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A paper waste prediction model

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Abstract

The aim of this paper is to develop a model predicting the collected amount of waste paper at the regional level of municipalities. Learning about the factors that influence the amount of collected paper is a prerequisite for the evaluation and reorganization of collection systems. We hypothesize that the amount of collected paper depends on both, the waste potential and factors which influence the convenience such as the density of collection sites.

For this study, we use a sample of 649 municipalities. The data show a high variance in terms of the collected waste paper per person and year between the municipalities. We develop a multivariate regression model providing valuable insights about the relationship between demographic parameters and the amount of collected waste paper. Furthermore, in this novel approach we found a significant positive impact of the convenience of the collection system.

1 Introduction

In the 70s, due to the rapid increase of solid waste from households in addition to decreasing capacity of landfills, increasing environmental consciousness and recycling opportunities, Austria, as most of the middle European Countries, established a system for collecting household waste in separate fractions.

Beside the necessity of reducing the total amount of municipal solid waste brought to landfills, some of its fractions such as paper, glass or metal turned out to be profitably recyclable.

In order to determine the type and capacity of facilities for waste treatment, the necessity for reliable data concerning

- quantity and
 - composition
- of municipal solid waste has increased.

As each waste category has to be collected, transported and treated separately, an significant increase in costs can be attributed to a separate waste collection system. As a consequence, recently some municipalities decided to change the existing collection system for some waste categories from curbside collection into a bring system. In a bring system, households have to transport their own waste to collection centers.

The absolute mass of waste generated by households can be described by the different waste potential of the main fractions, such as organic material, paper, plastics, glass or metal. For the case of a (hypothetical) non-separated waste collection, the collected amount of waste represents the entire waste potential (apart from waste illegally dumped or used as domestic fuel). In contrast, if waste is collected in waste categories, the potential of a specific category such as paper must be determined as the sum of

- paper collected separately in paper bins,
- paper found in the bins of the other separated collected waste categories,
- paper which is part of the residual waste and
- the amount of paper going to some other sinks as e.g. used as domestic fuel.

Therefore, the exact waste potential of a waste category can only be determined by simultaneous analysis of residual waste and each separately collected waste category, which is highly time consuming and cost intensive. Therefore, only isolated analyses mainly for single cities are available [1,2].

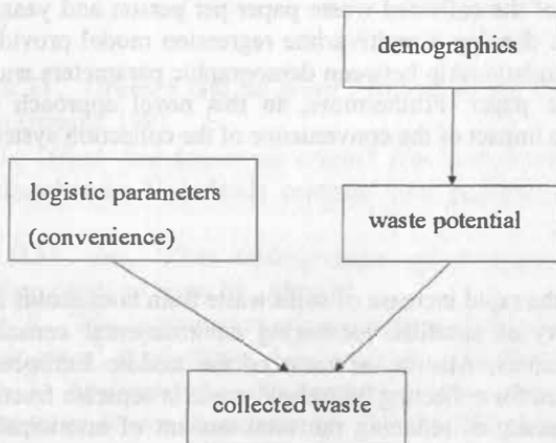


Figure 1: Determinants of collected waste

Conventional models for prediction solid waste generation are based on socio-economic and demographic factors [3,4]. We hypothesize the amount of collected waste paper to depend on the waste potential and logistic parameters for waste collection. While the waste potential represents the upper limit of waste to be collected, the actual amount of collected waste is lower. As waste separation cannot be fully controlled (privacy, costs of control) and is subject to consumer's propensity to collaboration, the amount of collected waste also depends on convenience factors such as the average distance to the next collection site or recycling center (bring system) or the collection frequency (curbside collection).

The waste potential can hardly be influenced in the short term and it only sets the frame for decision makers. On the other hand, the design of the waste collection system allows to actively influence the amount of the different collected waste streams.

In the light of the recent discussions about cost- and environmental effectiveness of grown waste management structures, encompassing models are needed which describe all the influences and complex interactions within the entire waste management chain.

The aim of such a model is the identification of parameters which significantly influence the amount of collected waste in order to provide decision makers with a tool for accurate planning of future restructuring activities, investment decisions, adoptions to new national or EU directives and negotiations with waste collection firms. Up to now most of the decision support systems for management planning take the amount of generated waste as given [5,6,7,8,9,10].

As most of the decisions (number of collection sites or capacity decisions of recycling centers) are made on a very local regional level (municipalities), existing aggregate models dealing with the problem of waste generation are not appropriate and lack applicability [11,12]. Our contribution aims at identifying parameters which help to explain the average amount of waste paper collected per person in different municipals.

2 Data

The lack of reliable models in waste chain management is either due to methodical problems in determining waste generation [13] or can be attributed to the fact that comprehensive data on a regional scale were hardly available [11,14].

Detailed data as e.g. the density of collection sites or the amount of the different collected waste categories is hardly available on a regional scale as at the level of municipalities as in most countries waste reports only exist at an aggregate level.

In order to develop our model, we had to cooperate with local representatives who provided us with the data on amounts of collected paper and their collection system from 649 municipalities.

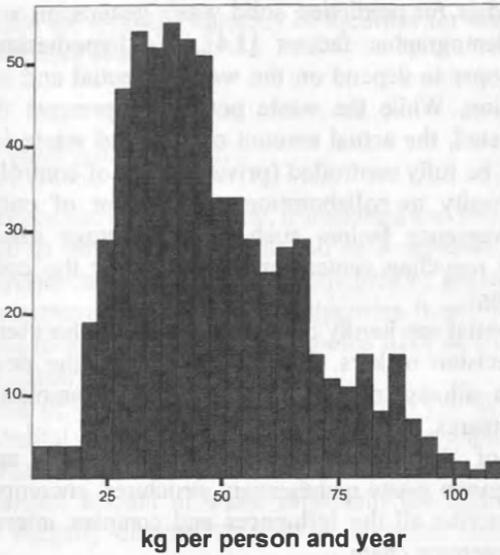


Figure 2: Histogram of waste paper [in kg] per person and year

Figure 2 shows the histogram of waste paper per person and year for our sample of 649 municipalities representing 25% of the inhabitants of Austria. The histogram shows the surprisingly high variance in the amount of collected waste paper per person between municipalities.

Additional demographic data from central statistical organizations were available at the level of municipalities. This data contained information about the income, industrial, topographical and family structure. Furthermore, data on the number of inhabitants, overnight stays and households were available.

Social-economic parameters and demographic features had been used in waste management to question the behavior of consumers in terms of their willingness to take part in separate waste collection [15].

3 Models and Analysis

Our approach is based on hypotheses about the relationship between collected waste and several independent variables. The available data offers multiple operationalizations for these variables. Purchasing power, for example, is measured by 7 different variables partly highly correlated. The inclusion of all variables typically causes collinearity problems leading to ill-conditioned models. Starting from an encompassing specification [16] including linear and log-transformed alternatives, we chose the final model by backward regression (model selection).

Table 1: Log-Linear regression model for waste paper. r-square adj. 48,7%.

* indicates variables which have been transformed into (50) percentiles.
649 observations. In order to reduce the impact of outliers, values outside $\mu \pm 3 \cdot \sigma$ have been eliminated.

dependent: ln(waste paper)	coefficient.	t-value
intercept	3,5191	45,8
overnight stays per person	0,0013	4,4
income index (household)*	-0,0063	-7,6
income index (per capita)*	0,0091	7,3
pctg. housewives*	-0,0048	-5,7
pctg. employees in businesses and industry*	0,0038	3,9
pctg. employees in service sector*	0,0055	5,3
nr. agricultural firms*	-0,0033	-3,9
ln(nr. sites for collection/(0.0001*sq.km))	0,0709	3,8

Table 1 contains the parameters and t-values of our model for waste paper per person and year. The dependent variable is log transformed, significantly increasing r-square as compared to the linear alternative. All parameters are significant at the 1% error level. The model explains 48.7% of the variation of waste paper between municipalities providing a useful decision support model for waste chain management.

Figure 3 plots the predictions of our model against the actual amounts of waste paper on a per-capita level (left hand side).

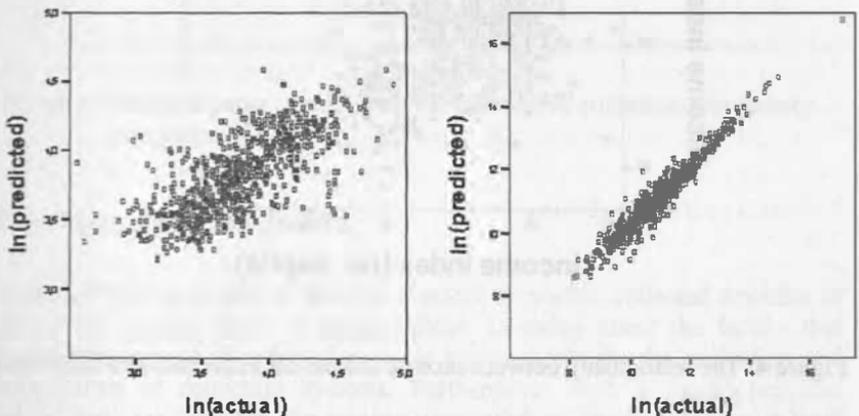


Figure 3: Actual vs. predicted waste paper on a log scale. Left side shows waste paper per person and year whereas right side shows waste paper per municipality and year.

The model represented in Table 1 is also the most appropriate specification we found for the prediction of total waste paper per municipality and year yielding an almost perfect fit (see Figure 3 right-hand side) in terms of r-square (higher than 99%). The predicted values shown in Figure 3 were computed by multiplying the predicted amount of paper per person by the number of inhabitants of each municipality.

The following factors were found to have a significant impact on the amount of collected waste paper:

1. Municipalities with a higher number of overnight stays per person show a higher number of collected waste paper. This can be directly attributed to the increased waste potential of municipalities in tourist regions.
2. The income index shows a strong effect on the amount of waste paper collected supporting the hypothesized influence of demographic factors on the waste potential. Measured on the basis of households (per capita), a higher index shows lower (higher) amounts of collected waste paper. A suspected strong correlation between this two indicators causing collinearity problems proofed wrong ($R=-0,05$, see Figure 4).

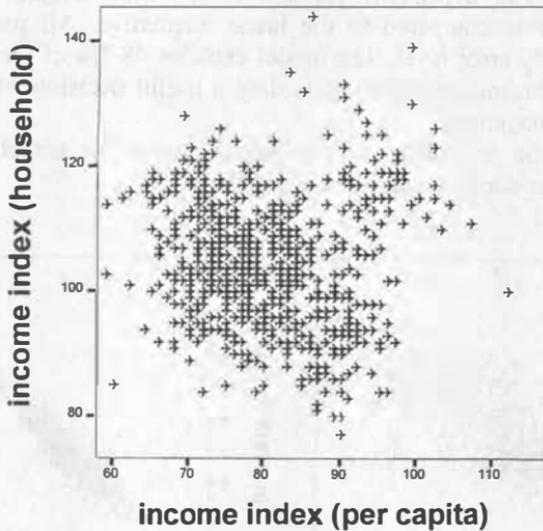


Figure 4: The relationship between income indices on household and individual Level

3. Municipalities with a higher percentage of housewives in the population show a significantly lower amount of waste paper per person.
4. Higher amounts of waste paper are predicted for municipalities with a higher percentage of employees in businesses and industry as well in the service sector. This can be due to the fact that people living in these municipalities

have a higher education causing higher newspaper consumption. Furthermore, small offices are allowed to dispose waste paper via the household collection system.

5. The model associates a higher number of agricultural firms with a smaller amount of collected paper.
6. The density of collection sites positively influences the amount of collected waste paper, due to increased convenience, supporting the hypothesized relationship (see Figure 5). However, an increasing number of collection sites per sq.km increases the amount of collected paper at a decreasing rate. We have incorporated this saturation effect by using a logarithmic transform in our model.

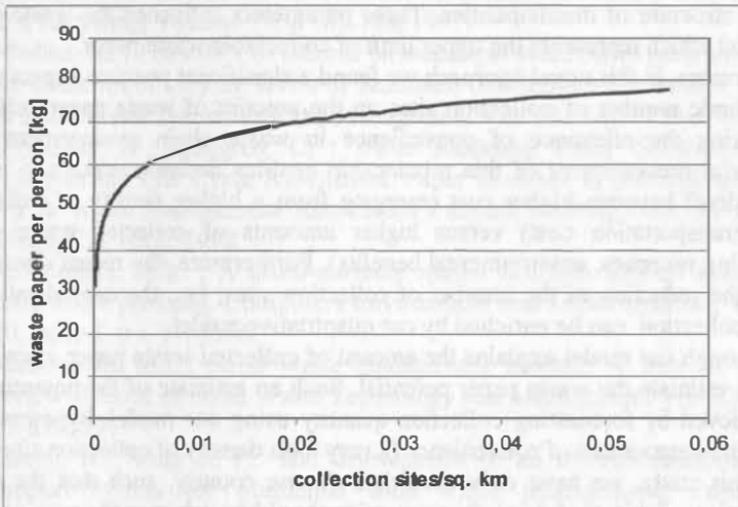


Figure 5: Collected paper as a logarithmic function of collection site density (correlation=45,9%)

4 Summary and Conclusion

The aim of this paper was to develop a model to predict collected amounts of paper at the regional level of municipalities. Learning about the factors that influence the amount of collected paper is a prerequisite for the evaluation and reorganization of collection systems. Furthermore, such a model provides essential input for decisions like restructuring activities, implementation of legal directives or investments into new recycling plants.

We have hypothesized that the amount of collected paper depends on both, the waste paper potential and factors which influence the convenience such as the density of collection sites.

The data used in our analysis consists of a sample of 649 municipalities. The

data show a high variance in terms of the collected waste paper per person and year between the municipalities. Prior studies tried to explain this variation by mere use of socio-economic factors. Additional data were available, including information about the income structure, industrial and topographical structure as well as information about their collection system at the level of municipalities.

We have developed a multivariate regression model providing valuable insights about the relationship between demographic parameters and the amount of collected waste paper, as well as between logistic parameters and collected waste paper.

We identify several factors enabling an accurate explanation of waste paper generation. We found a significant impact of the number of overnight stays per person, income indices, parameters describing the employment structure and family structure of municipalities. These parameters influence the waste paper potential which represents the upper limit of collectable waste paper.

Furthermore, in this novel approach we found a significant positive impact of the logarithmic number of collection sites on the amount of waste paper collected supporting the relevance of convenience in waste chain management. The successful measurement of this relationship enables decision makers to model the tradeoff between higher cost emerging from a higher density of collection sites (transportation cost) versus higher amounts of collected waste paper (recycling revenues, environmental benefits). Furthermore, the recent discussion about the reduction of the number of collection sites; i.e., the centralization of waste collection, can be enriched by our quantitative model.

Although our model explains the amount of collected waste paper, it can also help to estimate the waste paper potential. Such an estimate of the potential can be achieved by forecasting collection quantity using our model, hypothetically assuming a maximum of convenience (a very high density of collection site).

In this study, we have only used data of one country, such that the direct application of this model in other countries should be taken with some caution. When the definition of variables such as income indices is differing, the model needs re-estimation.

Our investigation directly indicates several lines of interesting future research. Our model would suggest to increase the number of collection sites in order to increase the recycling rate. However, a more encompassing view of the waste chain could be achieved by including aspects of environmental costs such as emission of collection vehicles. An integrated view of these aspects could help to define optimal collection systems in terms of economical and ecological costs. In this paper, we have focused on waste paper. It would be interesting to have comparable models for other waste categories such as glass or plastic waste.

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