Abstract The European Commission is tightening waste laws, and many local authorities, particularly in countries with low recycling rates, face the question of what system to introduce for the source-separate collection of food waste from householders. This study provides empirical data in form of fuel consumed and waste yield from four councils that already have source separate organic waste collections in operation. Two systems were compared: (i) door-to-door collection and (ii) bring systems where the householder walks to the bin in her/his street to drop off organic waste. Fuel consumption for the collection operation with the bring system was dramatically lower compared to the door-to-door system. Organic waste yield was constant over the observation year in the door-to-door system employing small 20- to 30-litre bins, but increased notably in the summer with the bring system that used 240-litre bins. The metric used to quantify seasonality was the summer/winter yield ratio. As commercial waste companies do not normally allow the making of data public, this is a rare opportunity to learn from collection systems currently in operation.

Keywords food waste · collection · organic waste · bring system · door-to-door · collection efficiency · waste-to-energy

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Seasonal yield and fuel consumed for domestic, organic waste collections in currently operational door-to-door and bring-type collection systems

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1 Introduction

About one third of municipal solid waste consists of organic, biodegradable material ([11]) and in way too many European countries this ends up in the residual waste stream, often going to landfills. This practice is unsustainable and the EU as well as individual countries including Wales, Scotland and Germany have intentions to introduce tighter legislation and make source-separate collection of organic waste from households[1] mandatory ([14], [46]). Taking organic waste out of the general waste stream is also a proclaimed target in Asia ([27], [43]) and the US ([23], [28]). Among waste-to-energy technologies (e.g. [10]), biogas in particular has a large fossil CO_2 abatement potential ([25]).

Leaving organic waste to go to landfill has well known undesirable effects. First, such a practice emits large amounts of carbon dioxide and methane into the atmosphere ([39], [45]). Second, macro nutrients from organic waste are not taken back into the natural nutrient and carbon cycle (e.g. [2]). Third, as non-renewable phosphorus is currently mined and globally depleted for mineral fertiliser production ([30], [15], [3], [17]) phosphorus recycling from organic waste is made impossible. And fourth, organic household waste has been identified as a true 2nd generation biofuel ([44], [32]) and as such we are squandering resources and the term 'waste' is actually inappropriate ([18]). Provided organic waste is collected in a

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[1] Definition of terms:

- **Organic waste:** Waste material of animal or plant origin; it degrades naturally within a short time frame, e.g. months; this includes both food waste and garden waste;
- **Food waste:** A subset of organic waste, that consists of biodegradable leftovers and residues that arise in the preparation and consumption of meals; includes food that was not consumed;

Fig. 1 The organic waste collection system in these four waste collection authorities was examined: Flintshire County Council (red), Broadland District Council (blue), City of Kaufbeuren (yellow), and City of Landshut (brown). The latter two authorities are city authorities and their areas are small. An interactive map is at http://www.valorgas.soton.ac.uk/papers/seasonal.html.

clean, source-separate fashion, the residues from anaerobic digestion are not wastes - they are valuable fertilisers. A natural waste management principle can be adopted - that of cyclicity.

If taking out organic waste from the residual waste stream receives more priority ([41], [21]), domestic food waste collections will need to increase further ([42]). However, if more waste streams are to be collected separately, there is a drawback: "... collection of waste-products such as municipal organic waste, are often a significant source of emissions" ([8], page 469). When it comes down to choosing a collection system, advice is often inconclusive ([9], [47], [7]). Many of the non-recycling residual waste collections have been in place for decades with little change over the years and the simplest way to take out organic waste from the residual waste stream has been to 'bolt on' a food waste collection round to the residual waste rounds that are already in place. A logistically more demanding approach is the use of split-body systems, but matching compartment sizes so that they fill up in an equal manner through a collection round can be a challenge. Because bolt-on systems for organic waste collections are so popular, the performance of two of these systems is compared in this study. The research questions addressed in this study on domestic, organic waste collections are:

1. Do bring systems using 240-litre bins offer better fuel economy than door-to-door systems ?
2. To what extent do the two collection systems exhibit seasonal variations (e.g. [24]) ?
3. Is distance a factor for yield with a high-density bring system (e.g. [22]) ?

There exist, of course, multiple stream (non-source-separate) co-collection methods, with subsequent, advanced separation methods at the target plant. These are, for example, practiced in Groningen and Friesland, Netherlands (e.g. [31]), and offer low fuel consumption in the collection process. However, this study looks exclusively at source-separate collection of organic waste and excludes multi-stream collection options.

1.1 Organic waste collection systems

Both in the UK and Germany as well as in other EU countries door-to-door organic waste collection systems are becoming the dominant way of collection ([6], [5]). However, other systems do exist, and organic waste collection systems for domestic households can broadly be split into two or three classes:

1. Door-to-door collections: Every household is equipped with a bin. Bin density is roughly equal to household density. This type of collection is typical for residential areas where high rise buildings are

Fig. 2 The position of two organic bins in the City of Landshut, shown as small squares in brown/yellow colour. The dotted line roughly indicates the residential area covered by by these two bin locations in a high-density organic waste bring system. In this example approximately 20 households share one 240-litre organic waste bin. One of these two bin locations is photographed in the top of Figure 3. Map modified from http://maps.google.com.

not dominant. Bins remain on or very near private ground. Contrary to a bring system, the collection vehicle has to traverse all roads to empty householder bins left on the kerbside. In Figure 2 residential roads are highlighted in white lines, and the collection vehicle in a door-to-door system would have to traverse all of these roads.

2. High-density bring systems: The householder needs to traverse a small distance on public roads to drop off his waste into a public container, which is typically placed on public local authority ground rather than private ground. Figure 2 illustrates the concept. Two bin locations (squares in brown colour) serve a number of residential homes indicated by the dotted line in brown colour. The organic waste collection vehicle only needs to service the two squares that represent bin positions in this residential area.
3. Low density bring systems: The householder needs to traverse a somewhat longer distance on public roads to reach a bin. Fewer bins per area exist compared to a high-density system. Low density systems are not investigated here.

It is intuitive to assume that bring systems require less travel and stop-and-go compared to door-to-door collection systems, but this claim has not been substantiated with evidence from real systems. The hypothesis that a high-density bring system is more fuel efficient than a door-to-door system is investigated in this study based on field data from currently operational organic waste collections.

1.2 Fuel consumed in food waste collections per tonne of waste

Fuel consumption is always a matter of concern, but especially if a new, source-separated food waste collection stream is introduced in an authority ([19]) on top of the existing collections. Fuel consumed in any waste collections depends on various factors including housing density, vehicle type, driver behaviour. Reported Diesel consumptions for door-to-door kerbside collection of waste in urban areas are:

- Waste incineration plants: 3.3 l Diesel/tonne of organic waste ([26]).
- Anaerobic digestion/compost plants: 7.2 l Diesel/tonne of organic waste ([33], page 37).
- Co-combustion plants: 6.6 l Diesel/tonne ([26], [20]).

In this study specific fuel consumption in litres of Diesel per tonne of organic waste collected is used. A simple example shall illustrate the effect of fuel consumption on a biogas generation process chain.

Assuming that organic waste is collected from households and taken to a biogas plant, the average methane yield from one tonne of food waste is almost 100 m^3 ([4]) and this contains about the same energy as 100 litres of Diesel. If the collection of one tonne of food waste consumes 15 litres of Diesel, a value experienced in practice, then the parasitic demand for the whole renewable energy operation is 15 out of 100 or 15 % of the methane yield - a substantial amount that needs to be reduced. The potential of organic waste-to-energy technology has been recognised: "...best available technologies can make the overall process a carbon sink" ([12]) and recent publicatons demonstrate similar interest ([35], [16], [29]).

2 Methods

Two different organic waste collection systems from four local authorities were investigated - Figure 1. An online map depicting the locations is at http://www.valorgas.soton.ac.uk/papers/seasonal.html. All collection systems were active at the time of the study in 2010/11 and all four authorities operated weekly organic waste collections.

2.1 The four local authorities studied

The two door-to-door systems chosen for this study are typical bolt-on systems representative of UK practice. Bring-type organic waste collections like the one in Landshut and Kaufbeuren are rare. The federal state of Bavaria[2], where these two authorities are located, consists of 101 waste authorities, and only two, the City of Landshut and the City of Kaufbeuren have high-density bring-type collection systems for organic household waste[3]. All other waste authorities in the federal state have door-to-door type organic waste collections.

1. **City of Landshut**, 62612 inhabitants (http://www.landshut.de): Operate a high-density bring system with 240-litre bins usually located on public ground - Figure 3. For longer roads bins are placed at a suitable spot serving all households in that road. If one 240-litre bin is not sufficient, several bins are placed on the same spot - Figure 3. Householders cannot choose to have a private organic waste bin on their property. The collection vehicle has 26 t gross weight and is operated by two crew, one driver and one loader - Figure 4. Most households (25000 out of 30000 households) own a 23-litre caddy bin, which is used to tip their food waste into the 240-litre communal bin. All organic waste is taken to a waste transfer station and bulked to an anaerobic digestion plant.
2. **City of Kaufbeuren**, 42450 inhabitants (http://www.kaufbeuren.de): This system is very similar to the bring system in Landshut, with the difference that the bin density is even higher than in Landshut. The organic waste collection system in Kaufbeuren could therefore be described as a *very high-density* bring system. In many cases households share a 240-litre organic waste bin that is located on public ground, e.g. on a pavement. Householders are allowed to receive their own, private organic waste bin should they want one but this is not taken up widely. All organic waste is currently taken to a composter within the city. A 26 t gross weight collection vehicle is used - Figure 4. The number of crew in the organic waste collection vehicle is three.
3. **Flintshire County Council**, 148594 inhabitants (http://www.flintshire.gov.uk): Have only recently introduced food waste collections using 23-litre bins in April 2010. Before that food waste went into the residual waste stream. Every household was furnished with one 23-litre food waste bin on a mandatory basis. Only larger conglomerations in the county are served with food waste collections. The number of crew is two per collection vehicle.
4. **Broadland District Council**, 118513 inhabitants (http://www.broadland.gov.uk): Have had source-separated food waste collections for several years. Two 7.5 t gross weight collection vehicles very similar to the ones in Flintshire are used. Weekly food waste collections are strapped onto residual collection rounds that now run fortnighly in turn with dry recyclables. Collections take place only in densely populated areas of the district. The number of crew per vehicle is two.

[2] Germany is divided into 16 federal states, and the largest of these states is Bavaria (http://en.wikipedia.org/wiki/Bavaria).

[3] Civic amenity sites like household waste recycling centres are also classified as bring systems. The important difference is that household waste recycling centres are of very low density, where the householder would typically use a car, rather than walk, to drop off unwanted materials.

Fig. 3 Typical distribution of 240-litre bins in the City of Landshut. The yellow circle depicts the position of organic waste bins on a longer residential road.

The criterium where to introduce food waste collections in both Flintshire and Broadland was population density relative to area, so that travel of the collection vehicle is minimised. All four authorities are classical 'bolt-on' systems, where source-separated organic waste collections with dedicated vehicles have been introduced later on top of the traditional residual rounds. The dominant organic waste collection system in the UK is a door-to-door system like the ones in Flintshire and Broadland. No bring-type organic waste collection systems are known in the UK.

2.2 Data collected

All collection schemes were visited in person and data including

- collected organic waste tonnages per month
- collection vehicle type and total fuel consumption in the observation period
- bin size and bin numbers
- population served
- crew size

were recorded from these schemes for an observation period of typically 12 months: 1 January to 31 December 2010 for Landshut and Kaufbeuren. The observation period for Broadland was 1 April 2010 to 31 March 2011. Source separated food waste collections in Flintshire only started on 19 April 2010. The observation period is 350 days, starting on 19 April 2010 and finishing on 3 April 2011. This amounts to $350/365 = 0.956$ or 95.6 % of a year. Fuel use and food waste yield from the 350 measured days was extrapolated in Flintshire to reach the 365 days observation period that the other three authorities had.

Fig. 4 Top: Collection vehicle used in Flintshire. A similar vehicle was used in Broadland. Middle: Collection vehicle used in the City of Landshut. Bottom: Collection vehicle used in the City of Kaufbeuren.

2.3 Organic waste collection metrics

Waste-to-energy processes deserve attention ([37]) and waste collection represents the first part of such a process chain. The largest input energy in any waste collection process is fuel, and thus Diesel consumed per tonne of organic waste collected was determined for all collection authorities as follows:

$$\text{specific Diesel consumption} = \frac{\text{Diesel consumed in collection } [l]}{\text{organic waste collected } [t]} \tag{1}$$

where both the numerator and denominator denote values for identical observation periods, e.g. for one year. The use of litres per Diesel rather than gigajoules is intuitive for practitioners, and reflects the current situation where Diesel engines dominate collection vehicles. This may change in the long term if there is a switch to either electrically powered vehicles or vehicles running on compressed biogas. A disadvantage of the above metric is its' dependence on yield. In this study organic waste yield is measured in kg per inhabitant, rather than in kg per household, because inhabitant numbers are more readily available than the number of households.

2.3.1 Seasonal variations and the summer/winter ratio

Food waste collection systems are ideally providing a continuous stream of high quality waste material. In reality, there will be seasonal differences and plotting the tonnage collected per month indicates how

	inhabitants served	households served	inhabitants per km^2	no. of bins	kg per inhabitant	inhabitants per bin	no. of vehicles	crew per vehicle
Broadland 2010/11	22726	10330	214.3	10330	36	2.2	2	2
Flintshire 2010/11	53130	24150	434.5	24150	33	2.2	5	2
Kaufbeuren 2010	42500	ca.20000	1062.5	3358	80	14	1	3
Landshut 2010	62612	ca.30000	948.7	1440	37	43	1	2

Table 1 Comparison of metrics between the two door-to-door systems (Broadland and Flintshire) and the two high-density bring systems (Kaufbeuren and Landshut).

the yield changes over the year. The ratio of summer to winter tonnage indicates the degree of seasonal change in the amount of organic waste collected over one calender year:

$$\text{summer/winter ratio} = \frac{\text{organic waste summer months June to Oct } [t]}{\text{organic waste winter months Nov to May } [t]} \tag{2}$$

For a collection system where this ratio is close to unity, the amount of organic waste collected in the summer months will be similar to the amount collected in the winter months. For collection systems which allows garden waste to go into the organic waste stream, this ratio will be larger than unity, as garden waste will primarily occur in summer, which is the numerator.[4]

2.4 Assumptions

Fuel consumed is, of course, not only a function of the collection method, but also depends on driver behaviour, percentage laden, vehicle engine, distances covered, onboard hydraulic system parasitic demand, and road network. An attempt was made to compare cities and collection areas with similar geography and density. The vehicles for the two bring systems were similar and the vehicles for the two door-to-door systems were similar. Even though Flintshire and Broadland are much larger in area than the two city councils, the *collection areas* in Flintshire and Broadland are small, and have city-like housing density, which renders them more amenable to performance comparisons.

3 Results and discussion

3.1 Collection characteristics

From Table 1, the following observations can be made:

- In both Kaufbeuren and Landshut almost the whole population is served with organic waste collections, i.e. collection coverage is virtually 100 %. Both cities have a similar population density of around 1000 inhabitants per km^2, and thus geographically both cities are comparable.
- Broadland, Flintshire and Landshut exhibit household organic waste yields between 33 and 37 kg per inhabitant per year. For Kaufbeuren yield was substantially higher at 80 kg per inhabitant per year. There are more bins per head in Kaufbeuren, and thus citizens do not have to walk as far as in Landshut to reach a bin. This could explain disposal of more waste in Kaufbeuren compared to Landshut.
- In the two door-to-door systems in Broadland and Flintshire one bin serves 2.2 inhabitants (assuming 2.2 inhabitants per household in Wales and England; one bin per household[5]). In the two bring systems one bin serves 14 inhabitants in Kaufbeuren and 43 inhabitants in Landshut. This is the key difference between door-to-door systems and bring systems.

[4] For countries in the southern hemisphere the summer and winter months used here would need to be swapped.

[5] The average household size in Wales is projected to decrease from 2.27 persons in 2008, to 2.10 in 2023 ([13]).

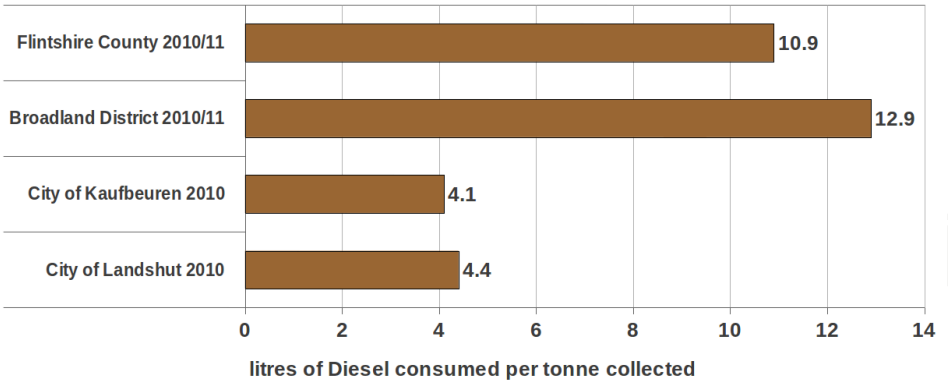

Fig. 5 Diesel fuel consumed per tonne of organic waste collected in four collection authorities. Both city authorities operate high-density bring systems.

- Kaufbeuren has a very high yield of 80 kg per head per year; the remaining three authorities report yields between 33 to 37 kg per head per year. The high yield in Kaufbeuren is what leads to the lowest fuel consumption per tonne collected across the authorities.
- Plastic bins contain embodied energy ([40]) and Landshut and Kaufbeuren get by with fewer communal collection bins. In Landshut, about four fifths of the households were also supplied with smaller 23-litre bins[6] and thus little embodied energy advantage exists for Landshut's bring system.
- The bring system in Landshut gets by with a single vehicle with only 2 crew and this is obviously an effect of the comparatively low number of bins that need to be emptied per week. Both door-to-door systems require a larger work force.

3.2 Fuel consumed per tonne collected

All four collection authorities operate Diesel powered vehicles and the Diesel consumed per tonne of organic waste collected from domestic properties is plotted in Figure 5. The two door-to-door systems both exhibit similar fuel consumptions of 12.9 litres in Broadland and 10.4 litres in Flintshire per tonne collected[7]. The two bring systems require much less fuel with 4.1 and 4.4 litres per tonne of organic waste collected. The consumption of 12.9 litres per tonne of food waste collected in Broadland includes a journey of about 15 km to the composting plant, and taking the effect of this journey out would lead to a slightly lower consumption very similar to the one in Flintshire with 10.9 litres per tonne collected. In essence, the specific fuel consumption for Flintshire and Broadland are very similar. The City of Landshut consumes 4.4 litres of fuel per tonne collected. Yield for Landshut is similar to the yield in Flintshire and Broadland, and this makes a comparison with between these three authorities straightforward. The City of Kaufbeuren has the lowest specific Diesel consumption of 4.1 litres per tonne collected but this is to some extent caused by higher yield in Kaufbeuren. Low fuel consumption in Kaufbeuren is not solely due to the bring system, but also due to high yield, and two plausible explanations for this high yield are: Firstly, the recycling discipline is high and secondly, domestic gardens are larger and therefore more green waste is going into the weekly bin. The major result from a comparison of specific fuel consumption between the four authorities tested is that high-density bring systems appear to be more fuel efficient than door-to-door systems.

3.3 Seasonal variation and garden waste in bring and door-to-door systems

It is clear that larger bins (e.g. 240-litre) are more suited to garden waste than small (23-litre) UK type food waste bins. But the addition of non-woody garden waste does not necessarily need to be a disadvantage as apples and grass cuttings are good substrates for anaerobic digestion ([48], [34], [36]).

[6] The 23-litre bins used in Landshut are not shown in Table 1.

[7] Fuel consumed can be allocated to collection and to transportation ([42], [19]). In this study only fuel used for collection is considered. For example, waste could be collected and taken to a transfer station where it is then bulked to the target plant. The latter bulking process is not subject of this study, even though strictly speaking, the fuel consumed in the food waste collections in Broadland District Council, was fuel for collection *and* transport.

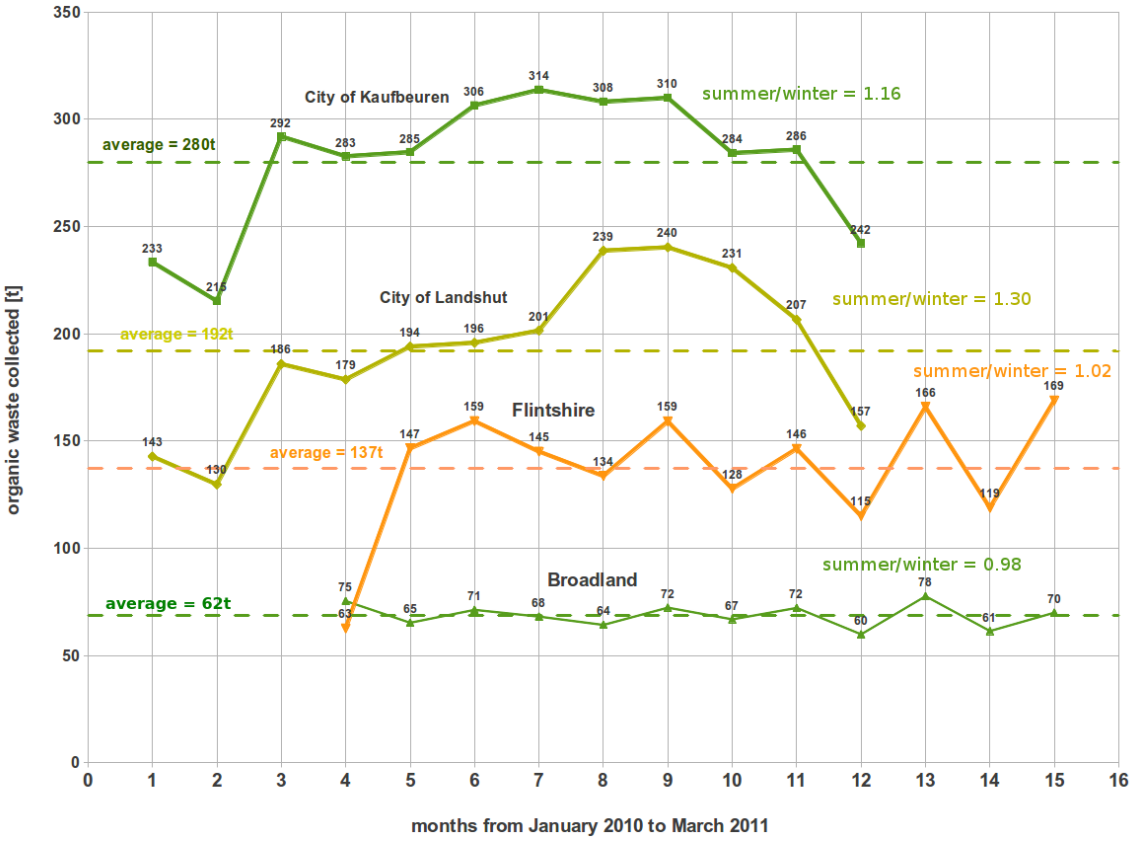

Fig. 6 Plot of monthly organic waste collected across all four collection authorities. Summer/winter ratios are given on the right hand side.

The amount of organic waste collected in tonnes is plotted in Figure 6 for all four local authorities in 12 consecutive months. The average yield in the year is plotted as a dotted line for each of the four authorities. The summer/winter ratio as defined in Equation 2 is displayed on the end of the monthly yield plot in Figure 6. The following observations can be made from the plot of monthly yields in Figure 6:

- For both bring systems in Kaufbeuren and Landshut more organic waste is collected in the six summer months than in the six winter months. The yield for these two bring systems drops off during the winter months, indicating that a certain amount of garden waste is going into the organic waste stream. Landshut shows particularly sharp rises in yield in August, September and October, and exhibits a large summer/winter ratio of 1.30.
- Broadland demonstrates an extraordinarily constant yield over the months and visually no difference between winter and summer months is discernable - bottom graph in Figure 6. Clearly a system that has settled in with the population over the years. The bin size of 23 litres can hardly take garden waste. The summer/winter ratio is 0.98 (i.e. < 1) meaning that there is slightly less food waste in the summer months than in the winter months. Completely different to the bring systems with larger bins in Landshut and Kaufbeuren.
- In Flintshire the variations in yield are more pronounced than for the similar door-to-door system in Broadland, and one explanation for this is that householders were still new to the system - 3rd graph from the top in Figure 6. The data value in April is low because food waste collections only started on 19 April 2010 rather than at the beginning of the month. To be able to compute the summer/winter ratio, the April value was replaced by the average yield of the remaining five summer months and the the summer/winter ratio computed in this way is close to 1 at 1.02, indicating almost no seasonal yield changes in Flintshire.

	Broadland 21-litre bins	**Flintshire** 23-litre bins	**City of Landshut** 240-litre bins	**City of Kaufbeuren** 240-litre bins
Contamination:	0.1 to 0.5 % estimate	0.2 to 0.4 % measured	(<13%) estimate	6.5 % measured

Table 2 Contamination with non-organic material in percentage weight across the four authorities. The two small bin systems exhibit lower contamination than the two large bin systems.

3.4 Contamination rates

Table 2 lists measured or estimated contamination rates in the collected organic waste from non-organic materials for the four authorities:

- **Broadland** with 21-litre kerbside bins: The operator of the composting plant taking organic waste for Broadland stated that contamination is '... extremely low'. The operator does not record rates though and he estimated contamination to be between 0.1 and 0.5 % (personal communication, 14 November 2012). The compost achieves PAS100 compost standard ([1]).
- **Flintshire** with 23-litre kerbside bins: Contamination rate in the target anaerobic digestion plant taking Flintshire's food waste was measured between 0.2 and 0.3 % by weight ([38], page 9 and 10). Digestate is taken to agricultural fields and is very low in heavy metals.
- **City of Landshut** with 240-litre kerbside bins: No exact contamination rate for organic waste is known. However, the target anaerobic digestion plant had a total, yearly contamination rate of 13 % (personal communication with plant operator 14 November 2012), but this rate was dominated by taking in wrapped food waste from the food industry, and the contamination rate for organic waste from households from the City of Landshut is potentially much lower than this, but not as low as in the two British collection systems. The residue reaches or exceeds the voluntary RAL GZ 245 standard for digestate from waste materials.[8]
- **City of Kaufbeuren** with 240-litre kerbside bins: The target in-vessel composting plant measured contamination at 6 % by weight. Contamination is dominated by plastic film from carrier bags (personal communication with plant operator, 14 November 2012). Plastic film is removed with a mobile screening machine (http://www.komptech.com).

As expected, contamination with small 21 and 23-litre bins in Broadland and Flintshire is substantially smaller when compared to the two authorities using 240-litre bins. Material collected in 240-litre bins required somewhat more screening effort/energy in the target plant compared to waste collected in small 21 and 23-litre bins. None of the source-separate organic waste collections had problems with heavy metal content, which is in line with [49].

3.5 Organic waste per bin emptied

Two observations can be made on average organic waste bin weight and bin numbers - Figure 7:

1. The average amount of organic waste per bin is higher in Landshut (31 kg) than in Kaufbeuren (22 kg).
2. The number of bins serviced is lower in Landshut than in Kaufbeuren (Table 1).

Despite these two advantages this did not result in a lower fuel consumption Landshut. One reason causing this discrepancy is the slightly longer distance to the waste transfer station in Landshut, another may be the higher yield in Kaufbeuren. This shows that servicing fewer bins in a bring system does not automatically lead to lower fuel consumption. Even though bins in Kaufbeuren contain less waste than bins in Landshut - Figure 7 this is not filtering through to give higher fuel consumption. The vehicle is probably filled slightly quicker in Kaufbeuren than in Landshut due to more waste.

The average weight of organic waste in Flintshire is 2.5 kg per bin emptied[9]. The average weight per emptying in Broadland District is even lower at 1.5 kg but this assumes a set-out rate of 100 % which

[8] Information about the German RAL GZ 245 digestate quality standard is at http://www.kompost.de; also http://www.beuth.de/en/technical-rule/ral-gz-245/102184286, last accessed Nov 2012.

[9] A total of 1738.5 t of food waste was collected in Flintshire in 12 months. The number households served is 24150, but the set-out rate is only 55 % and thus the real number of households served is $24150 \times 0.55 = 13283$. This is the number of bins emptied weekly by the collection crew. Dividing the food waste yield of 1738.5 t by the latter number of bins and by 52 collections per year gives approximately 2.5 kg of food waste per bin per emptying.

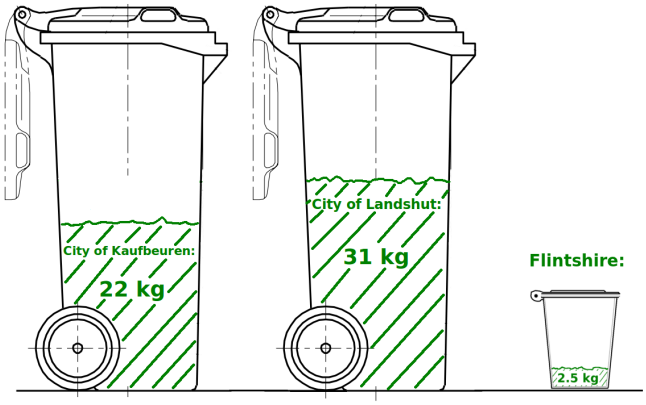

Fig. 7 Average weight of organic waste per emptied bin in 2010 for the cities of Kaufbeuren and Landshut and for Flintshire County. In Broadland the amount of food waste per emptying is even lower at 1.5 kg.

is not true in reality[10] and thus actual weight per emtpying will be somewhat higher than 1.5 kg. From Figure 7 it is clear that the vehicle crew need to handle many more bins in the door-to-door systems in Flintshire and Broadland than in the two bring systems. Even though a so-called slave bin[11] is used in Flintshire, the engine of the collection vehicle is on all the time which increases fuel consumption.

4 Conclusions and recommendations

The data presented in this study are not normally made public and it is hoped that they are useful for authorities thinking of introducting a new organic waste stream in their area. Two door-to-door organic waste collections in the UK and two high-density bring systems in Germany were compared in terms of yield and fuel consumed and the following conclusions can be drawn:

1. Collection efficiency: Large variations in fuel efficiency of a factor of three or more exist across collection systems in real life systems. These differences can be attributed to the collection system. A high-density bring system using 240-litre bins had a substantial advantage over door-to-door systems in terms of Diesel consumed per tonne of organic waste collected. The high-density bring system also fares better in terms of number of lorries required compared to the door-to-door system. As householders were also equipped with 23-litre bins in the high-density bring system in Landshut, there was no saving in bin numbers and embodied energy in the high-density bring system compared to door-to-door collections. The smaller collection vehicle with 7.5 t gross weight did not lead to lower fuel consumption compared to a 26 t gross weight collection vehicle.
2. Seasonal variations in organic waste yield: Occur in bring-type collection systems with 240-litre bins due to garden waste in the summer months. Door-to-door collections with smaller 23-litre bins don't exhibit seasonal variation.
3. Effect of householder distance to organic waste bin on yield: Kaufbeuren with higher bin density (lower between-bin-distance) compared to Landshut exhibits higher yield. It is possible that there is a causal relationship between bin distance and yield.
4. Government administrations ought to extend their waste data capture to include specific fuel used for waste collections, so that performance of collection systems can be monitored for improvement.

For local authorities planning the introduction of a source-separate food waste collection system the options would be:

– to carry out door-to-door collections with small containers which provide constant, high quality organic waste yield over the year; this system is more fuel intensive in the collection phase.

[10] Set-out rate in Broadland is believed to be high but a precise figure is unknown.

[11] A slave bin is typically a 120 or 240-litre bin which the refuse collector pulls along to the 23-litre bins. Once the slave bin is sufficiently full, it is emptied into the refuse collection vehicle using the hydraulic lift.

– to introduce a bring type system as this will have increased yield in the summer and has the advantage of lower fuel consumption in the collection phase.

Provided householder discipline is high and organic waste contamination is not a problem, it is justifiable to look at bring-type systems more favourably.

4.1 Additional material

An Open Document and Excel spreadsheet containing the yield data for the four authorities and a slippy map is available at http://www.valorgas.soton.ac.uk/papers/seasonal.html.

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