups according to municipal waste treatment types. The results obtained from correspondence analysis (Figure 1) are very similar with the results obtained from cluster analysis.

Table 1. Clusters of the countries via hierarchical Cluster analysis

Clusters	Countries
Group 1	Estonia, Ireland, Italy, Slovenia, Great Britain, Iceland
Group 2	Belgium, Denmark, Germany, Netherlands, Austria, Sweden, Norway, Switzerland
Group 3	Bulgaria, Greece, Croatia, Republic of Cyprus, Latvia, Lithuania, Malta, Poland, Slovakia
Group 4	Czech Rep., Spain, Hungary, Portugal
Group 5	France, Luxembourg, Finland
Group 6	Romania, Rep. of Macedonia, Serbia, Turkey, Bosnia and Herzegovina

In order to make a comparison of the clusters, boxplots of clusters are drawn for each municipal waste treatment type and they are given in Figure 2. Looking at the boxplots, it is possible to investigate the similarities and differences of different clusters and treatment types.

Cluster 1 and Cluster 2 have the highest amount of municipal waste that were recycled. Moreover, their median values are alike; however, cluster 2 has got a higher variability than cluster 1. Cluster 2 is formed of leading countries in incinerated municipal waste and Norway is in the first place. A discriminatory feature of Cluster 1 is that it includes the EU28 which is the average of 28 countries in European Union. Hence, it can be considered that the countries in this cluster show the average characteristics of European Union. In

close inspection, it can be seen that the countries in cluster 2 have got their municipal waste distributed on only three methods. They have very little amount of landfilled waste. Countries in Cluster 3 have got the second highest amount of landfilled municipal waste. Another property of these countries in this cluster is that they share the second place in incinerated amount of waste with countries in the cluster 6 is the first. Slovakia stands out as an outlier with 10.1% of incinerated amount. Countries of Cluster 5 have got less variability in incinerated amount of municipal waste amongst all other clusters. In addition, they have the least amount of landfilled waste following Cluster 2. Cluster 3 is the third cluster in the ranking of highest amount of landfilled municipal waste.

In Figure 3, combining the information from the cluster analysis and correspondence analysis, a Biplot is produced. From left through the right of the biplot, the grouping of the countries can also be easily recognized in Figure 3.

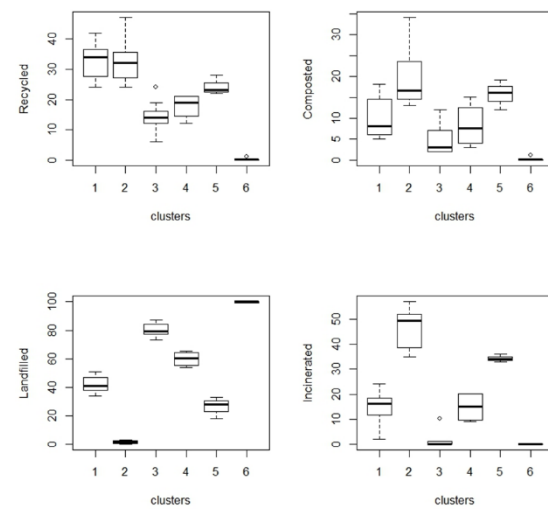


Fig 2. Boxplots of the clusters

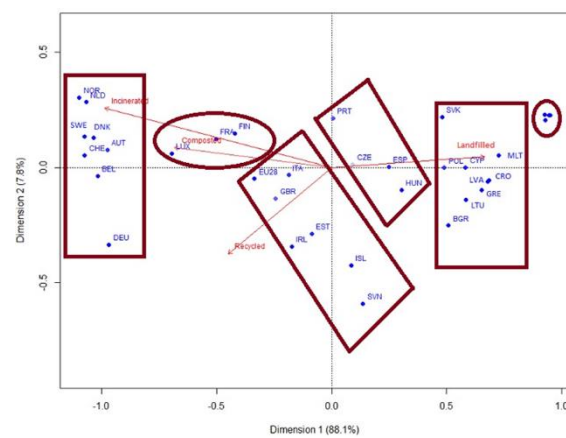


Fig 3. Clustering shown in the CA biplot.

In Figure 4, Clustering dendrogram is given. The relationship of similar countries in terms of treatment type is obvious in clustering dendrogram. As the height of the dendrogram increases, dissimilarity of the objects/countries gets higher.

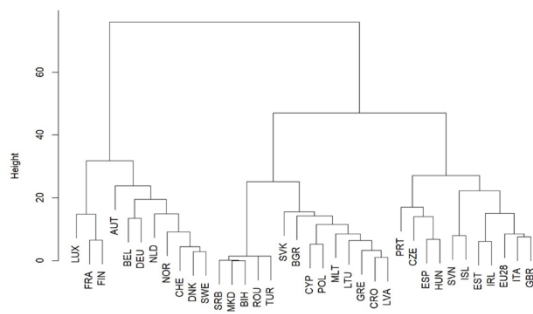


Fig 4. Clustering dendrogram of waste management data

#### 4. CONCLUSIONS

Vujić et al. [14] investigate the relationship between the GDP and municipal solid waste management of 27 European Union countries in the period between 1995 and 2007. In the study, correlation and regression analysis is used to show the relationship. Moreover, they found positive correlation with GDP and incineration, recycling and biological treatments. On the other hand, a negative correlation for landfilling and GDP was found out. Hence, as the ratio of landfilling increases, the GDP decreases dramatically. The study described three phases of economic development for countries with three GDP levels. An initial phase where approximately 100% of the waste is landfilled while in intermediate phase, the majority is still landfilled but recycling and incineration is also improving. Lastly, there is too little or no amount of landfilled waste in some cases and majority is recycled or incinerated in final phase. This can be thought as a clustering into three groups in our case. Our study supports the findings of this study. Cluster 6 coincides with the initial phase countries given. This cluster consists of EU candidate countries like Former Yug. Rep. of Macedonia, Turkey and Serbia and also Romania as a recent EU member and Bosnia and Herzegovina as a potential EU candidate. Additionally, Cluster 2 is similar to final phase countries including EU and EU founder countries with a noticeably higher GDP value compared to others.

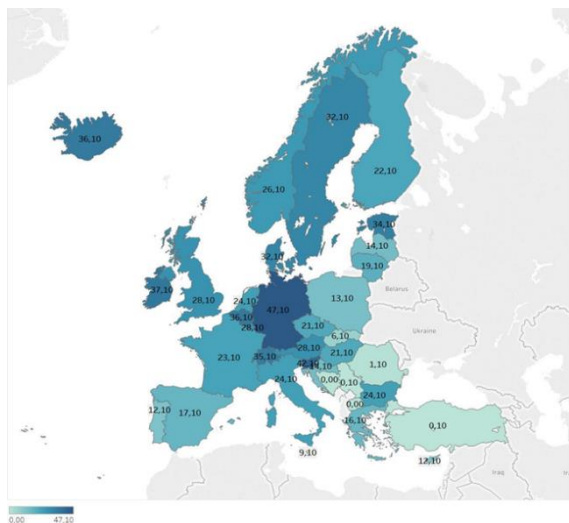


Fig 5. Thematic map of countries for Recycled waste

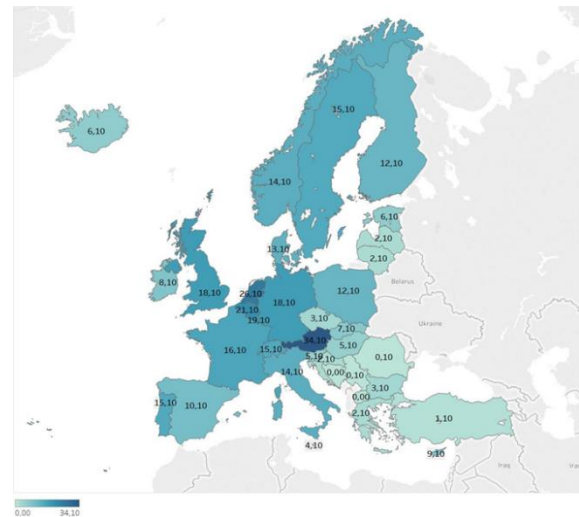


Fig 6. Thematic map of countries for Composted waste

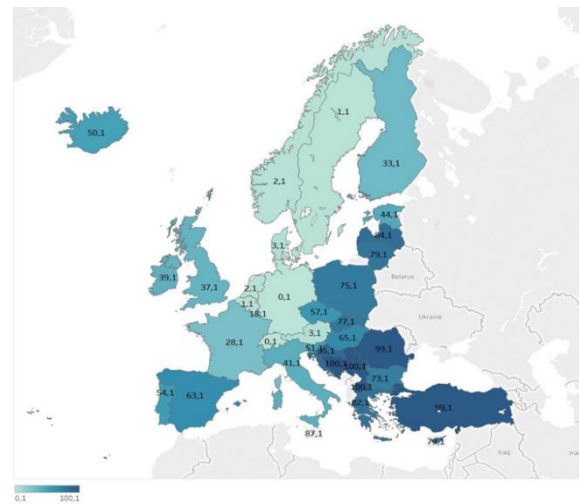


Fig 7. Thematic map of countries for Landfilled waste

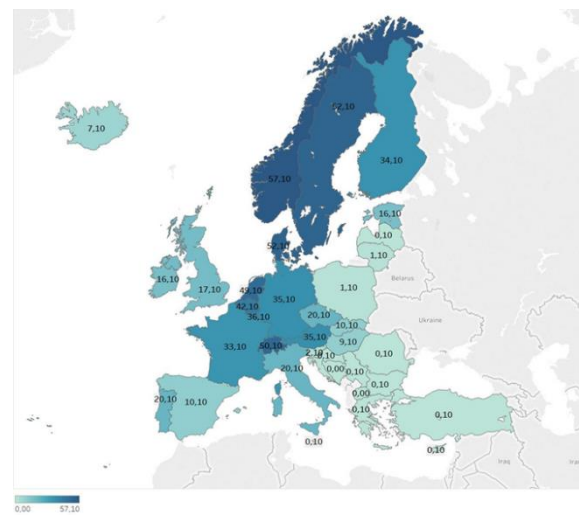


Fig 8. Thematic map of countries for Incinerated waste

Using Tableau software [15], in Figure 5, 6, 7, and 8; the thematic maps of countries in terms of their waste management are shown. By using these maps, we believe that it is not too difficult to see which countries



depends on which waste management type more than the others.

In this study, the data set is a very special one where each row representing a country adds up to 100%. The suitable technique to analyze this type of data set is the correspondence analysis. Additionally, the cluster analysis helps us to interpret the results of correspondence analysis. By looking at the clusters and geographical information, each country may create policies towards better municipal waste treatment. We believe that, this study will offer guidance for countries in terms of the positions of the countries for municipal waste treatment. The countries in the same clusters may learn from the other countries in the same cluster and also learn from the countries in different clusters. Looking at the results, it is not too difficult to see which country is inclined towards a specific treatment type. Therefore, the countries' authorities responsible for municipal waste management may decide which direction to go, and once they decide to continue on the direction of the treatment type, they are able to see which countries should be taken as an example to follow.

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