# 3D-$CO_2$-MODELLING FOR WASTE MANAGEMENT IN STYRIA/AUSTRIA

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***Abstract***
**3D-$CO_2$-modelling for waste management in Styria/Austria**
The paper in hand focuses on a calculation model which had been developed for calculating the $CO_2$ production of a garbage truck during a waste collection tour. The challenge is the integration of not only the distance and loading weight but also the different petrol consumption and therefore $CO_2$ production in regard to the topography of the whole collection tour. Additionally the increase of waste load at each stop during the whole collection tour has to be taken into account for the calculation.
The model has been developed on basis of Excel. In order to get the real data from the collection tours these had been accompanied. There not only the whole tour but also all waste bins and stops for loading the waste had been registered. Both GPS (Global Positioning System) and RFID (Radio-Frequency Identification) had been used. The huge amount of data had to be scrubbed. This process of amending or removing data in a database that is incorrect, incomplete, improperly formatted, or duplicated was an important step to have reliable data for further calculation processes.
The identification of the $CO_2$ production during a waste collection tour including the topography and continuous revenue load had not been done so far and allows the identification of tour segments with lower but mainly higher or very high ecological impact. However, this is the basis for further discussions about options for optimizing the actual tours and habits of waste collection. That approach is part of a more comprehensive investigation of waste collection tours with general focus on economic, ecologic and social potentials for optimization.
***Key words***
Waste management, $CO_2$ production of trucks, Styria, Austria

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## 1. Theoretical Background

Austria (around 84.00 km$^2$ and around 8.2 million inhabitants) has a tradition of controlled waste management spanning more than 30 years. It was the Austrian law for waste management of 2002 was an integral turning point for this transformation. Following the implementation of the law Austria´s waste management began to operate towards sustainability principles. It resulted in increasing collection, separation and recycling rates. Parallel to the positive economic development in Austria also waste quantities grew and the approach of waste reduction through waste avoidance became an essential part of waste management. For that purpose children in kindergarden and primary schools became familiar with the handling of different sorts of waste. With that knowledge children then educated their parents. More and more laws and guidelines passed a bill, and especially the so called “Landfill Ordinance” (Austrian Federal Government, Directive 164/1996 BGBl) of 1996 lead to a new way of thinking: the eradication of the majority of waste. According to the five steps of the recent EU waste hierarchy (European Commission, Directive 2008/98/EC) waste avoidance, re-use, recycling and preparation for recovery reduced the amount of Austria´s waste to around 3% (Federal Waste Management Plan 2010).

In Austria´s county Styria (around 16.400 km$^2$ and 1.2 mio. inhabitants) each inhabitant produces around 120 kg residual waste per year, in cities more, in the rural area less.  The quota of waste separation is very high, nevertheless impurities are also very high. The reason can be seen not only in missing information and lack of behavior but also in ignorance. In the Styrian residual waste can also be found 51.300 t organic waste, 24.300 t synthetic material, 16.200 t paper, 6.700 t glass and 5.400 t metal. In sum an economic damage of 10 mio. Euro occurs (Land Steiermark website 2015). Together with inefficient collection systems the potential economic saving rates in Styria´s municipalities represent an important factor that should not be disregarded.

Austria´s recent Federal Waste Management Plan from the year 2010 includes beside

- an analysis of the actual situation of waste management and an estimation of the future development of waste streams,
- the regional distribution of waste disposal facilities and of significant facilities for the recovery of waste,
- an assessment of the need to decommission facilities,
- an assessment of the need for additional plant infrastructure for the purpose of establishing and maintaining a network of facilities to ensure waste disposal self-sufficient and to ensure the treatment of waste in one of the closest appropriate facilities,
- also includes existing waste collection systems and an assessment of the need for new collection systems (Federal Waste Management Plan 2010).

The research is legitimated via the requirements of the Federal Waste Management Plan 2010 and should be understood as a contribution to protection of climate and the sustainability of waste management in regard to it relevance for climate. Additionally the assessment of the traditional tours can be a basis for arguments within a decision making process in municipalities.

The main focus lies on the question which environmental impacts during a collection tour originate and which impacts do the long drive to single remote locations within the collection area cause. Out of that different fields of research can be deduced. Not only economical but also ecological evaluations and frameworks should flow into the results. Therefore the following questions and statements are part of the project agenda (ADENSO 2014):

- How sustainable is the actual collection-logistic (Fig. 1)?
- How is it possible to increase the transparency of waste collection?
- What should a comprehensible and measureable service provision look like?
- Which basic criteria must a call for bids for waste collection have?
- Proposal for citizen targetted incentive schemes for residential waste prevention.
- Concept/test for technical tools, e.g. GPS and RFID.
- Dynamic tour guidance and renunciation from fix assignments.
- Requirements (ecology, logistics) on waste management companies and service
- providers.
- Preparation of a basic concept for objective benchmarking.
- The influence of infrastructure and topology will be assessed.


Fig. 1: An overfull waste bin, how it should not be!

## 2. Methods for fieldwork

The field work is methodologically extensive and entails accompanying residual waste collection trucks during the collection tour. This is the only possibility for gaining real drive collection data. Data is not limited to the length of route, but also entails measurement of time, topography, stops for loading waste containers, filling rates, and sometimes – if the municipality or waste management association is interested – the quality of the residual waste allocated by the households of the municipality (an indicator for the quality of waste separation).

Basically the methods of investigation are divided into a preparation phase and a field work phase. The preparation phase consists of statistical data collection about waste management such as waste containers, size of waste containers, economic data, fees and costs etc. As well as regional data on inhabitants, households, size of municipality etc. Differences arose from the type of vehicle and the layout of the payload. Even by only considering these circumstances, a range of challenges for the exact collection of the data occurred. Because of that, a public servant of the municipality was assigned to verify the accuracy of the data with the help of an analogue list of households that contained both the addresses and registered garbage bins. This task required an excellent knowledge of place by the responsible public servant. Moreover, the velocity at which the waste containers were loaded onto the truck had to be considered, especially if the containers had been picked up and emptied at a high rate in compact areas of settlement. Refuse collectors worked in a very experienced and uninterrupted manner in order to avoid obstructions of the traffic and to be able to fulfill their daily workload. Owing to the early morning hours and darkness as well as occasional bad weather conditions (rain or snow), the research team too had to cooperate efficiently and work with a high degree of concentration. The data (filling level and quality) were communicated via notes that were attached to the waste containers (Fig. 2). The notes were facing in the direction of the approaching collection vehicle. Problems were caused by different ways of attaching the notes, wind and if several waste containers were closely strung together.


Fig. 2: Investigation of the filling level of the container and the quality of waste by an employee of the Waste Management Association Weiz in May 2015.

## 3. Calculation of the Ecological Optimization potential

Ecological issues are an integral component of sustainable areal and tour optimization and were, thus, also incorporated into the study. Incurred $CO_2$-emissions usually play a crucial role in this matter. The examination at hand, therefore, specifically paid heed to this factor. The Fig. 3 shows the modified idea behind: the truck on the chart drives ups and downs but always has the same load and weight. A waste collection truck loads waste from stop to stop and therefore becomes heavier and heavier. The truck needs e.g. 3 minutes for that part of the tour which could be 900 meter. RFID measures that distance every second. That means in accordance to the driving speed for the whole three minutes 180 data about distance driven per second and difference in elevation are being generated.

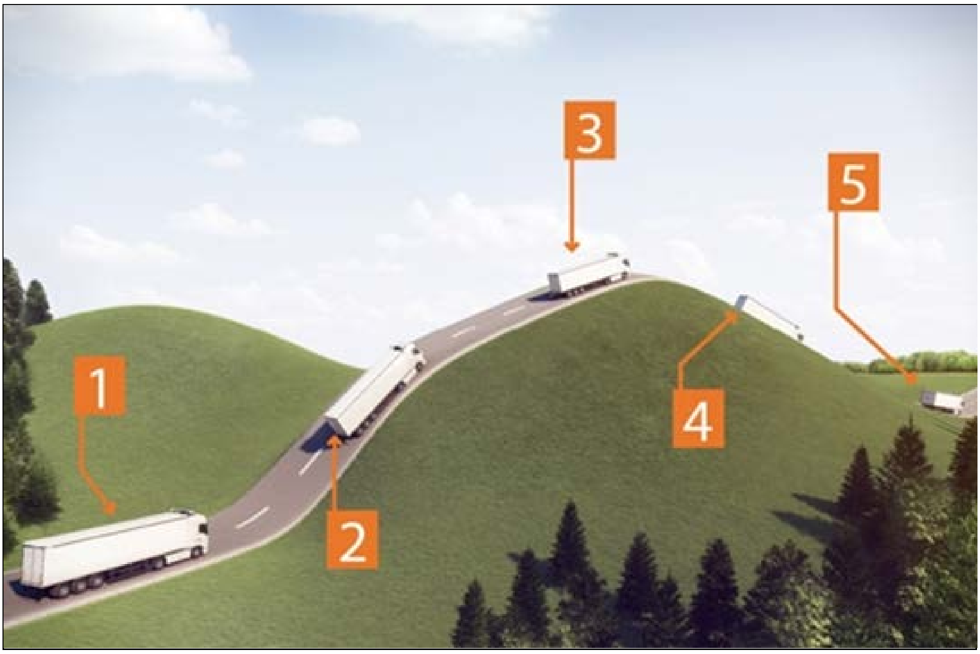


Fig. 3: A typical part of a waste collection tour with five stops for uploading waste bins.

The model developed for the study at hand was utilized for calculating the overall $CO_2$-emissions produced during the waste collection tours. For this purpose, the model made use of several parameters which included the length of the tour combined with the topography as well as the cumulative weight of the collected residual waste and the net weight of the waste collection truck.

In principal following two calculation approaches are possible:

1. from the start of the collection tour to the end of the tour and
2. from the end of the collection tour back to the start of the tour.

For the calculation introduced in the paper in hand the second way of calculation had been chosen because at the end of the tour the exact fuel consumption is known. This value can be used as a reliable parameter for the calculations. What has to be done is to calculate the fuel consumption backwards to the start of the tour according to all known tour specifics such as:

- all the stops for loading waste,
- all the distances between those stops,
- the route of lines in sections (RFID measure per second, distances depending on the driving speed)
- the differences of elevation between the per second measurement points done with RFID.

The result of that kind of calculation is the proportional backward distribution of fuel consumption under the consideration of the tour specifics. Out of that e.g. fuel consumption factors for different inclinations in tour topography can be detected. The more tours are calculated the more precise that factor becomes. Of course this method of calculation always needs the same typ of waste collection truck. Finally it will be possible to simulate tours from the start to an end. It has to be underlined that this method of calculation and simulation mainly should be used for the direct comparison of a traditional tour with a proposed optimized waste collection tour. It is not the goal of the introduced approach and method to calculate the real fuel consumption and finally $CO_2$ production but to calculate on a as realistic as possible basis with the above mentioned tour specifics with focus on increasing load and topography of the tour in order to compare different waste collection tours!

For this calculation, established basic formulas were combined with applicable enhanced formulas, which resulted in the development of a complex calculation method. In combination with the known fuel consumption data of each residual waste collection tour, it was possible to calculate a target value. These calculations could then be extrapolated with the help of type-specific data on the standard consumption. The extrapolation simultaneously included the relevant parameters of the tours. Thereafter, the calculations and the results were compared with each other. The individual results were ultimately tested for plausibility and consolidated.

The objective of this process was to compare the optimized areal collections developed for the new municipality of Birkfeld with the current structures and processes from an ecological point of view. The results of the present study can be appropriated for quantifying and deducing the ecological benefit of future spatial optimizations from submitted proposals.

The data that were collected within the framework of this study allows conclusions on the residual waste collection tours. These collection tours can be depict as distance profiles. The data are detailed to such an extent that they record the gradient ratios per second (in this case, the varying velocity has to be considered). The length of the tour and the differences in altitude that were measured rendered it possible to calculate the gradient angle (uphill and downhill). At every stop, rises and slopes of the routes were identified, averaged and categorized relative to their inclination (Fig. 4). In parallel, the waste containers were added up per stop by way of filling degree and standardized weighting.

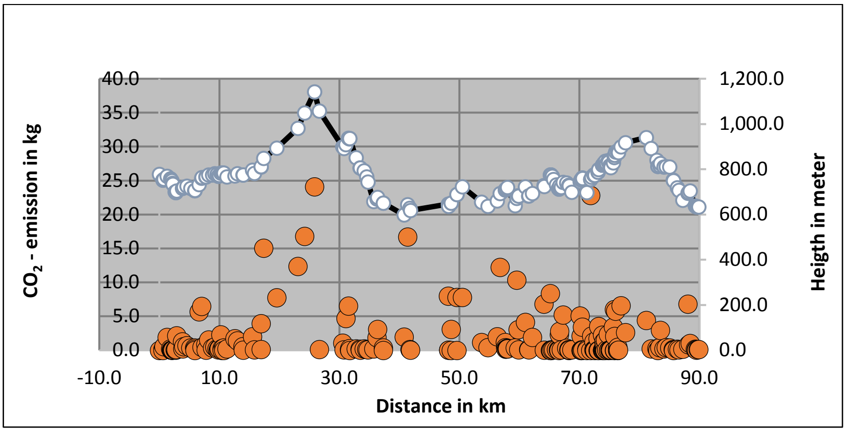


Fig. 4: The black line shows the topography of the collection tour. The white dots are the stops for loading waste containers. The red dots show the amount of the individual $CO_2$ production on the way to each household (residual waste container resp. stop).

## 4. Results

The final goal of the investigation is to define factors that determine the environmental impact of waste collection tours in catchment areas. These factors could help creating zones with above-average environmental impacts in order to generate a waste producer friendly mode of fees. According to the interpretation of the collected data, the municipality Birkfeld can be divided into three different waste collection catchment areas:

1. The local center of Birkfeld is a relative compact collection area with a high density of waste containers. The density of households is the highest in the whole area of investigation (143 households per $km^2$). The distance covered by the collection trucks is the shortest. The topography – calculated as the difference in altitude per household – is also the lowest. Therefore, the $CO_2$-emissions - presented in kg $CO_2$ per household – are relatively low at a rate of 0.38 and with around 27 % below the average of the whole new municipality (Fig. 5 and 6).

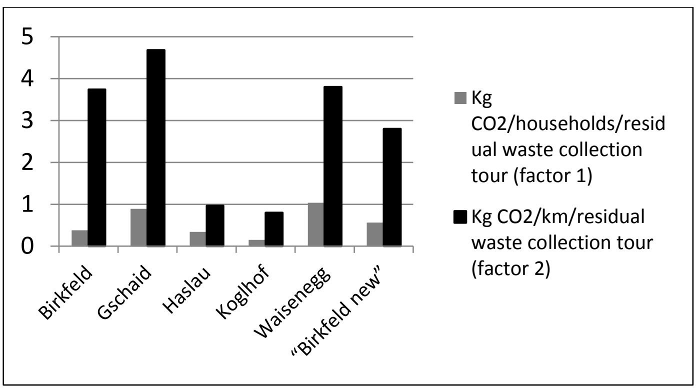


Fig. 5: Ecological factors according to geographical structures of collection areas.

2. In the local center of Birkfeld, 3.74 kg of $CO_2$ are produced per km in the course of the collection tour. This rate can be attributed to the enhanced stop-and-go traffic which, in turn, results from the large number of picked up containers. The rate is also influenced by the total of approx. 4,000 meters covered in altitude per collection tour, the structure of the tour, the preparation of the bins as well as the type of the collection truck (in this case only a single vehicle type is utilized).

3. The local centers of Gschaid and Waisenegg can be more or less summed up as a second group due to similarities in size, population density and topography. In detail, however, there are some differences connected to waste disposal. The values of kg $CO_2$ per household of the two local centers, namely 0.89 (Gschaid = 71% above the average) and 1.04 (Waisenegg = 100% above the average) are on top of the comparison, with Waisenegg ranking first. This can be explained by examining the baseline values for household density (Waisenegg 12.71 and Gschaid 19.67) and production of $CO_2$ as a function of route length (Gschaid : Waisenegg = 1 :1.6) and covered difference in altitude (Gschaid : Waisenegg = 1 : 1.44). The collection vehicles are of the same type. The values 4.68 (Gschaid) and 3.80 (Waisenegg) are associated with the factor '$CO_2$ produced per kilometer of covered collection tour'. Consequentially, Gschaid is above the average at around 63% and Waisenegg at around 30%, which can be ascribed to the higher relief intensity along the collection route within the two local centers.

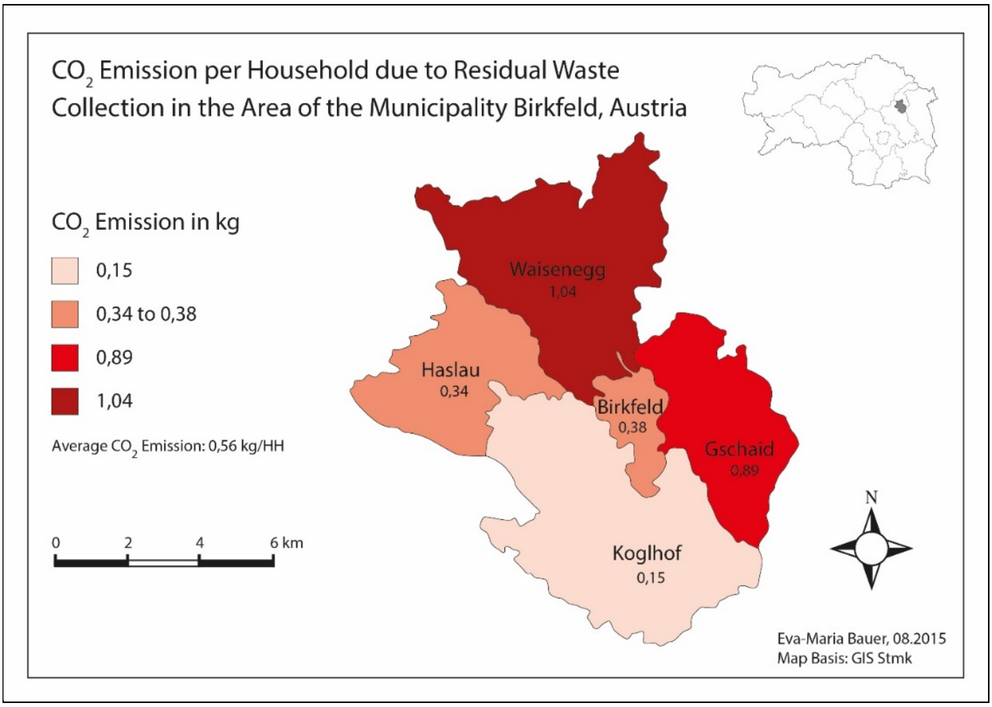


Fig. 6: The map shows Kg $CO_2$/households/residual waste collection tour (factor1) in the local centers of the new municipality of Birkfeld.

4. The waste collection systems of the local centers Haslau and Koglhof, on the other hand, function differently. The waste is managed by means of a concentrated collection of refuse bags at predefined collection spots and via partial delivery to the Haslau civic amenity site. Moreover, $CO_2$-saving pickup trucks are employed that – aside from topographical factors – consume less than half of the fuel compared to standard-type collection trucks.

As a result of the predefined collection spots, the distance covered along the residual waste collection tour is shorter than in local centers of similar size, for example Koglhof compared to Waisenegg (ca. 65 to ca. 90 km). Even if the topography is considered too, the respective values come off well compared to the other local centers and lie far below the average. The collection structures and processes of both local centers can be regarded almost ideal from an ecological point of view. In the case of a bonus-malus regulation, the local centers of Haslau and Koglhof would be attested ('rewarded') with a bonus. In the case of Koglhof, this bonus would be even more positive than in Haslau if factor 1 was considered (in Koglhof, more than 4 times as many waste bins or bags are collected). The same applies to factor 2 (Fig. 5) although in a weakened form.

The calculated factors are a clear expression of the differences between the local centers of a municipality with different geographic development. By calculating and then modelling the generated figures it is possible to do that on different areal scales: from the individual household up to all higher areal units such as unit residential areas, parts of municipalities, whole municipalities, districts (waste management associations), counties, etc. (even for whole Austria e.g.). Unified and therefore comparable figures are necessary to set benchmarks and for the comparison of the efficiency of waste collection (resp. waste management).

Tab. 1: Some recommendations to reduce $CO_2$ emissions.

| Opportunities | Description | Considerations for implementation |
|---|---|---|
| Improved routing | Sub-optimal routing of waste bin collection generates unnecessary tonne-kms | Use more advanced logistics planning and vehicle routing tools<br>Cost implications |
| Improve vehicle operation (eco-efficient driving) | The operation of a vehicle can be improved by driver training. Driver training can be supported by intelligent electronic systems that monitor driving behaviour and fuel-consumption. | Cost-benefit of different measures. Potential impact on service levels. |
| Make use of energy sources with a lower carbon intensity | Increase use of alternative fuels with lower carbon intensity (e.g. bio-fuel) | Sufficient cost advantage. Availability of technology and suitable equipment. |

## 5. Conclusion

The research work focuses on potentials of the residual waste collection in rural areas with very different household densities and presents first results out of a very broad and intensive research work throughout the next years. Out of that result different efforts per household what means that those household which are in the very periphery have a higher economic effort than those in the center of the municipalities. In connection with the evaluated ecological load in form of $CO_2$ production of the waste collection truck during the collection tour it of course follows that the longer the distance and the more topography the tour includes the higher the values are. On the basis of an own developed calculation model it is possible to show the economic and ecological costs not only per defined area but also per household. On that basis it is possible to create areal zones with understandable (waste producer friendly) fees. Additionally proposals for new residual waste collections tours had been made which increase the efficiency of waste collection in a both economic and ecological way.

The mode of investigation - from fieldwork to modelling - offers an ideal opportunity for a more sustainable waste collection management especially but not only in rural areas. The author therefore invites especially politicians but also public servants to think about existing structures and processes concerning waste collection under the aspect of changing developments in their divergent administrative units. The detailed knowledge about the operational systems of waste management is a crucial point and can be enhanced by proper basic research. The development shows an increasing interest coming from the municipalities because the can see the potentials of optimization. It would be fine if also waste management companies would follow that development.

Anyhow, this example of basic research work meets the requirements of a future optimized sustainable waste management (Stegmann 2009) and should be understood as a contribution to fighting against climate change even it is only a very small contribution. But it is not only this approach it is also the local positive influence on waste management when the populations becomes aware of questions around waste collection. The more often waste management affairs come to their mind the public awareness will be increased. The experiences show that people are interested in what is been done during the field work. That is the necessary basis in order to be successful in changing waste collection systems by optimizing them. It also needs the co-operation with the population at least in those parts of the catchment areas of waste collection which are identified as areas with high potential of optimization, so in very peripheral areas with ongoing depopulation processes. Without the willingness and co-operation of the population it will not be easy to realize proposal for optimization!

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***Summary***

Austria´s waste management began to operate towards sustainability principles. It resulted in increasing collection, separation and recycling rates. Parallel to the positive economic development in Austria also waste quantities grew and the approach of waste reduction through waste avoidance became an essential part of waste management.The main focus of the article lies on the question which environmental impacts during a collection tour originate and which impacts do the long drive to single remote locations within the collection area cause. The final goal of the investigation is to define factors that determine the environmental impact of waste collection tours in catchment areas. These factors could help creating zones with above-average environmental impacts in order to generate a waste producer friendly mode of fees. The research work focuses on potentials of the residual waste collection in rural areas with very different household densities and presents first results out of a very broad and intensive research work throughout the next years. Out of that result different efforts per household what means that those household which are in the very periphery have a higher economic effort than those in the center of the municipalities. In connection with the evaluated ecological load in form of CO2 production of the waste collection truck during the collection tour it of course follows that the longer the distance and the more topography the tour includes the higher the values are. On the basis of an own developed calculation model it is possible to show the economic and ecological costs not only per defined area but also per household. On that basis it is possible to create areal zones with understandable (waste producer friendly) fees. Additionally proposals for new residual waste collections tours had been made which increase the efficiency of waste collection in a both economic and ecological way.