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Waste Production and Treatment Modelling for EU Member States

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The modern way of life places considerable demands on energy and material resources. The limited amount of primary resources and the burden on the environment have supported the circular economy's tendencies which has EU recently incorporated into its legislation as Circular Economy Package. The aim of this package is to turn waste into material or energy source. The waste treatment methods are also regulated in EU legislation through recycling and landfilling targets. Estimation of future waste production and treatment is a fundamental prerequisite for adjustments in waste management. The aim of this paper is to model the municipal solid waste production and treatment at a national level for the EU member states. The principles of linear regression were used to reveal the relationship between waste management data (waste streams production and treatment) and 19 socio-economic, demographic and other factors. Among the EU states, the resulting models explain at least 66 % of the variability in waste streams production and 52 % in case of waste treatment methods. The most influential variables are GDP, income and educational level of inhabitants. The results of these analyses could be used for forecasting production and waste treatment on the state level and can indicate the gaps between probable development and waste management targets set by the EU. The accuracy and comparability of waste production data across the EU should be further analysed.

1. Introduction

The current state of waste management in the EU is at different levels depending on the individual countries' development. Significant differences were also observed in terms of municipal solid waste (MSW) generation. Waste management in the EU is currently undergoing a transition from a linear economy to a circular economy (Morseletto, 2020). The smooth transition to the circular economy and the transformation of waste management is enshrined in the new legislation as Circular Economy Package (CEP). The waste treatment methods are regulated, and tangible recycling targets are given as well. Specifically, landfill prohibition is planned since 2035, where only 10 % at most of the total amount of MSW generated could be landfilled (Directive 2018 / 850). Further targets regulate the amount of MSW recycled, with specific percentages increasing over time in 2025, 2030, and 2035 (Directive 2018 / 851). Based on the mentioned directives, a change is needed in most countries. The motivation is to find a solution for transition, which is associated with a detailed analysis of the current state and the search for future trends. Figure 1 shows the MSW treatment in the EU member states in the year 2017 based on visualisation method presented Pomberger et al. (2017). Green area is the place of fulfilling the EU's targets from 2035.

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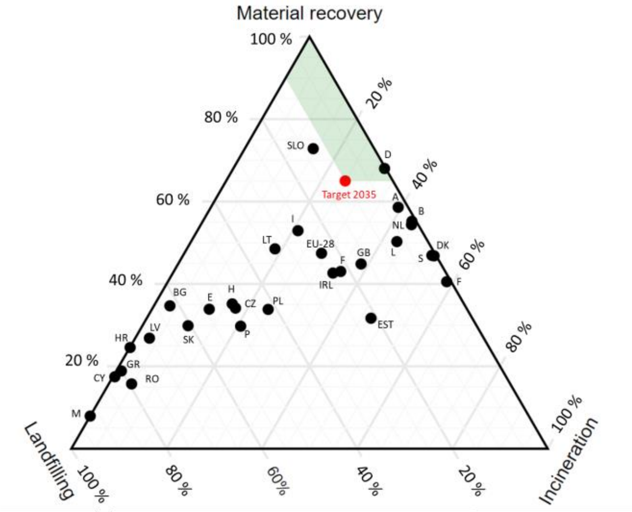

Figure 1: The current situation of municipal solid waste treatment for the EU-28 member states, year 2017 (data source: Eurostat, 2019), note: B – Belgium, BG – Bulgaria, CZ – Czechia, DK – Denmark, D – Germany, EST – Estonia, IRL – Ireland, GR – Greece, E – Spain, F – France, HR – Croatia, I – Italy, CY – Cyprus, LV – Latvia, LT – Lithuania, L – Luxembourg, H – Hungary, M – Malta, N – Netherlands, A – Austria, PL – Poland, P– Portugal, RO – Romania, SLO – Slovenia, SK – Slovakia, FIN – Finland, S – Sweden, GB – United Kingdom

No country is meeting its targets, except Germany. Some countries have a high energy utilization rate despite landfill restrictions. In such cases, it will be necessary to increase the separation of mixed municipal waste (MMW). Over the past few decades, most countries are moving towards material recovery and incineration. The aim is to save primary raw material resources and develop approaches to minimize emissions from waste treatment (Fan et al., 2019).

The necessary step of waste management planning is to map the current situation in detail and compare it with EU requirements. It may also be key to find factors and aspects that have a significant impact on developments in waste management. Information on the amount of waste production is essential when planning waste management. It is also important to pay attention to waste treatment methods and to analyse the factors associated with it. Many authors do not deal with waste treatment modelling, most of the papers are devoted exclusively to issues of waste production (Goel et al., 2017). There are several studies from the last years addressing the EU policy, its targets and sustainability, but most of them are oriented on particular country, e.g. Croatia (Traven et al., 2018), Italy (Di Maria et al., 2020), Romania (Căilean and Teodosiu, 2016) or particular waste streams e.g. plastics (Baran, 2020), construction and demolition waste (Nunes and Mahler, 2020) or only on waste treatment without waste production aspects that are the prerequisite for the treatment (Castillo-Giménez et al., 2019). This contribution presents an analysis of both production and waste treatment in EU countries. The main links between waste management and socio-economic, demographic and other factors are included. Global plans are being developed, and the issue needs to be approached in a similar metric from the perspective of significant factors affecting waste management and treatment methods. It is important to design methods for forecasting of waste production with a link to subsequent use from the perspective of waste treatment method and EU targets. The possibility of forecasting waste management data for the future is discussed.

2. Application of intent – reviews on strategic planning

Waste management in the EU is currently in the process of transition from linear to a circular economy. As stated above, many EU member states are not yet meeting given targets. A smooth transition to a circular economy requires the development of relevant plans. Strategic planning is necessary at a several levels: businesses, municipalities, regions, states. Zorpas (2020) provides a holistic approach processing how to develop, implement, monitor and improve a strategy in the framework of waste management at a local level as well as at a central level. Zotos et al. (2009) developed an approach for waste management strategy planning at both the household and companies level. Waste management involves multiple stakeholders such as government agencies, suppliers, consumers, providers of treatment and transport. An optimal waste management strategy should utilize the synergistic effect of multiple participants. Diaz-Barriga-Fernandez et al.

(2017) presented the multi-objective model for waste management strategy planning. The aim is to maximize the benefit of all the participating stakeholders.
Strategic waste management plans are often based on operational research. The issues solved are often dealing with the waste collection routes (Hrabec et al., 2019), smart waste management technologies integration (Bong et al., 2018), the appropriate technology development (Deng et al., 2017), searching the optimal location for waste management facilities (Yadav et al., 2017) and design of waste management facilities (Becker, 1995). In terms of planning new facility capacities, information on waste production and management is essential. A review on waste generation modelling methods concluded the same statement (Beigl et al., 2008). The current situation in waste management research is not sufficient prerequisite for strategic planning, and it is also necessary to make projection of future development of waste management as well as of underlying factors influencing the waste management situation in the EU states.

3. Waste production and treatment modelling

Waste generation modelling is currently a widely discussed topic, as demonstrated by the ever-increasing number of publications on this subject. Approaches to waste generation modelling have been summarized in: Beigl et al. (2008) – 45 publications and Goel et al. (2017) – 100 publications. Existing approaches have used different methods that can be divided into two basic groups – modelling relationships in data and time series analysis. Waste production is influenced by a number of socio-economic, demographic, environmental and other factors. Numerous articles show the preference of this method, which identifies the factors influencing waste production in individual states.
The aggregated data can suppress variability at the municipal level. This is demonstrated by case studies from the Czech Republic. The linear regression model presented by Rybová et al. (2018) at the municipal level considered 12 factors for modelling MSW production in Czech municipalities. Eight characteristics were identified as significant but were able to explain only 5.1 % of the variability in MSW production. Compared to Kováčová et al. (2011), where it was possible to create a model for the regional level with R^2 equal to 0.86. The higher accuracy compared to the work results of Rybová et al. (2018) is probably due to higher territorial details (regions).
Other important information includes waste treatment methods, although it is not considered often in terms of modelling. It is key information in terms of meeting objectives and planning infrastructure. At the national level, waste generation and treatment can be modelled relatively successfully. The available data both on waste management and socio-economic for member states of EU in the year 2017 are collected from the Eurostat database (Eurostat, 2019). The influence of available socio-economic data on waste production and treatment is analysed. The linear regression model is applied in the form:

$$y_i = \beta_0 + \sum_{j \in J} \beta_j x_{i,j}, \quad (1)$$

where set $i \in I$ is set of EU member states and $j \in J$ is set of considered independent variables. $x_{i,j}$ is an independent variable, β_0 is an intercept and β_j is searched regression coefficient.
A total of 11 linear regression models in the form (1) are made for the various dependent variables, which are listed in the headers of Table 1 and Table 2. At total, 19 parameters of independent variables from the set J are considered for each linear regression model. The estimation of regression coefficients β_j is solved by the least squares method, while the assumptions are verified. The parameter test reveals independently significant independent variables. The null hypothesis $H_0: \beta_j = 0$ is tested, as opposed to the alternative hypothesis $H_A: \beta_j \neq 0$. Due to the probable high correlation between some independent variables, the effect of multicollinearity in individual models was controlled and eliminated. The significant independent variables are summarized in the Table 1 and Table 2 together with assumption testing results and quality assessment.
The header of the Table 1 specifies the modelled waste production variables (total household waste production, recyclable waste, MMW and MSW) which present dependent variable. For each of these dependent variables was build an individual linear model. The first part of the Table 1 marked as "Verification of linear regression assumptions" summarizes results of linear regression assumption testing. Significance level α was set to 0.05. For all cases, the hypothesis of residual normality (Shapiro-Wilk test), zero mean (t-test), and correlation (Durbin-Watson test) are not refused. The table includes the p-values of the tested hypothesis. The quality of the model is quantified by R^2adj (adjusted coefficient of determination), which is higher than 0.82 for each dependent variable of waste production, except MSW production. The problem is that MSW is not defined everywhere in the same way. This fact limits the quality of the model. The significant variables are specified in the table and marked by plus (✚) for a positive estimated regression coefficient β_j. A minus (▬) indicates a negative regression coefficient. Other variables without plus or minus symbols were found as insignificant so

the value of their regression coefficient β_j equals zero. The nonzero intercept was found to be significant only for MSW production model.

Table 1: Linear regression results for waste production

		Households production	Recyclable waste	MMW	MSW
Verification of linear regression assumptions	Normality	0.545	0.291	0.438	0.796
	Zero mean	0.547	0.948	0.990	1.000
	Correlation	0.478	0.474	0.978	0.778
Model quality	R^2adj	0.931	0.822	0.952	0.659
Significant independent variables *j*	Intercept β_0				1,186
	GDP*				−
	Young-age dependency ratio				−
	Life expectancy at birth– males			+	
	Upper secondary education	+		−	
	Tertiary education				+
	Median equivalised net income (PPS*)		+	−	−
	Median equivalised net income (Euro)	+			+

**Note:*
GDP – Gross domestic product
PPS – Purchasing power standard

Total production of household waste is influenced by education and income. The economic strength of the country naturally has an impact on recycling. An important waste stream is MMW, which is often landfilled or used for energy recovery. A significant influence on its production plays the life expectancy, education of population and income. The education can be purposefully supported at state levels. It is not possible to expect fast changes in the near future, but it is necessary to address these issues in the long term. However, MSW is more complex and depends on most of the factors listed. Countries have quite a lot of possibilities for a systematic shift such as informational campaigns, adjustment of waste fees or balance of technical solutions.

The regression model (1) was then applied to the MSW treatment data. The results are summarized in Table 2, linear regression assumptions are fulfilled. The accuracy of these models is diverse based on waste treatment method. In the context of waste management planning, the model for material recovery of waste is essential, R^2adj equals to 0.719. Composting is a way of material recovery and its R^2adj is equal to 0.797.

The significant independent variables *j* are depicted in the same way as in the Table 1. The intercept is included in all waste treatment models. As with waste production, the economy influences the treatment of MSW rapidly. Material recovery, which is the fundamental identifier from the perspective of the EU's objectives, is influenced by the economic force of the country. In the case of waste composting, the gender factor also affects the model. An essential factor is also related to the way of living. In this respect, it is possible to support especially young citizens, families with children or other household features. Analysing the determinants of waste management behaviors, results reveal that waste management behaviors are different, and are likely to be driven by different motivations. (Minelgaitė and Liobikienė, 2017). Some independent variables, which were considered in the model for both the waste production and treatment, were not statistically significant. These are population, environmental protection expenditure, number of persons employed in circular economy, single person households and households with children.

Table 2: Linear regression results for waste treatment

		MSW treatment	MSW incineration + energy recovery	MSW landfilling	MSW incineration	MSW energy recovery	MSW material recovery	MSW composting
Verification of linear regression assumptions	Normality	0.674	0.056	0.747	0.386	0.380	0.124	0.941
	Zero mean	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Correlation	0.296	0.822	0.076	0.284	0880	0.948	0.854
Model quality	R^2adj	0.518	0.857	0.584	0.584	0.832	0.719	0.797
	Intercept β_0	317.2	-139.3	482.8	-278.3	-139.5	267.5	-965.4
Significant independent variables *j*	GDP				−			+
	Young-age dependency ratio						−	
	Old-age dependency ratio							−
	Persons per square kilometre				+			
	Life expectancy at birth– females				+			
	Tertiary education				−			
	Median age							+
	Masculinity index							+
	Median equalised net income (Euro)	+	+			+	+	
	Single person households		+	−	+	+	+	

4. Conclusion

The aim of this paper was to model the municipal solid waste production and treatment at a national level for the EU member states. 19 variables possibly influencing the waste production and treatment were selected and tested. Linear regression models on the national level achieved satisfying quality based on R^2adj and significant independent variables that can partly explain the current variability in waste management situation across the EU countries were identified.

When planning waste management in EU countries, it is appropriate to focus on meeting EU targets. These targets set minimum recycling rates and maximum landfilling of MSW. It is necessary to analyse both waste production and in particular, waste treatment methods. Initial results mainly show the impact of the country's economic power on waste management. But individual modelled variables from waste management are characterized by different socio-economic, demographic and other factors.

This linear regression approach is unsuitable for forecasting unless significant factors can be well predicted. There exist some forecasts for socio-economic factors but their quality is often worse than the trend of data in waste management. The quality and length of the forecast for single variables is highly heterogeneous. Among economic factors, GDP and unemployment are usually predicted. However, given the dynamic development of the economy, quality long-term forecasts of economic factors are not usually available. On the other hand, demographic development can be predicted in the long term.

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References

Baran B., 2020, Plastic waste as a challenge for sustainable development and circularity in the European Union, Ekonomia i Prawo, Economics and Law, 19(1), 7-20.

Becker R.,1995, Developing an industrial waste management facility design, Plant Engineering, 49 (1), 56-60.

Beigl P., Lebersorger S., Salhofer S., 2008, Modelling municipal solid waste generation: A review, Waste Management, 28 (1), 200-214.

Bong C.P.C., Lim L.Y., Lee C.T., Fan Y.V., Klemeš J.J., 2018, The role of smart waste management in smart agriculture, Chemical Engineering Transactions, 70, 937-942.

Căilean D., Teodosiu C., 2016, An assessment of the Romanian solid waste management system based on sustainable development indicators, Sustainable Production and Consumption, 8, 45-56.

Castillo-Giménez J., Montañés A., Picazo-Tadeo A. J., 2019, Performance and convergence in municipal waste treatment in the European Union, Waste Management, 85, 222-231.

Deng L., Liu Y., Zheng D., Wang L., Pu X., Song L., Wang Z., Lei Y., Chen Z., Long Y., 2017, Application and development of biogas technology for the treatment of waste in China, Renewable and Sustainable Energy Reviews, 70, 845-851.

Di Maria F., Sisani F., Contini S., Ghosh S. K., Mersky R. L., 2020, Is the policy of the European Union in waste management sustainable? An assessment of the Italian context, Waste Management, 103, 437-448.

Diaz-Barriga-Fernandez A.D., Santibañez-Aguilar J.E., José Ezequiel, Radwan N., Neyara, Nápoles-Rivera F., Fabricio, El-Halwagi M., Mahmoud M., Ponce-Ortega J.M., José María, 2017, Strategic planning for managing municipal solid wastes with consideration of multiple stakeholders, ACS Sustainable Chemistry & Engineering, 5 (11), 10744-10762.

Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste (Text with EEA relevance), <eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L0850> accessed 23.06.2020.

Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance), <eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32018L0851> accessed 23.06.2020.

Eurostat, 2019. European statistical office, <ec.europa.eu/eurostat/home> accessed 08.11.2019.

Fan Y.V., Klemeš J.J., Chin H.H., 2019, Extended waste management pinch analysis (E-WAMPA) minimising emission of waste management: EU 28, Chemical Engineering Transactions, 74, 283-288.

Goel S., Ranjan V.P., Bardhan B., Hazra T., 2017, Forecasting solid waste generation rates, Modelling Trends in Solid and Hazardous Waste Management, Singapore: Springer Singapore, 35-64.

Hrabec D., Senland P., Nevrlý V., Popela P., Hoff A., Šomplák R., Pavlas M., 2019, Quantity-predictive vehicle routing problem for smart waste collection, Chemical Engineering Transactions, 76, 1249-1254.

Kováčová A., Louda J., Rybová K., 2011, Demographic changes and prediction of municipal waste, Waste forum, 4, 208-217. In Czech.

Minelgaitė A., Liobikienė G., 2019, Waste problem in European Union and its influence on waste management behaviours, Science of The Total Environment, 667, 86-93.

Morseletto P., 2020, Targets for a circular economy, Resources, Conservation and Recycling,153,104553.

Nunes, K. R. A., Mahler, C. F., 2020, Comparison of construction and demolition waste management between Brazil, European Union and USA, Waste Management & Research, 38(4), 415-422.

Pomberger R., Sarc R., Lorber K.E., 2017, Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method, Waste Management, 61, 558-571.

Rybová K., Slavík J., Burcin B., Soukupová J., Kučera T., Černíková A., 2018, Socio-demographic determinants of municipal waste generation: case study of the Czech Republic, Journal of Material Cycles and Waste Management, 20 (3), 1884-1891.

Traven L., Kegalj I., Šebelja I., 2018, Management of municipal solid waste in Croatia: Analysis of current practices with performance benchmarking against other European Union member states, Waste Management & Research, 36(8), 663-669.

Yadav V., Bhurjee A.K., Karmakar S., Dikshit A.K., 2017, A facility location model for municipal solid waste management system under uncertain environment, Science of the Total Environment, 603, 760-771.

Zorpas A.A., 2020, Strategy development in the framework of waste management, Science of the Total Environment, 716, 137088.

Zotos G., Karagiannidis A., Zampetoglou S., Malamakis A., Antonopoulos I.-S., Kontogianni S., Tchobanoglous G., 2009, Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies, solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction, Waste Management, 29 (5), 1686-1692.