Forecasting Municipal Solid Waste Generation in Major European Cities

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Abstract: An understanding of the relationships between the quantity and quality of environmentally relevant outputs from human processes and regional characteristics is a prerequisite for planning and implementing ecologically sustainable strategies. Apart from process-related parameters, continuous and discontinuous socio-economic long-term trends often play a key role in the assessment of environmental impacts. This paper describes the development of a prognosis model for municipal solid waste (MSW) generation in European regions. The objective is to assess future municipal waste streams in major European cities. We therefore focussed on cities, which face significant social and economic changes, e.g. in central and east European (CEE) countries. The investigations covered waste-related data and a broad set of potential influencing parameters that contained commonly used social, economic and demographic indicators as well as previously proved waste generation factors. An extensive database was created with an annual time series up to 32 years from 55 European cities and 32 countries. The evaluation of this historic time series and the cross-sectional data by means of multivariate statistical methods has unveiled significant relationships between the status of regional development and municipal solid waste generation. We identified a core set of significant indicators, which can describe a long-term development path that predetermines the level of waste generation. These findings concerning this analogy have been integrated in an econometric model for European cities.

Keywords: Waste management; Municipal solid waste; Waste generation; Modelling; Forecasting

1. INTRODUCTION

The development of waste management models over the last decades can be characterised by an increasing level of integration of related processes with consideration of environmental, economic and social aspects. The genesis of these decision support tools [Björklund, 2000] is reflected by extending system boundaries, which are shown in Figure 1. In early models, attention was paid to the problems in subsystems, e.g. routing of vehicles and location of treatment and disposal facilities, with a focus on only a few criteria (e.g. costs). Recently, waste management models have started to evaluate entire waste management systems, considering broad sets of quantitative and qualitative criteria.

Up to now, most of these decision support tools for waste management planning use the amount of waste generation as the given input parameter [Björklund, 2000; White et al., 1999]. Thus the impacts of demographic, social and economic dynamics as well as other factors (e.g. consumption patterns or waste prevention) are not taken into consideration for the accurate assessment of future waste generation.

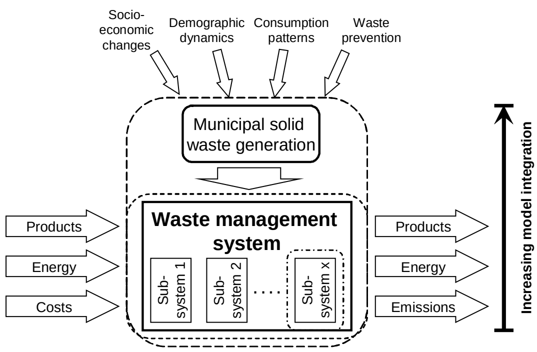

Figure 1. System boundaries in waste management models with different level of integration.

This paper aims to identify parameters which help to explain the present situation and to assess the future amount of municipal solid waste (MSW) generated per capita in different European cities.

This study is part of the European Commission project "The Use of Life Cycle Assessment Tools for the Development of Integrated Waste

Management Strategies for Cities and Regions with Rapidly Growing Economies.” The goal of this project is to develop a highly integrated decision support tool for cities in southern, central and east European countries which helps to evaluate waste management options with regard to environmental, economic and social criteria. In this context, MSW forecasts should arouse the consciousness of the municipal decision makers to implement ecologically sustainable measures (e.g. increasing recycling quotas).

2. METHODOLOGICAL CONSIDERATIONS

Due to the high heterogeneity of municipal solid waste streams and the diversity of their ways through the economy, the identification of parameters is a highly complex problem. An overview of studies in this scientific field by Beigl et al. [2003] describes previous approaches, which can be classified by the type of model:

- **Input-output models:** Here the input of the waste generator is assessed by using production, trade and consumption data about products related to the specific waste streams.
- **Factor models**: These models focus on analyses of the factors, which describe the processes of waste generation. Examples of proved parameters are e.g. the income of households, dwelling types or the type of heating.

Based on this comparative study, only a few methodological procedures came into consideration for application within the aimed forecasting model for cities. This was due to the following reasons:

- **Level of aggregation**: The identification of parameters has to be based on a database, which describes regional peculiarities. The exclusive use of national aggregates in input-output models [Patel et al., 1998] is not appropriate for explaining regional dynamics. Therefore preference was given to factor models that focus on socio-economic and demographic indicators available at a regional level [Bach et al., 2003].
- **Predictability of parameters**: The selection of model parameters has to prioritise parameters at the city level, which can be forecasted with a relatively high accuracy and a long forecasting horizon. Examples of such parameters with high inertia are the population age structure, household size or infant mortality rate [Lindh, 2003].
- **Applicability** refers to the user-friendliness of the aimed forecasting tool. Therefore methods that provide easily available, standardised secondary data have to be favoured over elaborate and time-consuming qualitative approaches such as the Delphi method [Karavezyris, 2001].

Based on these considerations, the amount and composition of municipal solid waste were hypothesised in this approach dependent upon easily available socio-economic and demographic parameters. Under the assumption of an analogous development of regional characteristics and MSW generation, this could explain regional differences between cities as well as long-term changes concerning a city by means of an ex post analysis.

3. DATA

Due to their relevance for waste management planning, the waste potentials of the main materials -- such as organic material, paper and cardboard, plastics and compounds, glass or metals -- were defined as variables to be explained. As the waste potential of a certain waste stream (apart from illegally dumped waste) contains the separately collected material and a partial stream of the residual waste, data about the *collected quantities* of residual waste and the separately collected materials as well as about the *composition* of residual waste (derived from sorting analyses) were both defined in order to be collected as data.

The investigation covered the collection and inspection of the mentioned waste-related data as well as the data in terms of economic, demographic and social indicators in all major European cities with more than 500,000 inhabitants. Together with six regional partners we co-operated with local city representatives who provided us with waste-related and socio-economic data at the city level. Additionally, national data were obtained from international organisations, such as the United Nations or OECD.

To enable the analysis of regional dynamics, the collection of data covered the years from 1970 to 2001. This formed the basis for the hypothesis of the existence of a long-term development path, which is based on the analogous time-shifted changes of different regions.

Finally, it was possible to collect data about the municipal solid waste quantities (including general data at the city and country level) in 55 major cities (out of a total of 65) in the EU-15 and 10 CEE countries with an average time-series length of ten years. In terms of the waste potential of the main materials, only 45 data sets from 31 cities were available.

4. STATISTICAL EVALUATION

There are remarkable differences in the MSW generation rates as well as in the growth rates in European cities. As an example, a comparison of economic areas in the year 2000 shows that major EU-15 cities were characterised by far higher MSW generation rates (510 kg/cap/yr) than the CEE cities (354 kg/cap/yr), while from 1995 to 2001 annual growth in CEE cities is more than twice as high (4.3%) as in cities of EU-15 countries (1.8%).

Therefore several bivariate and multivariate statistical analyses were carried out to identify indicators with a significant impact on MSW generation and composition. Table 1 shows the considered socio-economic indicators, which were available as a time-series at both the city and national level.

Table 1. Available socio-economic indicators.

Available indicators at city and national level	
• Population	• Population density
• Population age structure (0 to 14 years / 15 to 59 years / 60 and more years)	• Sectoral employment (Agriculture / Industry / Services)
• Gross domestic product	• Infant mortality rate
• Overnight stays	• Life expectancy at birth
• Average household size	• Unemployment rate

Firstly single regression analyses (using Kolmogorov-Smirnov tests) proved that the single parameters at the city level explain only an unsatisfactory part of the intertemporal and interregional variance. The infant mortality rate (R^2=0.37, n=86) as the most significant indicator performed even better than the commonly used gross domestic product (R^2=0.22, n=86) as well as all other mentioned urban indicators. This is mainly due to the fact that the (usually available) mean urban gross domestic product is a less meaningful indicator of the social standard than the infant mortality rate as it does not reflect the social and economic inequality, which is especially high within CEE cities [Förster et al., 2002].

Secondly the hypothesis of a general long-term development path concerning urban waste generation was tested by means of multivariate analyses. A hierarchical cluster analysis was therefore carried out to categorise each case (representing a city in a certain year) within homogeneous groups with a similar social and economic standard, here defined as the 'prosperity level.' Four national development indicators (see Table 2) were selected as cluster criteria in order to explain this latent 'prosperity level' variable.

Table 2 shows the assumed prosperity indicators and the MSW generation rates, which prove the hypothesised relationship. Low MSW generation rates coincide with low gross domestic products, high infant mortality rates and agriculturally dominated economy and vice versa. Similar results were obtained by a principal component analysis. An analysis of variance using One-way-ANOVA confirmed the rejection of the null hypothesis, which states the identity of the group means, with an F-value of 61.7 and an F-significance of below 0.1%.

Table 2. Municipal solid waste generated and development indicators.

National development indicators and MSW generation	Prosperity level			
	Low	Medi um	High	Very high
Gross domestic product per capita[1]	5841	11400	19418	21317
Infant mortality rate[2]	15.0	8.7	7.6	5.5
Labour force in agriculture (%)	24.0	18.7	4.8	3.2
Labour force in services (%)	44.4	52.2	59.4	66.2
Municipal solid waste (kg/cap/yr)	287	367	415	495

1 USD Purchasing power parities at 1995 prices
2 Per 1,000 births

Based on this prosperity-related classification, the analysis of the waste potential data unveiled long-term trends in the municipal solid waste streams (Figure 2). While the generation of paper and cardboard, glass, plastics and compounds in

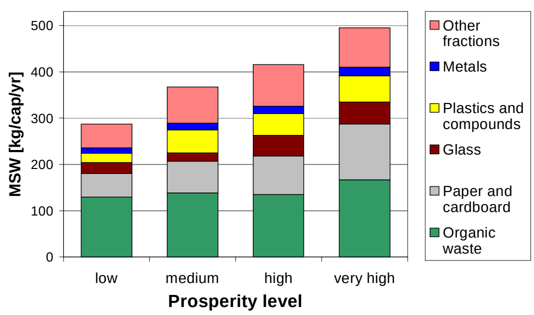

Figure 2. Municipal solid waste streams at different prosperity levels.

prosperous cities is significantly higher both in absolute (per capita) and relative (mass percentage) figures, the amount of organic waste generated is very similar in these four city groups. Additionally the impact of the remaining MSW indicators (see Table 1) was tested and is closely related to the model development described below.

5. MODEL

5.1 Approach

The developed model was designed for repeated use by municipal representatives to appropriately assess the future municipal waste streams of major European cities. In order to support decisions concerning waste management strategies, the planning horizon was defined by 15 years.

Due to the background of these addressed users (municipal representatives), a model concept was created in order to enable a suitable compromise between ease of use and forecasting accuracy. Usability primarily refers to the preference for model input parameters that are adequately predictable at a city level, such as demographic or social indicators.

The selection of the applied approach was based on recent forecasting methodology [Armstrong, 2001]. The size and type of database as well as the existing knowledge of relationships were the criteria for the method selection.

Thus different methodological approaches were selected for the following two modules: an 'MSW generation module' forecasting the total MSW generation rate and an 'MSW composition module' assessing the future mass percentage of main waste streams within the municipal solid waste. The extensive database with time series and cross-sectional data from the total MSW quantities allowed the implementation of an econometric model. The small database concerning waste potentials enabled the application of only the comparably simple extrapolation method.

Figure 3 shows the elements of the overall model. The first calculation step is similar for both modules and is based on the findings for the long-term analogies between prosperity and MSW generation. A given city in a defined future year will be assigned to one of four prosperity groups using forecasts or assumptions for development-related indicators, such as the gross domestic product or infant mortality rate.

The MSW generation module is an econometric model, which consists of a system of multiple linear equations for each city group. Due to the short length of the available time series, the classical econometric approach, rather than the vector autoregression (VAR) approach, was implemented.

The MSW composition module is based on the assumption that prosperity-related changes in the waste composition are similar. Due to the limited waste potential data, the objective lies on a rough trend estimation represented as default values.

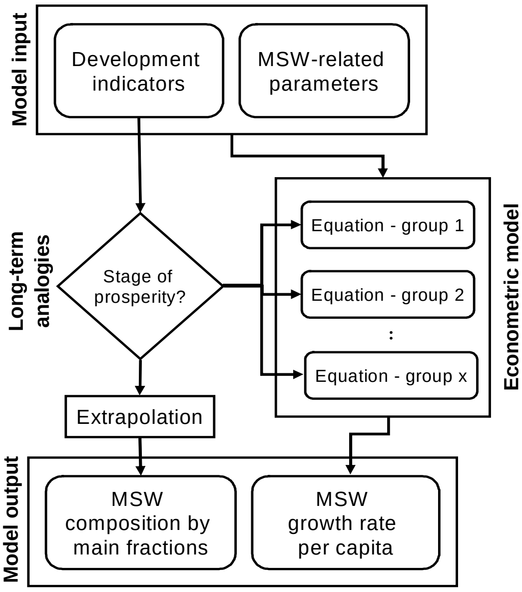

Figure 3. MSW generation model.

5.2 Implementation issues

The main issues concerning the implementation refer to the estimation of the econometric model using socio-economic data, which are represented as cross-sectional time series. The following potential problems were considered to avoid misspecifications of the model [Armstrong, 2001]:

- **Collinearity of parameters:** Social and economic indicators often are highly correlated. The inclusion of too many variables within multiple regression models typically causes collinearity problems leading to ill-conditioned models. A suitable measure for the identification of collinear variables is the variance inflation factor that was therefore used.
- **Autocorrelations** between residuals of neighbouring cases often occur during analyses of time series or structured data. This can depend on wrongly assumed functional relationships or on measurement errors during the data collection. Thus residual analyses including the use of Durbin-Watson coefficients were applied.
- **Outliers:** The full consideration of outliers, which can occur due to measurement errors (a

well-known problem in waste management), deteriorates the accuracy of regression model estimations. Hence the median absolute percentage error (MdAPE) [Armstrong, 2001] was used to avoid the overrepresentation of unrealistic values.

5.3 Procedures

The attribution of the cases according the prosperity level was based on the classification mentioned in Chapter 4. The initial specification included the indicators listed in Table 1. The final model was selected by backward regression using the ordinary least squares method. To avoid autocorrelation and collinearity problems, Durbin-Watson statistics, collinearity tests and residual analyses were carried out.

6. RESULTS

The estimated equations of the final MSW generation model for cities are represented by:

$$MSW^t = 359.5 + 0.014 \cdot GDP^t - 197.1 \cdot \log\left(INF^t_{urb}\right) \quad (1)$$

for cities with *very high* prosperity,

$$MSW^t = 276.5 + 0.016 \cdot GDP^t - 126.5 \cdot \log\left(INF^t_{urb}\right) \quad (2)$$

for cities with *high* prosperity, and

$$MSW^t = -360.7 - 375.6 \cdot \log\left(INF^t_{nat}\right) + 8.93 \cdot POP^t_{15-59} - 123.9 \cdot HHSIZE^t + 11.7 \cdot LIFEEXP^t \quad (3)$$

for cities with *low or medium* prosperity,

where MSW^t is the municipal solid waste generated per capita and year, GDP^t is the national gross domestic product per capita at 1995 purchasing power parities, INF is the infant mortality rate per 1,000 births in the city (INF_{urb}) or in the country (INF_{nat}), $POP_{15\text{-}59}{}^t$ is the percentage of the population aged 15 to 59 years, $HHSIZE^t$ is the average household size and $LIFEEXP^t$ is the life expectancy at birth and t is the year.

Concerning the definition of prosperity levels, Table 3 shows the approximate threshold values for three national indicators among the city groups. For exact calculations, a set of canonical discriminant functions was determined to allocate a city with a given (present or future) characteristic.

All parameters are significant at the 5% error level. Only the 'infant mortality rate' parameter is log transformed because of its obviously exponential nature. The model explains 65% of the variation of the MSW generation rate per capita between cities and in time. The model was validated with a hold-out sample which included 59% of all cases. The out-of-sample error represents a median absolute percentage error of 8.0%, providing a useful model for waste management planning.

Table 3. Approximate threshold values between city groups (national indicators).

Prosperity level	Gross domestic product[1]	Infant mortality rate[2]	Labour force in agriculture (%)
Low			
	7,100	12.0	21.4
Medium			
	13,800	8.1	10.5
High			
	20,200	6.3	4.0
Very high			

[1] USD Purchasing power parities per capita at 1995 prices
[2] Per 1,000 births

In the following, the factors are described which were found to have a significant impact on the amount of municipal solid waste:

- **Gross domestic product**: This commonly used indicator proved to be a significant factor in cities with a high prosperity, but not for cities with a lower economic output. This is due to the fact that the high regional income inequality in CEE countries [Förster et al., 2002] causes a big gap between the usually available *mean* values compared with the clearly lower *median* values, which is a more meaningful, but rarely observed indicator for the social well-being and living standard.
- **Social indicators**: Previous studies never used the infant mortality rate and life expectancy parameters to indicate MSW generation, but they showed a remarkable ability to serve as an additional or alternative variable for the gross domestic product. The advantages of their use are the high explanatory power for regional welfare, the good availability of data, the high quality of data (due to easy compilation without complicated definitions) and the relatively good predictability on the part of city municipalities.
- **Age structure**: The positive relationship between the percentage of the medium age group and MSW generation confirmed the previous studies [Sircar et al., 2003; Lindh, 2003].
- **Household size**: As in the study of Dennison et al. [1996], the significantly negative

relationship between the average household size and MSW generation was analysed on a regional scale.

7. CONCLUSION AND OUTLOOK

At present environmental models, such as in waste management, are characterised by a high level of sophistication in terms of the technical and environmental optimisation within the drawn system boundaries, but also by an almost complete lack of consideration of social, demographic and economic border conditions. In waste management the usual municipal and regional waste forecasts (as the key starting point for the development of waste management plans) regard the total population as the only input parameter [Karavezyris, 2001]. As a consequence these strongly simplified assumptions can favour false estimations concerning future waste treatment capacities and dimensioning of restructuring activities.

This approach aimed to integrate the impacts of regional socio-demographic and economic dynamics on the municipal solid waste generation. A qualitative, analogy-related approach was combined with the econometric methodology in order to assess these relationships for 55 very heterogeneous European cities in a long-term perspective. The results showed that this model can be implemented as a helpful decision support tool for municipal waste planners.

In future work, this model will be statistically refined (especially the composition module) and realised in aJava environment. The beta version will be tested in six European cities from regions with rapidly growing economies to verify its practicability.

6. ACKNOWLEDGEMENTS

This study is part of a project initiated within the European Commission's Fifth Framework Programme (EVK4-CT-2002-00087).

The authors wish to thank the following people for their dedicated work during the course of the investigation (in alphabetical order): Heinrich Riegler (BOKU – University of Natural Resources and Applied Life Sciences, Austria); Emilia den Boer, Jan den Boer (Darmstadt University of Technology, Germany); Panagiotis Panagiota-kopoulos, Nantia Tsilemou (Democritus University of Thrace, Greece); Pouwel Inberg, Marjakke van der Sluis, Wim van Veen (De Straat Milieu-adviseurs, the Netherlands); Lothar Schanne (novaTec, Luxembourg); Francesc Castells, Montse Meneses, Julio Rodrigo (Universitat Rovira i Virgili, Spain); Iwona Mackow, Pawel Mrowinski, Marta Sebastian and Ryszard Szpadt (Wroclaw University of Technology, Poland).

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