A C T A U N I V E R S I T A T I S L O D Z I E N S I S
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METHODS OF FORECASTING CHANGES IN MUNICIPAL WASTE PRODUCTION IN CASE OF CITIES

Abstract. Waste management is currently one of the most important problems affecting densely populated areas, as in the case of cities. The main problem of waste management is to break a simple correlation between economic growth and the increase in the amount of waste. Forecasting the amount of municipal waste generation turns out to be inaccurate approach on the basis of previously applied methods in the situation of large changes in socio-economic environment. In the literature there is a wide variety of geographically diverse factors proposed for this purpose. This paper presents the results of modeling and forecasting the municipal waste generation changes in cities. In this study, the influence of the various socio-economic factors on the municipal waste production has been tested.

Keywords: forecasting, municipal waste, regression models, cities.

I. INTRODUCTION

Waste generation in Poland is characterized by significant spatial diversity. Nearly 50% of waste is generated in the provinces of Mazowieckie, Śląskie, Dolnośląskie and Małopolskie. There is also a variation in the quantity of waste generated in the cities and villages, the composition of generated waste and the level of technology implementation of recycling and transformation of waste before landfilling. On average, the amount of waste per capita is twice as much in cities as in villages, Beigl et al. (2005).

The most important problem with waste management is to break a simple correlation between the economic growth and the increase in the amount of generated waste. This problem concerns mainly developed countries with high levels of economic development, Berbeka (2005).

As it is shown in a number of European research conducted in the Netherlands, Hekkert, Joosten, Worrell (2000), Denmark, Christiansen, Fischer (1999) and Teheran, Jalili Ghazi Zade, Noori (2008), the currently used approach in forecasting waste consisting of the simple extrapolation of trends

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based on historical data does not correspond to today's rapidly changing socio-economic determinants Taking that fact into consideration we propose to move away from the previously used methods of forecasting the amount of waste and use factors including the socio-economic development.

The aim of the paper is to predict the changes in waste management taking into account the impact of various factors of the socio-economic changes in the amount of municipal generated waste. In addition to statistical data for provinces the statistical information describing the cities is included (the amount of generated waste is the biggest in cities).

"In order to achieve the aim of the paper the following research hypotheses are tested" put forward:

1. The changing social and economic conditions make it necessary to search for new methods of forecasting waste generation.

2. There are many socio-economic factors significantly affecting the changes in the quantity of generated waste, whose extent varies depending on the area of the study.

II. ADOPTED ASSUMPTIONS AND APPLIED RESEARCH METHOD

The organizing waste management system should take into account the changes that will occur in the coming years including the quantity and composition of waste generated in a particular area and the factors significantly affecting the observed trends in this field. The list of potential variables that may affect the amount of waste generated can be very different depending on e.g. the surveyed area. The main elements that will influence the amount of waste generated are: the changes of popul2ation, the affluence and style of life, the economic development of the country (region), the efficiency of production. Changing at a rapid pace socio-economic conditions are the reason for the devaluation of the forecasting methods concerning the quantity and the composition of generated waste. Therefore, in the studies which deal with the prediction of the quantity and composition of generated method it is proposed to move away from the previously used method of forecasting which involves the simple extrapolation in time both the amount of waste generated and the number of the population and use this to further a variety of socio- economic factors, den Boer et al. (2005). That is why for comparative purposes, to predict the changes in the production of municipal waste previously used methods were implemented involving the extrapolation of historical data using trend models and multiple regression models taking into account the impact on the quantity of waste generated factors as socio-economic development.

According to the assumptions set forth in the studies of: den Boer et al (2005), as variables of a socio -economic materially affecting the change in the waste stream at the level of provinces, indicated variable x_1 – gross domestic product (GDP) – determined as an indicator of the economic strength of the region, which was used to estimate both the quantitative and qualitative changes of waste generated; it was assumed that this ratio will have a positive impact on the amount of waste generated and the following social indicators: x_2 – infant mortality rate per 1,000 live births, for which assumed a negative impact on the quantity of waste generated; x_3 – average (expected) life expectancy positively affect the amount of waste generated; x_4 – employment in agriculture , measured as a percentage of the total workforce of the negative impact on the amount of waste generated; x_5 – the number of people at productive age (women 15–59 and men 15–64) per total number of the population; significant positive impact of this variable on the amount of waste generated has been confirmed in many studies, Sircar, Ewert, Bohn (2003); x_6 – the average household size, however it was assumed that smaller households produce more waste per capita, Dennison, Dodd, Whelan (1996).

However, in case of cities due to the availability of statistical data in addition to the variables: x_2, x_5, the studies also included a variable (x_7), which describes the number of available beds indirectly indicating the potential of tourism, with a positive impact on the amount of waste generated.

The collected data were used to estimate the model for forecasting changes of municipal waste generation rate at the level of provinces and cities with county rights. Modeling and forecasting the amount of waste generated, the data on the selected indicators in terms of regions, the data from the years 2003–2013 collected in the Local Data Bank GUS. However, in case of cities the interval trial collected data from the years 2005 to 2012.

III. PRESENTATION AND EVALUATION OF TEST RESULTS

The first stage of research confirmed the spatial differentiation of the amount of waste generated at the level of provinces and cities. The descriptive characteristics of the quantities of waste generated (kg/ capita) for provinces and cities, taking into account the division of the city to 150 thousand residents and more than 150 thousand which are shown in Table 1.

The results confirm the significant variation in quantity of waste generated, especially in the provinces. The share of individual provinces in the amount of waste generated in Poland in kg per inhabitant has ranged from about 2% Świętokrzyskie to over 14% for the provinces of Śląskie and Mazowieckie. However, in the case of cities the variation is less than 2% for Warszawa to

nearly 1% for Tarnobrzeg, GUS (2012). Relatively large differences between provinces or cities are mainly due to population density and the degree of the industrialization of cities. The range of variation for regions is not large and ranges from 2.73% (Śląskie province) to 9.50% (Podlaskie province). However, for most of the analyzed cities it is below 8%. It does not allow to extract clear development trend and to make a prediction by a simple extrapolation of the trend, even taking into account changes in the population of each city. In contrast, previously implemented method of forecasting waste management assumes a simple extrapolation in time, both in the population and long-term changes in individual rates of waste generation. The waste management plans usually assume a steady increase in the amount of waste generated at the national level and then a similar pace is taken into account at the lower levels of aggregation.

Table 1. Descriptive characteristics of the quantity of waste generated (kg/capita) in provinces and cities with county rights in Poland

Region	Participation in the amount of waste produced (%, 2012)	Descriptive characteristics (2003–2012)		
		average	standard deviation	coefficient of variation (%)
Łódzkie	6.48	258.84	16.73	6.46
Mazowieckie	14.36	297.93	19.76	6.63
Małopolskie	7.43	212.08	17.53	8.26
Śląskie	14.11	291.44	7.94	2.73
Lubelskie	3.62	160.48	9.11	5.67
Podkarpackie	3.84	174.91	9.87	5.64
Podlaskie	2.52	221.78	21.08	29.50
Świętokrzyskie	1.89	152.10	9.56	6.29
Lubuskie	3.17	292.02	15.04	5.15
Wielkopolskie	9.75	271.86	18.74	6.89
Zachodniopomorskie	5.34	310.10	10.85	3.50
Dolnośląskie	9.42	324.51	13.64	4.20
Opolskie	2.58	251.13	7.85	3.12
Kujawsko-pomorskie	5.38	237.78	15.53	6.53
Pomorskie	6.74	288.40	18.95	6.57
Warmińsko-mazurskie	3.37	229.84	6.51	2.83
Cities	Participation in the amount of waste produced (%, 2012)	Descriptive characteristics (2005–2012)		
		average	standard deviation	coefficient of variation (%)
Cities of less than 150 thousand residents	29.31	33.09	8.02	24.24
City of above 150 thousand residents	70.69	33.40	3.72	11.14

Source: own calculations based on CSO data.

The next stage of the study was to confirm the expected impact of each factor on the amount of waste generated. The correlation analysis was used for this purpose. The impact of five of the six factors analyzed for the amount of waste generated at the level of provinces (except indicator x_2 – infant mortality rate per 1,000 live births) was confirmed. Similar results were also obtained at the level of cities. The obtained results are used to estimate the model for forecasting changes of municipal waste generation rate based on data from 2012 r. estimating the regression models. It was assumed that the factors identified for a high impact on the amount of the generated waste would be taken into account Therefore variables x_1 and x_4 were included in the model for provinces. However, in the case of cities two variables: x_5 and x_7 were included.

The results of this phase of the investigation are as follows:

1) equation model for the provinces:

$$\hat{y}_t = 308.0645 + 0.0014x_{1t} - 4.1787x_{4t} \quad R^2 = 0.9542; \tag{1}$$

2) equation model for cities:

$$\hat{y}_t = 242.3742 + 0.0036x_{5t} - 4.2118x_{7t} \quad R^2 = 0.8762; \tag{2}$$

Adjusting the estimated models to empirical data is good. The first of the estimated models explains more than 95% of the variation rate of waste production unit. In contrast, the coefficient of determination of the second model is more than 7% lower and amounts to 87.62%.

IV. SUMMARY

In the context of summary of research conducted in the paper, a comparison of forecasts was made on the basis of data from the Mazowieckie province[1]. The estimated forecasts (obtained on the basis of the first model designated for the provinces) were compared with the results presented in the National Waste Management Plan 2014. The NWMP in 2014 assumed the increase in the amount of waste generated per capita to the level of 1 329 kg / M in 2013 and 377 kg / M in 2020, and the amount of waste from the rate of 1.2% in 2013 to 1.6% in 2020, the National Plan ... (2010). Therefore it was assumed, according to the amount of waste NWMP per 1 resident in Mazowieckie province will rise

[1] The forecasts only for the provinces were estimated because the forecasts for cities are not included in KPGO.

in the region by about 1%. However, in the case of projections estimated on the basis of the determined cause – descriptive model adopted for the variable x_1 adjusted GDP growth forecast to around 2.1% in 2013, while the forecast for the variable x_4 was determined by linear extrapolation of existing data. This estimate forecast rate of waste generation per capita per 1 indicates an increase in the amount of waste generated by about 0.7% (forecast error "ex ante" $V_p = 4{,}23\%$). The forecast determined on the basis of cause-and- descriptive model assumes a lower growth rate of municipal waste generated per 1 inhabitant than is assumed in the NWMP and provincial plans. The proposed method of forecasting the amount of municipal waste generated is an alternative to the usually practiced and often criticized method of forecasting waste management, consisting of the simple extrapolation of the time in both population and long-term changes in individual rates of waste generation. The forecasts estimated at the level of regions can also be estimated in relation to the cities in which the largest quantities of waste are produced. Modelling and forecasting the amount of waste generated should also lead to lower levels of aggregation. The paper attempts to search for factors affecting the level of waste in the cities, which provide the greatest amount of waste. A significant barrier in this case is the availability of statistical data at this level of data aggregation.

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METODY PROGNOZOWANIA ZMIAN WYTWARZANIA ODPADÓW KOMUNALNYCH

Gospodarowanie odpadami to obecnie jeden z istotniejszych problemów funkcjonowania skupisk ludzkich, szczególnie istotny w przypadku miast. Głównym problemem w gospodarce odpadami jest zerwanie prostej korelacji pomiędzy wzrostem gospodarczym a wzrostem ilości wytwarzanych odpadów. Prognozowanie ilości wytwarzanych odpadów na podstawie dotychczas stosowanych metod ekstrapolacji trendów, w sytuacji znacznych zmian w otoczeniu społeczno-gospodarczym okazuje się podejściem mało dokładnym. W literaturze przedmiotu proponuje się uwzględnienie w tym celu wielu różnych czynników zróżnicowanych geograficznie. W pracy przedstawiono wyniki modelowania i prognozowania zmian wytwarzania odpadów komunalnych w miastach. W badaniach testowano wpływ różnych czynników o charakterze społeczno-ekonomicznym na wytwarzanie odpadów komunalnych.