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Characterization of Household and Commercial BMW Generation According to Socio-economic and Other Factors for the Dublin Region

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Abstract: Both planning and design of integrated municipal solid waste management systems require accurate prediction of waste generation. This research predicted the quantity and distribution of biodegradable municipal waste (BMW) generation within a diverse 'landscape' of residential areas, as well as from a variety of commercial establishments (restaurants, hotels, hospitals, *etc*.) in the Dublin (Ireland) region. Socio-economic variables, housing types, and the sizes and main activities of commercial establishments were hypothesized as the key determinants contributing to the spatial variability of BMW generation. A geographical information system (GIS) 'model' of BMW generation was created using ArcMap, a component of ArcGIS 9. Statistical data including socio-economic status and household size were mapped on an electoral district basis. Historical research and data from the scientific literature were used to assign BMW generation rates to residential and commercial establishments. These predictions were combined to give overall BMW estimates for the region, which can aid waste planning and policy decisions. This technique will also aid the design of future waste management strategies as a function of demographic changes and development. By changing the input data, this estimation tool can be adapted for use in other locations.

Keywords: BMW; Dublin; solid waste management, waste prediction; household waste; commercial waste

Introduction

Waste management is widely recognized as one of the most problematic areas of Irish environmental management. With the rate of waste generation continuing to increase and existing waste disposal sites reaching the end of their useful lifetimes, waste management has become a matter of urgency (Forfás, 2001). For years, Ireland has lagged behind many of its European neighbours in preventing and managing solid waste. Some 72% of household and commercial waste is considered biodegradable municipal waste (BMW). It is estimated that approximately 2,007,900 tonnes of BMW was generated in Ireland in 2005, of which 65% was landfilled and the remaining recycled (EPA, 2006).

Economic growth during the last 15 years has stimulated greater consumption throughout Irish society, with a concomitant increase in waste generation so that waste management issues have become increasingly acute (Fahy et al., 2004). Until very recently, Ireland's economy was the fastest growing economy among OECD members, doubling in size during the 1990's (OECD, 2006). As gross domestic production (GDP) has increased, so has the volume of waste produced, because economic prosperity affects waste generation by stimulating increased consumer activity and business expansion (Mazars, 2003). It is important to focus on waste prevention – to decouple waste creation from economic growth – and reverse current waste trends.

Both planning and design of integrated municipal solid waste management systems require accurate prediction of solid waste generation. However, to achieve world-class waste management objectives through a process of continuous improvement, it will not

be enough simply to know the gross quantity of wastes being generated in a region; both the quantity and spatial distribution of waste must be defined as well. With this specific knowledge it will, for example, be possible to target waste prevention strategies to locations in which they are most needed. Appropriate waste management solutions vary from one locality to another (Diem Trang et al., 2007). Waste management models can improve the basis for decisions regarding waste management (Eriksson et al., 2003). Modelling of waste generation is a useful way to anticipate the design of waste management strategies as a function of demographic changes and development, and to approximate future management needs based on predictions according to social and economic changes. This process should lead to a more sustainable approach to waste management.

Many different studies have been conducted to predict waste generation rates, or waste-related human behaviour (Taylor and Todd, 1995; Ebreo and Vining, 2001; Phillips et al., 2002; Sharp and La Roche, 2007) and attitudes (Barr et al., 2001, Parfitt, 2002, Emery et al., 2003), based on numerous elements. Among these elements are income (Abu Qdais et al., 1997; Medina, 1997); household size (Dennison et al., 1996a); socio-economics (DeBúrca, 1995; Dennison et al., 1996b); historical collection rates (Bach et al., 2004) and observed behaviour (Tonglet et al., 2004). Studies have been conducted using both samples (Abu Qdais et al., 1997; Dennison et al., 1996; Dyson and Chang, 2005; Dahlén et al., 2006) and surveys (Dennison et al., 1996b; Tonglet et al., 2004; Robinson and Read, 2005; Fahy et al., 2004; Mosler et al., 2006,). Waste generation has been predicted on a per capita basis (Dennison et al., 1996), for administrative units (Grossman et al.,

1974; Chang and Lin, 1997), and at city scale in Europe (Beigl et al., 2003) and elsewhere (Chang and Lin, 1997), as well as at municipality scale (Bach et al., 2004; Dahlén et al. 2006).

The aim of this research was to develop a reliable and realistic model for predicting the BMW generation from both the residential and commercial sectors within the Dublin Region. For this study, BMW was defined as comprising of organics (food and garden waste) and paper / card waste constituting approximately 72% of overall residential / commercial waste (EPA, 2006).

This study used social class and household size statistics as well as commercial characteristics such as employee numbers, bed numbers, student seats, and bedroom numbers along with their spatial distribution to predict the generation of BMW from the Dublin region at the Electoral District level. It is anticipated that this combination of input data will result in realistic output regarding generation rates for the region and assist waste management decisions.

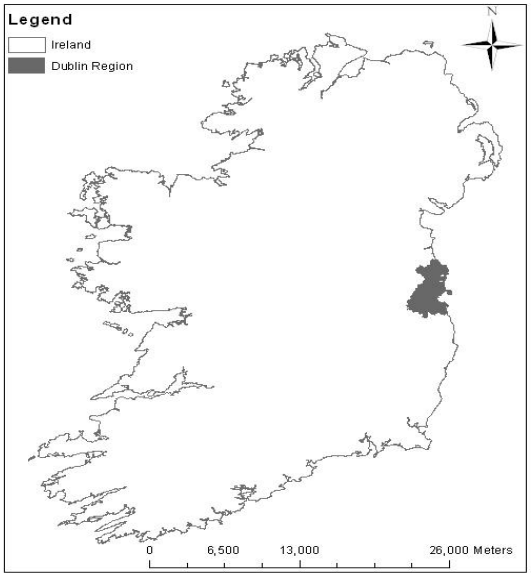
This was achieved by identifying, defining geographically, and characterizing the residential sector, as well as various commercial waste generators, and then translating this information into maps of waste generation for the Dublin Region. This paper focuses on waste generation prediction from demographic changes and development to aid design of waste management strategies. This paper describes the resulting GIS-based estimating system that can be used to quantify the generation of BMW in the Dublin (Ireland) region

(Figures 1 and 2). The system application requires housing and demographic statistics as well as the locations and types of commercial activity. The system facilitates the visual and spatial distribution of BMW to be assessed within the region, allowing for waste policy and planning decisions to be made optimally tailored to the specific region. By changing the input data, this estimation tool can be adapted for use in other Irish regions.

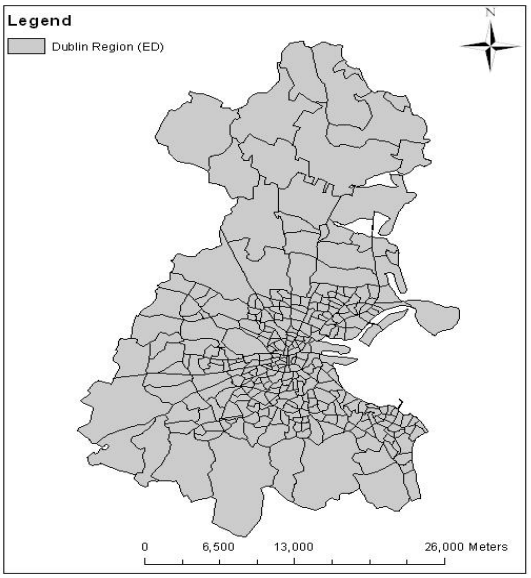
Methods

Study Area

This study was conducted in the greater Dublin, Ireland region (Figures 1 and 2). The Dublin Region consists of 92,184 ha, and is comprised of four Local Authority areas, namely Dublin City, Fingal, South Dublin and Dún Laoghaire-Rathdown. Each local authority manages solid waste separately, but all co-operate in doing so under a regional waste management strategy. The scale of study was conducted at the Electoral District (ED) level (the smallest administrative area for which population statistics are published). There are 322 Electoral Districts located throughout the Dublin region, all of varying sizes (e.g., "Ushers" of 14 ha to "Lusk" with 4238 ha) and ranging from inner city districts with high population densities to rural areas with dispersed populations.



Location of The Dublin Region in Ireland



The Dublin Region Electoral Divisions

Figure 1. Location of Dublin **Figure 2. Dublin Electoral Divisions (ED)**

Data sources

To geographically define the locations of BMW waste generation, vital statistics data were obtained from the Irish Central Statistics Office (CSO); these data (i.e. SAPS, Small Area Population Statistics, 2002) described the demographic profile (e.g., house types, number of occupants, household incomes, etc.) of the entire residential sector for the Dublin Region. These data were supplemented using the An Post / Ordnance Survey Ireland GeoDirectory (2006), a listing of all commercial establishments together with their geographic co-ordinates and other data, and the Kompass Ireland electronic database of businesses (Kompass Ireland, 2006). Data were also obtained from the Irish Department of Education and Science (Department of Education and Science, 2006) and the Dublin Transport Office (DTO, 2007) to locate educational institutions. ArcGIS 9

(ESRI, 2004) and ArcView *v*3.3 (ESRI, 2004) were used to map points or relate address points to Electoral Districts for plotting. The An Post / Ordnance Survey Ireland GeoDirectory 2006 (An Post & Ordinance Survey Ireland, 2006) was also used to verify the accuracy of points and to map some data points.

Preparing and analysing commercial sector information

In order to determine which elements within the commercial sector might contribute most to the commercial waste stream, a comprehensive literature survey was conducted (Massachusetts Department of Environmental Protection, 2002; Seattle Public Utilities, 2002; Barrett, 2003; CIWMB, 2004; Hogan et al., 2004; CIWMB, 2006; EPA, 2005; EPA, 2006). Seven types of commercial establishments were deemed to be the most significant producers of commercial BMW and were included in the study:

- Supermarkets / groceries;
- Hotels;
- Restaurants;
- Takeaways/fast-food establishments;
- Education (primary, secondary schools, and 3rd level);
- Hospitals;
- Public houses (e.g., bars, lounges).

A variety of data were collected to characterize each member of the commercial types:

- The size and nature of each establishment (all establishments)
- The number of employees (all establishments)

- The number of education places (schools, colleges/universities)
- The number of bedrooms (hotels)
- The number of beds (hospitals)
- The composition of waste generation (all establishments).

Hotel bedroom numbers and hospital bed numbers were acquired by contacting the specific establishment and / or by accessing their commercial literature (e.g., internet sites).

Waste generation rates for the various types of establishments comprising the commercial sector were taken from published research, specifically the following:

- Massachusetts Department of Environmental Protection (2002)
- CIWMB (2004)
- Hogan et al. (2004) [EPA]
- EPA (2005)
- CIWMB (2006)
- Barrett (2003).

Waste generation rates only were analysed in the study. Disposal rates or diversion rates were not calculated. Waste generation rates were used to create a 'BMW Generation Equation' for each commercial sector.

Lastly, each unique commercial point was assigned the relevant attribute data (e.g., number of employees, numbers of hotel rooms, etc.) and waste generation rate equation. Together these data were used to quantify and characterize the waste generated. These data were then integrated with the Electoral Division Identification Number (EDID) to aid precise mapping and apply the waste generations at the Electoral District level.

Preparing and analysing residential information

For the residential sector the following data were gathered:

- Household size (persons per household)
- Social class (according to the CSO)
- Waste generation rates ((Dennison et al., 1996; DeBúrca, 1995).

Two estimation techniques were utilised for assigning waste generation rates to this sector: household basis and social class basis. As with the commercial sector points, waste generation rates and demographic data were assigned as attributes to the relevant geographic locations and combined to give BMW generation rates at the Electoral District level.

Results

Data coverage

A total of 2,261 commercial points (unique commercial establishments) belonging to the seven different commercial types were identified. Approximately 87% of geocode locations in the electronic business directories were available for mapping of the

commercial sector, with a very high percentage available for the hospitals at 93% and the hotels at 88.7%.

Figure 3 depicts the distribution of establishments comprising the commercial sectors studied in this research.

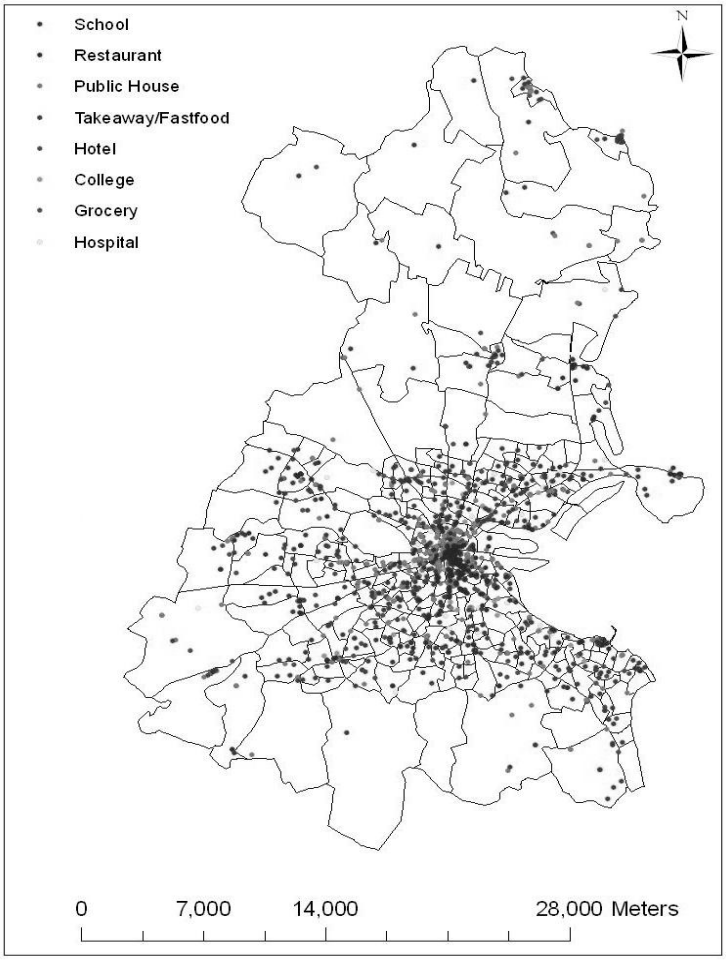


Figure 3. Commercial Point Source Locations in the Dublin Region.

Figures 4 and 5 are examples of how residential areas were mapped according to household size (Figure 4) and social class (Figure 5). Household sizes were registered in the SAPS database (CSO, 2002) for up to 7 persons per household; similarly there were 7 social classes.

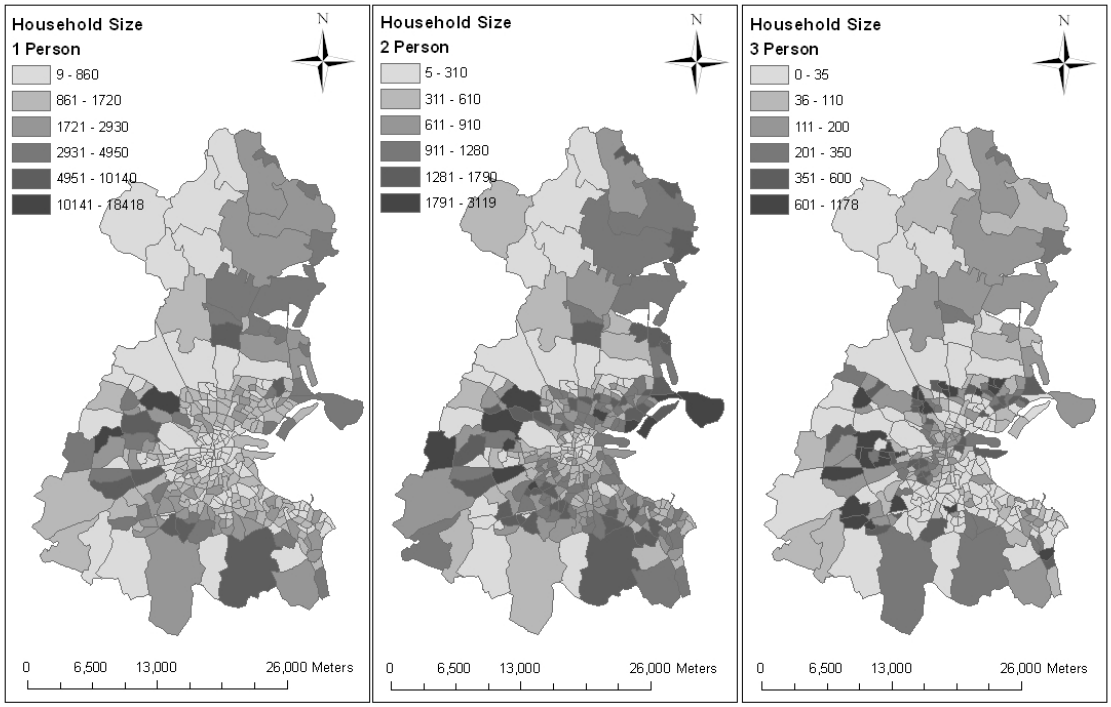


Figure 4. Example Household Size Distributions for the Dublin Region (1, 2 and 3 Persons per Household).

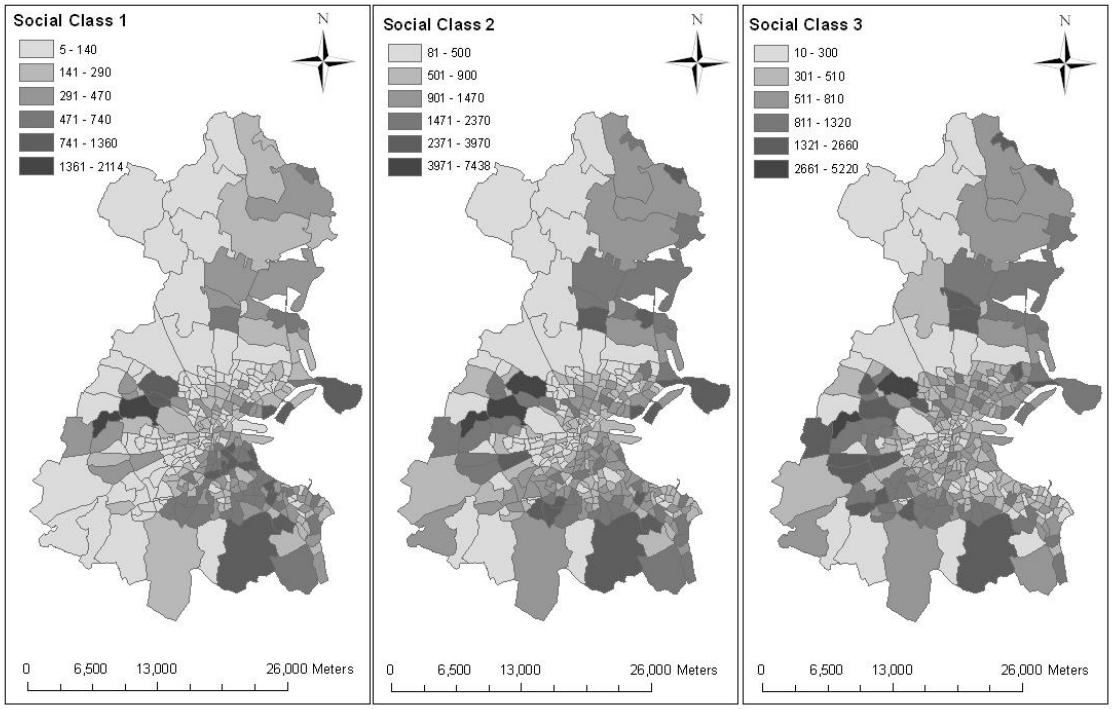


Figure 5. Example Social Class Distribution for the Dublin Region (Social Classes 1, 2 and 3).

Commercial BMW generation

Equations with which to estimate BMW generation from each type of commercial establishment were developed following a comprehensive literature review (Table 1). The equations use a variety of readily obtained measures (e.g., number of employees, number of beds) on which to base the BMW generation estimates.

Table 1. Commercial BMW generation equations

Sector	Equation	References
Hospital	(7.26 kg/bed/day)*0.72	(CIWMB, 2004; EPA, 2006; EPA, 2005)
Grocery	(No. Employee x 1360.78 kg) /52 wks + paper @ 45.12%	(Mass Dept Env Prot., 2002)* (Hogan et al., 2004)
Hotel	(7.74 kg / room / day)*0.72	(Hogan et al., 2004; EPA, 2006)
Restaurant	(No. Employee x 1360.78 kg) + paper @ 30.62%	(Mass Dept Env Prot., 2002)* (Hogan et al., 2004)
Pub	(2919.77 kg x employee x 0.53) /52wks + paper @ 34.4%	(CIWMB, 2006) (Hogan et al., 2004)
Takeaway	(7.71 kg x employee x 7 days)*0.72	(CIWMB, 2004; EPA, 2006)
School	(2.7 kg x education place number)*0.72	(Barrett, 2003; EPA, 2006)

*Massachusetts Department of Environmental Protection (2002)

Approximately 3,500 t of BMW are predicted to be generated per week in the commercial establishments included in this study (Table 2). There are a large number of schools (primary and post primary) located throughout the Dublin Region (658). Public houses are also abundant and widely dispersed in the region (496). The grocery sector is predicted to generate a large amount of BMW (1550 t wk^{-1}), which, at nearly half the total commercial BMW generated, was expected, as there is a large number of these point sources in the region. Grocery stores and supermarkets in Ireland generate a large amount of BMW, both from the delicatessen section (most supermarkets in Ireland have a “deli” section that serves both in-store customers and takeaway customers) and also from the

general sales department. The hotel, public house, restaurant and takeaway establishments together contribute 35% of the overall predicted BMW generated. There is also a large number of educational places (student seats) in the Dublin region (268576), which was also expected as Dublin, the capital city in Ireland, is the 'education capital' in Ireland, holding the majority of 3rd level institutions. The main education 'hotspot' was identified to be located in the Electoral District Clonskeagh-Belfield (18020) where the 3rd level institution University College Dublin is located.

The range in predicted generation rates from each electoral district (0 t wk^{-1} to 1015 t wk^{-1}) encompassed the ED "Ballymun A" (94 ha) [amongst others including Cabra West A (42.8ha) and Rathfarnham-Butterfield (76.8 ha)] at the lower end of BMW generation rates and ED Dún Laoghaire-East Central at the top end of BMW rates (Figure 6). The range in generation rates excluding zero values was found to be 42.7 kg wk^{-1} in ED Tallaght-Avonbeg (33.2 ha, 1645 population, 22 education places, 85 employees) to 1015 t wk^{-1} in ED Dun Laoghaire East Central (45.6 ha, 2144 population, 119 education places, 4248 employee places, six restaurants, two pubs, and two large grocery stores / supermarkets).

Table 2. Predicted Commercial BMW Generation by Sector.

Sector	BMW generation ($t\ wk^{-1}$)	% of Total BMW
Grocery	1550.6	44.01
Restaurants	262.3	7.44
Takeaways	55.3	1.6
Hotels	535.5	15.2
Pubs	378.3	10.7
Hospitals	219.4	6.2
Education	522.1	14.82
Total	3523.5	99.79*

*figures do not add to 100% due to rounding

The largest predicted quantity of commercial BMW was found to occur in ED Dún Laoghaire-East Central and the ED Royal Exchange A. The Frequency of BMW generation for Electoral Districts is shown in Figure 7 where the frequency of Electoral Districts found within the relevant BMW Generation ranges is displayed.

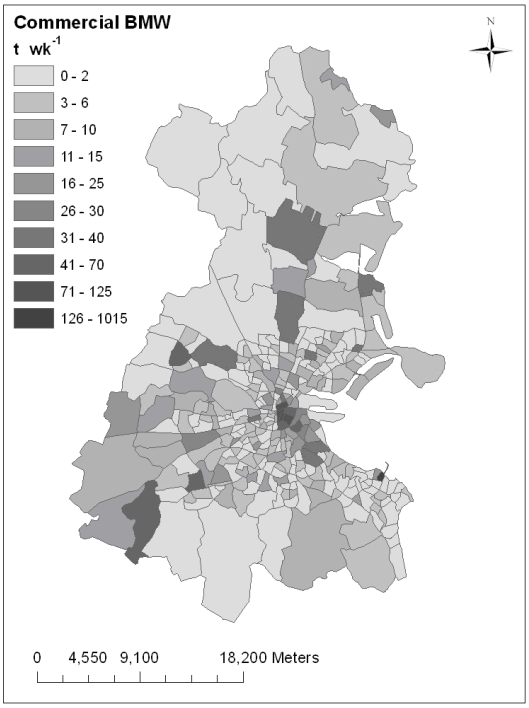


Figure 6. Distribution of Predicted Commercial BMW Generation Rates in the Dublin Region.

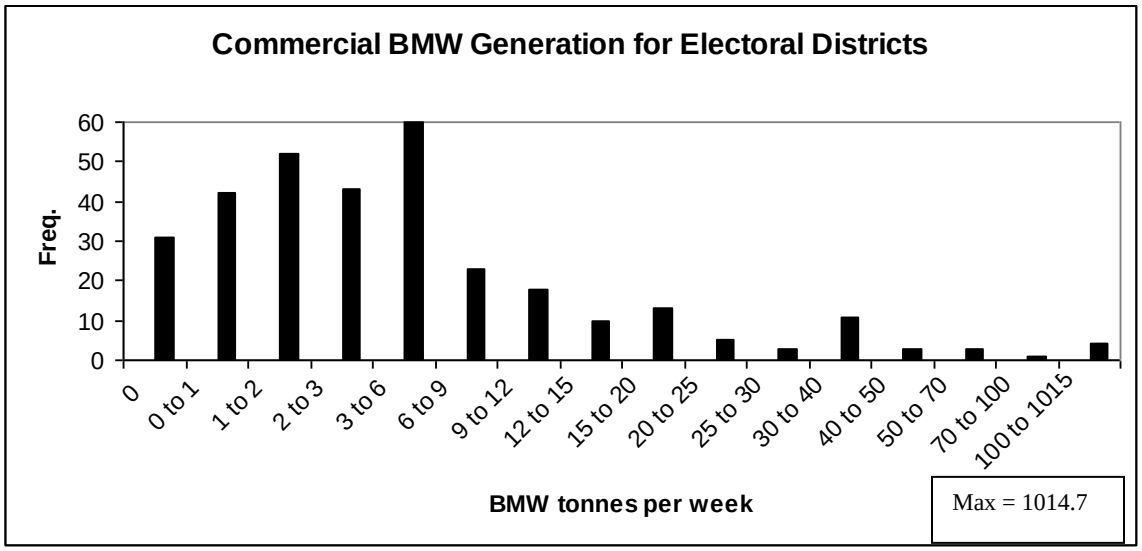


Figure 7. Frequency chart for predicted commercial BMW generation.

Residential BMW generation

The residential sector was predicted to generate significantly more BMW per week than the commercial sector; however, exactly how much more depends on the methodology utilized to estimate household BMW. On the basis of household size 8159 t BMW wk^{-1} were predicted, whereas on a social class basis, 13082 t BMW wk^{-1} were predicted (Table 3). Table 3 also shows the variations in frequencies with which Electoral Districts fell into a range of BMW generation rates when predictions were made on a household size and a social class basis, and when generation rates were scaled according to the area of an Electoral District.

Table 3. Residential BMW Generation Frequency for Electoral Districts

BMW Generation (t wk^{-1})	Household Size (No. ED)	Social Class (No. ED)	BMW Generation (kg wk^{-1} ha^{-1})	Household Size (No. ED)	Social Class (No. ED)
0 to 4	4	1	0 to 15	21	18
4 to 6	6	1	15 to 30	7	4
6 to 8	3	4	30 to 45	3	6
8 to 10	10	2	45 to 75	9	2
10 to 14	43	7	75 to 105	9	6
14 to 18	42	17	105 to 135	15	5
18 to 21	49	31	135 to 200	37	16
21 to 26	39	27	200 to 250	29	18
26 to 30	44	26	250 to 300	45	17
30 to 35	31	49	300 to 400	64	39
35 to 40	13	32	400 to 500	21	51
40 to 45	12	38	500 to 600	24	47
45 to 50	7	17	600 to 700	15	22

50 to 60	10	24	700 to 800	8	19
60 to 80	5	27	800 to 900	5	17
80 to 100	2	8	900 to 1000	2	14
100 to 150	1	8	1000 to 1500	8	18
150 to 300	1	3	1500 to 1970	0	3
Max	**152.4[1]**	**283.2[1]**	**Max**	**1424.7[4]**	**1967.6[5]**
Min	**0.3[2]**	**3.9[3]**	**Min**	**0.4[2]**	**3.1[6]**
Sum	**8158.5**	**13081.5**	**Area (ha)**	**92184**	

1 = Electoral District "Blanchardstown-Blakestown", 2 = Electoral District "Airport", 3 = Electoral District "Lucan North", 4 = Electoral District "Merchants Key B", 5 = Electoral District "Routunda A", 6 = Electoral District "Ballinascorney"

Table 4 further illustrates the extent to which predictions of BMW generation differed when made on a household size and social class basis. While predictions using the two bases were within 30% of each other for 56 Electoral Districts, the predictions differed by 30 to 50% for most (263) of the districts.

Table 4. Range in % difference between prediction techniques

Difference between prediction techniques (Percentage range)	**Electoral District Frequency (Number ED's)**
0 to 20	17[1]
20 to 30	36
30 to 40	142
40 to 50	119
50 to 60	7
60 to 100	1[2]

Total Districts	322

1 = For two Electoral Districts, "Rathmines West B" and "Blanchardstown-Tyrrelstown", predictions based on household size and social class differed by 16%; thus predictions for 15 Electoral Districts differed by between 16 to 20%.
2 = Electoral District "Airport"

The geographical distribution of household BMW generation rate predictions is shown in Figure 8. Interestingly, the areas of highest predicted BMW generation are not high density inner city Electoral Districts, but rather districts located north, south and west of the city centre that are experiencing large population growth.

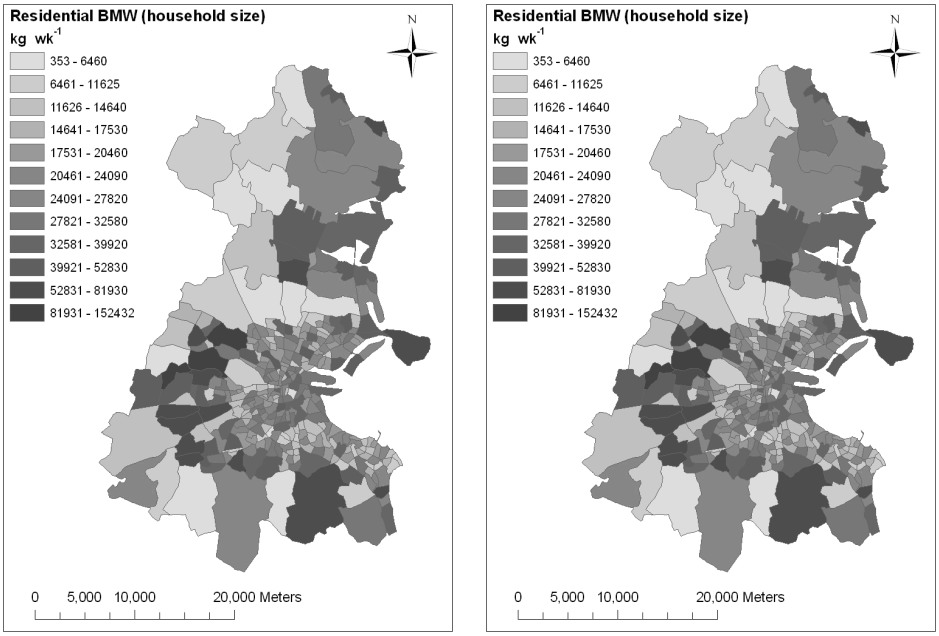


Figure 8. Distribution of Predicted Residential BMW Generation According to Household Size (left) and Social Class Statistics (right).

Combined Commercial and Residential BMW

Combined, the commercial and residential sectors in the Dublin Region are predicted to generate 11682 t BMW wk^{-1} when estimates are based on household size or 16605 t wk^{-1} when estimates are based on social class (Figures 9 and 10, Table 5).

Table 5. Combined Residential and Commercial BMW Generation Frequency for Electoral Districts

BMW Generation (t wk^{-1})	Household Size (No. ED)	Social Class (No. ED)	BMW Generation (kg wk^{-1} ha^{-1})	Household Size (No. ED)	Social Class (No. ED)
0 to 8	10	4	0 to 15	16	12
8 to 12	18	4	15 to 30	18	17
12 to 16	27	6	30 to 45	11	7
16 to 20	35	19	45 to 75	21	5
20 to 24	35	22	75 to 105	16	13
24 to 28	41	17	105 to 135	56	24
28 to 32	37	31	135 to 200	62	31
32 to 36	28	26	200 to 250	36	49
36 to 40	14	30	250 to 300	23	35
40 to 44	9	30	300 to 400	13	40
44 to 48	16	19	400 to 500	8	11
48 to 52	7	16	500 to 600	11	22
52 to 56	7	8	600 to 700	7	15
56 to 60	5	15	700 to 800	14	22
60 to 70	13	24	800 to 900	6	15
70 to 80	5	12	900 to 1000	2	1
80 to 100	4	16	1000 to 1500	0	1

100 to 105	11	23	1500 to 1970	2	2
Max	**1032.5[1]**	**1039.9[1]**	**Max**	**22622.5[1]**	**22784.7[1]**
Min	**2.3[2]**	**3.9[2]**	**Min**	**2.1[3]**	**3.6[3]**
Sum	**11682.1**	**16605.1**	**Area (ha)**	**92184**	

[1] = Electoral District "Dún Laoghaire East Central", [2] = Electoral District "Lucan North", [3] = Electoral District "Ballinascorney"

Figure 9 shows the distribution of predicted BMW generation from household and commercial sources, while Figure 10 shows the same distribution when scaled according to the sizes of the various Electoral Districts. The differences in the two distributions are readily apparent when portrayed graphically. Figure 10 makes obvious the differences in waste management collection faced by the three local authorities to the north, west and south of the Dublin City local authority.

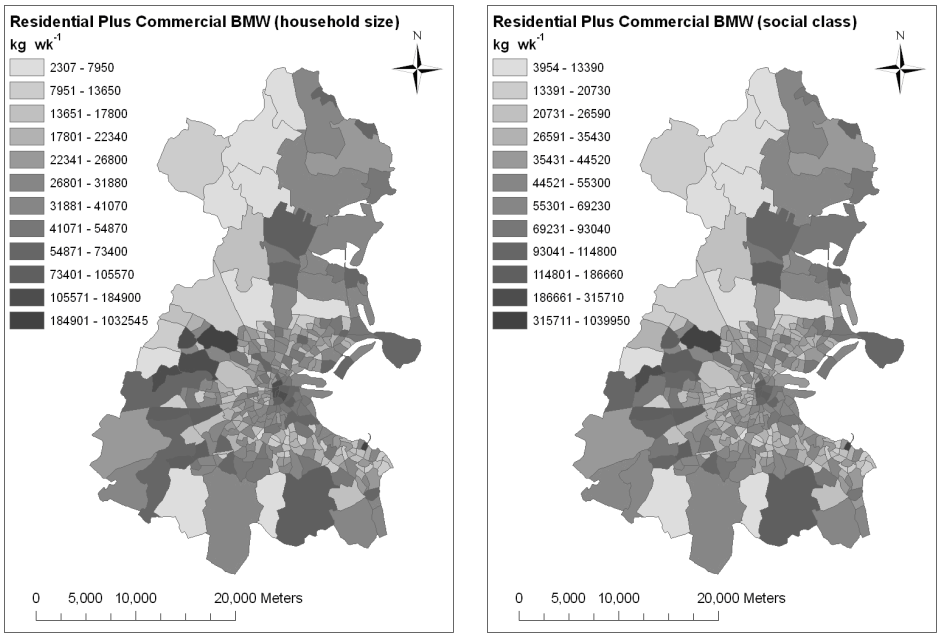


Figure 9. Distribution of Predicted Residential Plus Commercial BMW Generation According to Household Size (left) and Social Class Statistics (right).

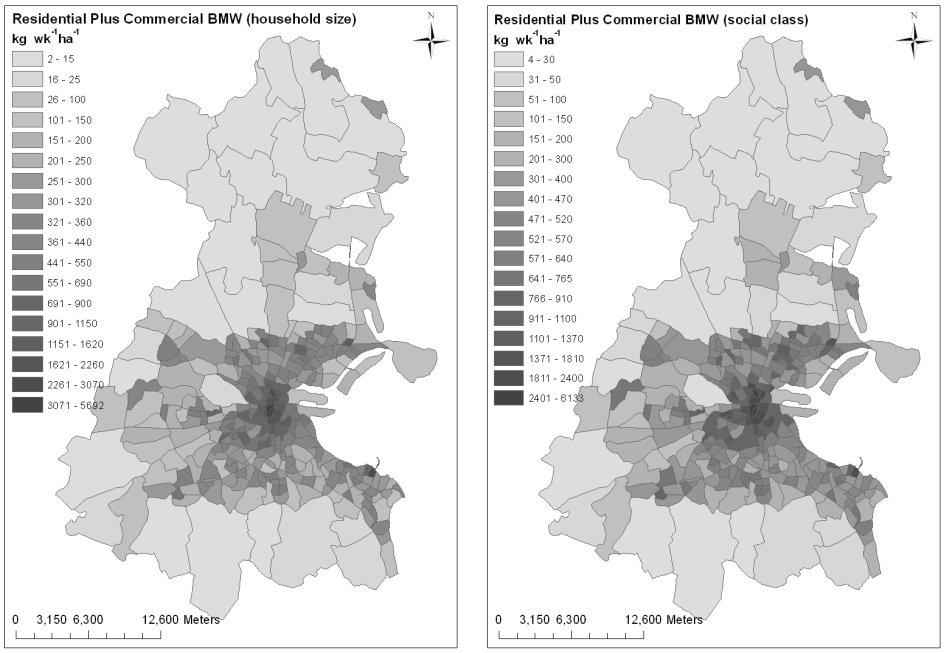


Figure 10. Distribution of Predicted Residential and Commercial BMW generation combined according to Household Size (left) and Social Class Statistics (right).

Discussion and Conclusions

BMW generation was predicted for the Dublin region within a diverse 'landscape' of residential and commercial areas. Household type and socio-economic status, as well as the types and sizes of commercial establishments, were hypothesized as the key determinants contributing to the spatial variability of BMW generation. A GIS 'model' of BMW generation was created using ArcGIS 9 (ESRI, 2004) and used to identify the geographic patterns of commercial and residential BMW generation. These spatial

patterns of predicted BMW distribution, based on generation rates from previous research, appeared to confirm the hypothesis about the importance of demographic factors in the generation of BMW. The spatial defining of waste generation is novel to the Dublin area and is an important step towards bringing Ireland's waste management practice up to world-class standards.

The commercial sector in Dublin is predicted to have the potential to generate >3523 t BMW wk^{-1}; adding to this the predicted residential sector BMW (household size basis) amounts to >11682 t BMW wk^{-1} for the Region (or, on a Social Class basis, >16605 t BMW wk^{-1}). These results not only highlight the relative importance of the two sectors in generating BMW, but also suggest a large difference in estimating the potential residential BMW according to "household size" and "social class" statistics.

Tables 3 and 4 highlight the differences in BMW generation rates resulting from the two prediction bases. Decisions about waste management based on one of these prediction bases would be grossly incorrect if, in fact, the other prediction basis were shown to be more accurate. Only by comparing these predictions to actual waste collection data (a process that is under way) can this discrepancy be explained. Regrettably, few data exist in the Dublin region on the actual quantities of BMW collected from households, as except for dry recyclables, the majority of municipal waste in Dublin is collected as mixed waste. The practice of separately collecting BMW in the Dublin area is only just beginning.

Grocery and supermarket establishments were predicted to contribute over 44% of the potential commercial waste for the region. Based on these results, key opportunities for waste diversion appear to be possible with the introduction of separate waste collections for organic wastes (i.e., "brown bin" service), composting, etc. For example, the education sector is estimated to contribute almost 15% of the total commercial BMW to the region; thus the Green Schools Programme (An Taicse, 2003), should have a large impact (immediate and long-term) on the Dublin Region in terms of BMW waste education and diversion as will the Greening Irish Hotels program (Irish Hospitality Institute, 2006) introduced by the EPA in 2005.

Results from the study reported here imply that there are large variations in the generation of BMW at the Electoral District level within the Local Authority areas. It can be seen from Table 5 that there are a number of ED's generating high rates of BMW from the combined residential and commercial sources. These ED's which generate high densities of BMW will affect waste management planning in terms of increased collection capacities / frequencies and route planning. Waste collection problems are one of the most difficult operational problems to solve (Nuortio et al., 2006) and this spatial analysis can contribute to the optimisation of vehicle routes and schedules for the collection of BMW. While on a real basis it would seem that the city centre and its immediate environs are a BMW "hotspot" (Figure 10), in reality the districts with high predicted BMW generation rates are rarely contiguous to one another (Figure 9), thus complicating route collection planning.

Particularly obvious from large variance in BMW generation rates among district electoral divisions is how population and socio-economic factors combine to affect waste quantity and distribution of residential waste and how employee numbers affect commercial waste generation in the region. Although the predictions need to be validated by comparing them to measured data, the technique is, nevertheless, a useful managerial tool to integrate the effect of demographic and economic changes on waste management. The variations in BMW generation rates within the region highlight the importance of tailoring waste collection strategies, and, indeed, waste management education and dissemination activities, to small management areas. There is a need to improve data and information on generation and management of BMW, including projections on future waste arisings.

Precise estimation of waste generation can lead to a more rational and efficient management of waste for the region, as well as within individual local authorities. Some local authorities in the Dublin region are experiencing phenomenal population growth and the associated development. The fact that the underlying elements to the model (population, socio-economics and commercial characteristics) can be altered as they change means that waste generation can be anticipated into the future to aid policy decisions as demographics and the commercial sector evolve. This GIS-based analysis was carried out using up-to-date small-scale (Electoral District) statistics for optimal precision. This can aid a more functional and economical design of waste management systems to address the massive changes in waste generation patterns that accompany

demographic changes. This system can also be adapted to other Regions in Ireland by altering the input data for the relevant areas.

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