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Characterisation And Compositional Analyses Of Institutional Waste In The United Kingdom: A Case Study Of The University Of Wolverhampton

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***Abstract*— Higher education institutions (HEIs) are often regarded as small municipalities due to their size and various complex activities that take place on campus. Operations within HEIs, in terms of energy use and waste management have major impacts upon the environment. Current trends in waste management indicate a shift from landfill-based to a resource-based management model. Implementation of this model requires accurate data on waste characteristics and composition. This study conducted over an eight week period across three sampling zones examined 500 waste samples in 2013. Findings indicate that 73%, 25% and 2% of waste materials could be recycled, composted or sent for anaerobic digestion and incinerated or sent to landfill respectively. Results from food waste composition analysis indicate a moisture content of 48.8% and a C/N ratio of 55:1. Overall, this study provides some examples of tools that can be used to assess waste management in large Institutions such as universities.**

***Keywords*— Solid waste characterization; waste composition analysis; Institutional waste management; United Kingdom**

I. INTRODUCTION

Higher education institutions (HEIs) are often regarded as small municipalities due to their size, population and various complex activities that take place on campus [1]. The day to day operations within these establishments, in terms of energy use, emission output, transportation, water consumption and waste management, can therefore have major direct and/or indirect impacts upon the environment [2]. According to Armijo de Vega *et al*., [3] universities as centers of learning, have a moral and ethical obligation to act responsibly towards the environment. This is even more important because universities play a multi-faceted role in the creation and transfer of knowledge and so are well positioned to catalyse pro-environmental behaviour amongst their staff, students, and the wider community [4]. Many HEIs use waste management activities as a starting point for their sustainability initiatives [1]. However, the generation and management of solid waste present significant challenges as the associated legislative, economic, social and environmental pressures can be difficult to govern [3]. Characterising and understanding the composition of a campus solid waste stream is therefore regarded as a critical first step toward developing successful and effective waste management strategies across university campuses [5].

Using the University of Wolverhampton as a case study, this paper attempts to capture the inherent peculiarities of waste management in large public institutions and current initiatives towards continuous improvement in waste management practices in a typical UK university. Waste management at the University of Wolverhampton is mainly supported by the Waste Management Policy and Guidelines (2011) and the Waste Recycling Strategy (2011). Both instruments align with the university's latest policy instrument on waste/environmental management, Sustainability and Environmental Policy (2012). The overarching principle behind these documents is that the university is committed to the continuous improvement in waste management practices so as to ensure that it meets its constantly changing legislative and regulatory obligations [6]. In fact, this commitment is evidenced by the impressive reduction in quantity of waste arising from the institution.

A. Location of Study

The study was conducted over an eight week period (May-June 2013) across the University of Wolverhampton, City Campus. Samples were collected at source from three sampling zones comprising: Campus South (mostly administrative blocks), Campus North (administrative and lecture halls) and Hall of Residence (Fig. 1).

FIGURE 1: MAP OF UNIVERSITY OF WOLVERHAMPTON CITY CAMPUS (UNIVERSITY OF WOLVERHAMPTON, 2013)

II. REVIEW OF LITERATURE

Waste is a perception-based subject; what represents waste to one person may be seen as an appreciated and valued resource to another [7]. The amount of waste produced indicates how efficient we are as a society [8]. Put simply, the more waste produced, the more resources are lost and the less efficient society is at adequately managing goods and services [9]. By its nature, waste is a heterogeneous material, in terms of substances, materials and products, and is therefore difficult to describe, define and classify [10]. However, waste has major socio-economic and environmental significance [11][12][13] for governments and organisations, hence the need for a generally acceptable definition [10]. Ezeah [14] believes that any contemporary definition of waste is dependent on the nature and source of the waste, including its characteristics and/or the potential to cause harm either to humans or the environment. Moniruzzaman et al. [15] see waste as the unwanted matter coming from the production and consumption of materials by human and animal activities. This thought is reinforced by the EU Waste Framework Directive (2008/98/EC) which defines waste as "…any substance or object which the holder discards or intends or is required to discard" . A common notion by all the cited works is that 'abandoned materials' are deemed to no longer have a functional use or economic value by the owner or producer of the waste [14][16].

A. *Waste Characterisation and Composition Studies*

Current trends in global waste management best practice indicate a shift from a landfill-based to a resource-based waste management model (i.e. reduction, reuse, recycling and recovery). Implementation of the resource based waste management model requires accurate quantitative information as to the character and composition of waste streams [17][18][3][19][5][1][4][20]. This position is reinforced by Igoni et al [21] who believe that designing appropriate waste treatment and disposal strategies require an understanding of the physical, biological and chemical properties of the refuse. According to Crowe and Carty [22] conducting a waste stream analysis can provide a useful baseline by which to measure progress, identify areas where simple changes could make big impacts on cost and environmental efficiency, and help achieve national and international legislative compliance. However, a waste audit takes time, resources and commitment [23]. Furthermore, calculating the amount of waste generated is a problem due to inconsistencies in reporting mechanisms [24]. Williams [10] believes that even for those countries, cities, institutions, and businesses that do collect data, difficulties arise in direct comparison of waste generation due to differences in standards, characterisation methodologies, approaches to data collection.

Dahlen and Lagerkvist [25] published a number of household waste characterisation methodologies now used globally. However, according to Roberts et al [26], two broad approaches predominate: material-based categorisation and methodologies based on the potential use of segregated materials (or the 'output' model). Sharma and McBean [27] highlight the advantages and disadvantages of both approaches. For the material based categorisation approach, they note that although the model provides reliable estimates of the waste stream percentages (by weight) within the various categories of waste, it focuses on product categories and not on waste stream categories. Similarly, although the 'output' model may provide useful and unique 'local' information, it is vulnerable to demographic issues, seasonality, and irregular events [27].

B. *Waste Characterisation and Composition Studies*

While numerous waste characterisation and composition studies have been conducted at country and city levels, including Crete, Greece [28], Siem Reap, Cambodia [29], Wales [30], Dhaka City, Bangladesh [18], Texas, USA [19], Tehran, Iran [31], Chihuahua, Mexico [32], Poland [33], Abuja, Nigeria [26], Kabul, Afghanistan [34], Muar, Malaysia [35], and Juba, South Sudan [36], only a small number have assessed the characteristics and composition of solid waste within HEIs. According to Armijo de Vega et al [3] there is a need for standardised waste indicators which universities can use to; understand their current performance, track changes over time, compare themselves with other institutions, and share sampling methods and strategies for SWM plans.

C. Case Studies From Around the World

Globally, significant expansion of the higher education sector in the recent past has continued to exact enormous pressure on existing waste management infrastructure, policies and practises [1]. Kahmeyer et al [37] are of the opinion that although many universities have a rough idea of the amount of waste they generate, little information exist as to the actual character and composition of the waste arising. Smyth et al [5] note that although activities in most campuses appear to be the same all year round, in reality there could be marked differences in terms of student numbers and waste arising between terms. Furthermore, the composition of waste may be different depending on seasonality [38]. Waste Watch, England, carried out a study of resource management in the education sector in 2005 [23]. One output from the study was a compositional breakdown of waste produced by participating institutions. The study found out that as much as 90% of the wastes produced on the campuses were potentially recyclable. Baldwin and Dripps [4] studied waste from halls of residence at Furman University, Greenville, USA. This was a rather unique study in that surprisingly few audits have looked at campus residential waste stream. They found that 61% (by weight) of all waste generated could have been diverted away from landfill using the university's current recycling and composting plan. They also found significant differences in the composition of the waste stream between halls of residence; age and class of students, meal plans, social patterns and presence/absence of kitchens [4]. The findings are similar to results from a study at the University of Newcastle (2010) whose campus waste audit found that two-thirds (by weight) of waste on campus was recyclable or compostable. Smyth et al [5] investigated the Prince George campus at the University of Northern British Columbia (UNBC) and discovered that more than 70% (by weight) of the waste could have been diverted through waste reduction, recycling and composting activities.

Kahmeyer et al [37] carried out another study at Kansas State University (KSU) which revealed a current recycling rate of about 40% recycled whilst the remaining 60% was defined as 'trash'. The category 'trash' is representative of the co-mingled waste, which has not been source separated and so is contaminated. Zhang et al [1] carried out another study at the University of Southampton, England, which found that putting recycling bins in kitchens of university halls increased recycling rate by an average of 25% with the lowest contamination level, supporting the theory that successful recycling programmes require a carefully designed and convenient infrastructure. Using this as a basis they were then able to identify, strengthen and develop a practical, staged, and holistic approach to manage waste in an sustainable fashion, taking into account the 'PESTLE' factors (political, economic, social, technical, legal and environmental), waste hierarchy and infrastructure, service provision and behaviour change [1]. Mason et al [39] also discovered that implementing source separation in the kitchen and cafeteria area at the Turitea Campus, Massey University, New Zealand, increased the recycling and composting rate to 88%. Taghizadeh et al [38] found from their study that more than 80% of the waste produced at the University of Tabriz, Iran, could be diverted through waste reduction, recycling, and composting activities. The compostable organic material was established to be the most significant waste component (1399.8kg of the 2500 kg of waste produced daily) and so the authors began to set up a feasibility study to produce compost from organic waste within the university campus. These findings reinforce those of Parizeau et al [29], Damghani et al [31], Hernandez-Berriel et al [40], Roberts et al [26], Salami et al [41], Forouhar and Hristovski [34], Kalanatarifard and Yang [35] and UNEP [36] who found that the high percentage of organic or putrescible material is typical of waste from developing countries.

III. Materials and Methods

Sample characterisation was carried out using the traditional material-based classification approach as adopted by Roberts et al [26]. Zhang et al [1] believe that the number of main/sub-categories depends on the objectives of a particular study. As such, the 14 material classification template developed by Roberts et al [26] was modified (i.e. 'dense plastic' was changed to simply 'plastic', whilst the 'disposable cups' was added); thus resulting in a classification system which contained 15 materials categories (Table1).

Table 1. Waste Material Characterisation Template (Adopted from Roberts et al, 2010)

Material	Description of Waste
1. Paper	Newsprint, magazines, printer paper, notebook paper, tissue paper, coloured paper, white napkins, envelopes, catalogues, flyers
2. Cardboard	Packing boxes, shoe boxes, toilet paper rolls, paperboard (cereal boxes, tissue boxes), liquid cartons
3. Plastic	Carbonated drink bottles, milk containers/sachets, water bottles, juice bottles, sauce bottles, foamed or rigid food trays, yogurt containers, cutlery, margarine/butter tubs, compact discs, plastic cups, pens, Tupperware, cleaning bottles, washing up and shampoo bottles
4. Plastic bags	Food wrapping, carrier bags, refuse sacks, other packaging
5. Disposable Cups	Single-use hot drink containers
6. Glass	Jars, soft drink bottles, wine/beer bottles
7. Metals & Cans	Cutlery, spray cans (deodorants), cans from food and drink preparation (i.e. soup, beer, soft drink)
8. Non-ferrous Metals	Aluminium foil, food trays
9. Putrescible	Organic waste, food waste (meat, dairy products, fruit, vegetables, salads, bread), tea bags, coffee grounds, cigarette

	buds
10. Misc. Combustibles	Crisp packets, sweet wrappers, wood, disposable nappies
11. Misc. Non-Combustibles	Bricks, stones, ceramics
12. Textiles	Clothing, cleaning rags, mop heads
13. WEEE	Electrical wiring, telephone, light bulb, USB drive, smoke alarm
14. HHW	Lighters, batteries, paint cans
15. Fines	Less than 10 mm in size i.e. soil, ash, dust

Waste samples were collected in black bin bags, labeled for ease of identification and transported by trolley or mini-van to a central sorting platform (Fig. 2a). The sorting area had restricted access and fume cupboards, to reduce odour problems. Each sample bag was initially weighed using a digital scale (±0.05 kg), then segregated using the pre-defined 15 character template (Fig. 2b). Segregated components were again weighed (kg) to determine their weights as a percentage of the total weight of sample. The contents were then put back in the bag and re-weighed for confirmation of total sample weight. Analysis of each sample had to be completed within 24-48 hours to reduce odour and environmental errors.

Figure 2a. Collected Waste Ready for Weighing and Characterisation (Authors Photograph, 2013)

Figure 2b. Manual Characterisation of Waste Materials (Authors Photograph, 2013)

Dahlen and Lagerkvist [25] list possible sources of error in solid waste characterization to include: fundamental errors, grouping and segregation error, increment delimination error, increment extraction, preparation error, and errors due to spatial and environmental conditions.

A. *Waste Composition Analysis*

Food wastes can be highly variable depending on their source. This was particularly the case for this research. Food samples used during the composition analysis originated from the university cafeteria. The cafeteria produces a wide range of waste food such as: bread, meat, potato, chips, vegetables, salad, pasta etc. For moisture content determination a mixture of food waste samples were used. However, for carbon and nitrogen content determination a range of individual and mixed food samples were used.

i. *Moisture Content Determination*

There are a variety of methods from literature which can be used to determine the moisture content of food waste, including; distillation, chemical reaction, physical identification, spectroscopic technique and evaporation. For the purpose of this study the evaporation method was used. According to Komilis et al [42] oven drying is always part of the sample preparation protocol for quantitative analysis. Although time consuming, this method is precise, straight forward and can be used to analyse many samples simultaneously.

The percentage moisture content of the food waste was determined by weighing samples into a pre-weighed dish and then drying the samples in an oven at 40°C for 48 hours (Fig. 3 a& b). Samuel [43] states that the drying time required to achieve constant mass will vary depending on the type, quantity, and condition of the material. In total 10 samples were collected and percentage moisture content was calculated as:

Moisture content (%) = [(Wet Weight−Dry Weight)/Wet weight] ×100%

Figure 3a. Selected Food Waste before Drying (Authors Photograph, 2013)

Figure 3b. Food Waste in Oven (Authors Photograph, 2013)

ii. Carbon Content Determination

A number of methods are available from literature for carbon content determination from food samples [44]. For the purpose of this study, wet oxidation followed by manual titration [45] was used after Walkley-Black [46]. According to Mettler-Toledo [47] titration, also known as volumetric analysis, is a quantitative chemical technique used to determine the unknown concentration of an identified analyte. The advantage of using this method is that it is an established technique requiring little specialised chemical knowledge [47]. Samples were first placed in a stomacher where they were homogenised. This significantly reduced the particle-size to a more even distribution and thus made the waste easily digestible. Following this, the samples were placed in the oven at 40°C for 48 hours in order to extract the water and moisture contained within. The ten food waste samples used for carbon content determination were: Sausage, Bread, Chicken, Banana Skin, Chips and Potatoes, Corn and four samples that were mostly mass of putrescible mixture.

Due to the toxic, corrosive nature of some of the reagents used, Personal Protective Equipment (PPE) such as Lab coats, safety spectacles and hand gloves were worn at all times. Around 0.1 grams of food waste sample was weighted using digital scales and placed into a 250 ml round-bottomed flask. 20 ml of standard potassium dichromate solution and 15 ml of concentrated sulphuric acid were added to the flask using a measuring tube (Fig. 4a). Sulphuric acid generates heat so caution was taken when adding the solution. Anti-bumping granules were then added to encourage smooth boiling (Fig. 4b). Once this was complete the reflux apparatus was set up ready for the experiment to begin.

Figure 4a. Potassium Dichromate Solution and Ferrous Ammonium Sulphate Solution (Authors Photograph, 2013)

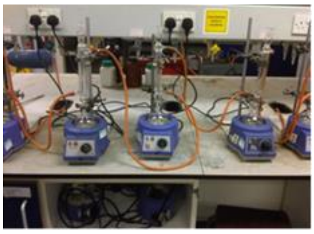

Figure 4b. Reflux Apparatus (Authors Photograph, 2013)

To overcome the concern of incomplete digestion of the organic matter, the solution was heated, using a heating mantle, for 30 minutes so that it boiled gently. Water was constantly flowing through the condenser to ensure that the vapours condensed and dripped back into the flask. A total of 10 samples were refluxed simultaneously to reduce time and make experimental conditions consistent.

While the food waste samples were being refluxed the blank titration was prepared. Approximately 100 ml of distilled water was placed into a conical flask. Following this, 20 ml of the standard potassium dichromate and 15 ml of concentrated sulphuric acid were carefully added. Again this generated a lot of heat so caution had to be taken. The titration reaction has to be easily observable and so has to be monitored by appropriate techniques. As such, two drops of the diphenylamine indicator (1% solution) was then added, which turned the solution dark brown/black.

The burette was then filled to the '0' mark with the ferrous ammonium sulphate solution (Fig. 5a) then slowly added to the acidified potassium dichromate in the conical flask. It was important to closely monitor any change in colour. As soon as it changed from dark brown/black, through to deep blue and then green, the end-point of titration had been reached (Fig. 5b). The volume of ferrous ammonium sulphate was recorded; this represented V2 in the equation. The burette was then refilled to the '0' mark for the titration of the food waste samples to begin.

Once the samples had been refluxing for 30 minutes the heating mantles were switched off and the flasks were allowed to cool. Two drops of the diphenylamine indicator were added and the samples were titrated with the standard ferrous ammonium sulphate solution. If no colour changes were noted before the solution ran out then more ferrous ammonium sulphate solution was added to the burette. Once there was a distinguished colour change (from dark brown/black to green), the volume added was recorded. This represented the V1 value in the equation. This process was repeated for the other food waste samples.

Figure. 5a:Burette Containing Ferrous Ammonium Sulphate Solution (Authors Photograph, 2013)

Figure 5b. Complete Titration (Lardbucket, 2013)

The amount of organic carbon in the samples (mg of carbon per g of food waste) was determined using equation 1

$$Organic\ Carbon\ (mg\ g^{-1}) = ((18 \times C \times V)/M \times (1 - V_1/V_2)) \text{……….equation 1}$$

Where:

C = the concentration of potassium dichromate (0.2 M)

V = the volume of potassium dichromate (20 ml^3)

M = the mass of the food waste samples in grams (to 4 decimal places)

V_1 and V_2 = the volume of ferrous ammonium sulphate from the titrations (as described above)

The amount of organic carbon was also converted to a percentage (%) of organic carbon using equation 2:

% Organic Carbon = Organic Carbon (mg g $^{-1}$)/10 ………………equation 2

iii. *Nitrogen Content Determination*

There are a number of methods currently used to determine nitrogen content in organic and inorganic products. However, one method dominates; the Kjeldahl method. According to Janben [48] the method has been modified and adapted over the years and, as a result, produces results that are widely acceptable. Furthermore, the relatively low cost, versatile and simple process makes analysis practical in most laboratories [49]. As such, this method was used when determining the nitrogen content in the food waste samples.

iv. *Data and Error Analysis*

Two sets of data were obtained from the study: waste composition analysis (moisture content, carbon content and nitrogen content) and waste characterisation study data. Data analysis was carried out using Microsoft Excel for Windows and Graph Pad Prism 6.00 for Windows. Descriptive statistics were used to highlight patterns and general trends in the data set by identifying key parameters such as central tendency and dispersion (i.e. standard deviation and standard error). Two Way Analysis of Variance (ANOVA) was used to explore any differences in the character and composition of samples over time and across sampling zones.

Dahlen and Lagerkvist [25] listed possible sources of error to include: fundamental, grouping and segregation errors, increment delimitation error, increment extraction, preparation error, long-range heterogeneity fluctuation error, and periodic heterogeneity fluctuation error. Kahmeyer et al [37] believe that such errors may result in an inaccurate profile of the studied waste stream. With regards to this investigation, appropriate training on the use of equipment was given to all that were involved in this research and waste samples were sorted within 48 hours to avoid errors due to physical and chemical changes [39][29][24][25][5][4].

IV. RESULTS

Table 2: Characterization of waste samples

Material Category	Campus North(%weight)	Campus South (weight %)	Halls (weight %)	Average Composition (%)
Paper	23	20	5	16
Cardboard	12	7	12	10
Plastic	17	17	18	18
Plastic bags	6	11	5	8
Disposable cups	4	6	0	3
Glass	2	2	12	5
Metals & Cans	4	4	9	6
Non-ferrous Metals	0	0	0	0
Putrescible	21	22	32	25
Textiles	3	2	3	3
Misc-combustibles	4	6	3	4
Mis. Non-combustibles	0	2	1	1
WEEE	0	1	0	0
HHW	0	0	0	0
Fine Element	4	0		1
	100	**100**	100	100

Table 3: Average Moisture Content of Food Waste Samples

Week	Moisture Content (kg)	Moisture Content (%)
1	0.170	48.39
2	0.101	47.82
3	0.105	55.11
4	0.134	43.89
Average	**0.127**	**48.80**

Table 4: Carbon content determination from food samples

	C	V	M	*V1*	*V2*	Carbon	%
Sample 1	0.2	20	0.1112	17.2	106.6	543	54.3
Sample 2	0.2	20	0.1078	26.9	106.6	498	49.8
Sample 3	0.2	20	0.1116	23.1	106.6	505	50.5
Sample 4	0.2	20	0.1480	12	106.6	431	43.1
Sample 5	0.2	20	0.1130	16.4	106.6	539	53.9
Sample 6	0.2	20	0.1059	10.2	106.6	615	61.5
Sample 7	0.2	20	0.0965	15	106.6	641	64.1
Sample 8	0.2	20	0.1247	6.9	106.6	540	54
Sample 9	0.2	20	0.1082	33.3	106.6	457	45.7
Sample 10	0.2	20	0.1362	15.3	106.6	451	45.1

Table 5: Carbon/Nitrogen Ratio of the Food Waste Samples

Food Type	C/N Ratio
Sausage	45:1
Bread	50:1
Chicken	56:1
Banana Skin	74:1
Chips and Potatoes	48:1
Corn	53:1
Mixture	100:1
Mixture	22:1
Mixture	61:1
Mixture	42:1
Average	55:1

IV. DISCUSSION

Results from the waste characterisation study indicate that about 73% of waste samples could be recycled, 25% could be composted and/or sent for anaerobic digestion, while the remaining 2% could be incinerated and/or sent to landfill. These results are similar to earlier studies conducted in other HEIs [3][5][37][4][38] who found that 61-82% of the waste stream could be recycled, composted or reduced. Moisture content determination and C/N ratio determination also averaged 49% and 55:1 respectively. Paper and paper products (i.e. newspapers and catalogues) represented the largest proportion of recyclable materials across Campus North and South, 23% and 20% respectively, but declined significantly to just about 5% in the Halls of residence. This is not surprising considering the academic nature of most activities on campus particularly, campus North and South where most of the administrative and teaching buildings were located. Previous studies on university waste stream equally indicated a level of variation in the proportion of paper products generated. Baldwin and Dripps [4] revealed that paper made up a composite total of only 8% in a waste audit conducted at Furman University, USA. On the other hand, Smyth et al [5] found that 29% of the waste stream by weight consisted of paper in another study at the Prince George campus of the University of Northern British Columbia, USA. Considered side by side with findings by Okeniyi and Anwan [20], Taghizadeh et al [38] and Kahmeyer et al [37] whose studies found paper composites of 10.52%, 14.45% and 28.2% respectively, a general picture of significant variations emerges with regards to the proportion of paper in campus waste streams.

Plastics constituted another significant category of materials in the waste stream, accounting on the average, for about 18% of waste samples across the campus. Previous investigations at other HEIs [5][4] recorded plastic proportions ranging from 9.4-13.3%; however each author included only certain categories of plastic in their investigations. The term ‘plastic bag’ was used in this investigation to encompass carrier bags, bin liners and packaging films, or more specifically low density polyethylene (WRAP, 2013). The proportion of plastic bags within the overall waste stream was approximately 8%. Disposable cups, made of paper or styrofoam, accounted for 4% and 6% of the waste stream in Campus North and South respectively. Both results are significantly less than the 15.21% found during a similar study by Smyth et al [5]. Putrescible accounted for 25% of the overall waste stream across the campus and so was the most significant material composite. Similar waste audits conducted at other HEIs found composites ranging from 10% to 48.1% [3][5][4][20][38] however most of these studies included green waste from university grounds in their figures [3][38]. Interestingly, there was only a small variation in the amount of putrescible between each block, with the largest proportion found in Halls of residence (32%)

Glass accounted on the average for 5% of the total waste stream from all sampling zone. The student Halls of residence had a significantly higher percentage of glass in their waste stream (12%) as compared to other sampling zones. On the average, these results compared favourably with results from similar investigations by Armijo de Vega et al [3] and Kahmeyer et al [37] who found composites of 3.3% and 1.5% respectively. The percentage of textiles from waste samples across the sampling area ranged from 2% in Campus South to 3% percent in Campus North and Halls of residence. This is similar to findings from Taghizadeh et al [38] who discovered a composite of 1.32%. The proportion of metals and cans within the overall waste stream was 6%. The highest proportion was found in the student Halls of residence (9%), whilst waste samples from Campus North and South both had 4% metals and cans content. The predominant item collected in this category was aluminium containers such as popular drink cans and soup tins. Miscellaneous-combustibles accounted on the average for 4% of the waste stream under study. The category was used to define items such as crisp packets, sweet rappers, wood and other materials that could be incinerated but did not fall into another category. All of these were relatively light weight in nature, yet when combined contributed a fair amount to the overall quantity of waste stream.

A. Data and Error Analysis

Findings from this investigation indicate that though the university has a very laudable waste management strategy, yet waste collection practices did not always conform to the objectives of the University’s waste strategy document. For instance, Fig 6a, b, c are examples of bins used in the university refectory. Note that it is not obvious what materials need to go into which bin. According to CIWM (2012) waste management should not be an afterthought, but carefully designed into every development or site. As such, it may be necessary to replace current waste collection systems especially in the Halls of residence with a more functional, aesthetically pleasing, easy to use and uniform waste collection system throughout the university campus.

Figure 6(a). Coca-Cola Bin found in the Refectory (Authors Photograph, 2013

Figure 6(b). Segregation Bin (Authors Photograph, 2013)

Figure 6(c). See-through Bin (Authors Photograph, 2013)

B. Communication

Zhang et al [1] state that resistance to change is a common problem in large organisations and has been a major obstacle to many sustainability programmes. However, there is a need to engage staff and students, make people rethink the perception of ownership and unlock the vision of waste as a resource. One of the fundamental issues facing waste management is organizational culture; behaviour change strategies needed to be phased-in on a solid foundation of education, training and awareness raising campaigns. This should be an upfront, comprehensive and transparent arrangement; designed in a way that allows the 'public' to understand the greater goal of what needs to be achieved [37].

A number of messaging strategies are available to provide staff and students with the knowledge and understanding they need to make their waste management practises more efficient and sustainable [37]. Bottom-up engagement with stakeholders across the campus may be particularly productive. This may involve giving first-year students introductory videos, workshops and informal talks so as to establish a campus culture and habit of waste management immediately upon their arrival on campus. It is recognised that taking responsibility for waste recycling is not top of a student's agenda when they first arrive at university so the messages need to be repeated quite frequently [1]. Another proposal is to implement a waste minimisation club within the University of Wolverhampton. This should engage a wide range of stakeholders from a variety of disciplines, including; staff, students, the student union, the waste contractor, and suppliers, so as to create a flexible platform, achieve greater collaboration, pool resources, share common experiences and goals, and identify best practises [50]. Zero Waste Scotland [51] believe that the scope of the project or initiative should follow a holistic framework, with emphasis on carrying out waste audits to establish base-lines, identifying barriers, drivers, incentives and motivations, setting objectives, organising resources through services, motivating and recruiting environmental champions who will be at the forefront of the scheme, co-ordinating training, implementing programmes, and monitoring and disseminating results.

C. Waste Composition Study

According to Igoni et al [21] the management and disposal of food waste requires an understanding of its biological and chemical properties. This includes proximate analysis (pH, temperature, electrical conductivity, calorific value, bulk density), ultimate analysis (volatile matter, ash content, moisture content, fixed carbon) and elemental analysis (carbon, nitrogen, hydrogen, oxygen, sulphur, mercury, fluorine, chlorine, phosphorus and potassium) [52][35]. These factors could vary considerably depending on the sample material and the condition under which the analysis was carried out, and so should be carefully controlled in order to achieve optimum process performance. Results from the composition study have been compared with previous studies. However, it must be taken into consideration that the composition of waste varies considerably amongst countries, regions and cities, depending upon; location, population density, income level, social background and cultural habits [32][42][13]. Furthermore, intra-annual variations in waste composition can occur in one particular location as a result of seasonal variations or changes associated with special events, i.e. tourism and holidays [53][26]. Monitoring variation is therefore important as they can help explain periodic changes in the factors affecting waste management programmes, their impacts on overall service quality and the best time for measures to be applied [13].

Results obtained from the food waste samples indicate an average moisture content of 48.80%. Previous investigations have found moisture contents ranging from 17.73% to as high as 82% [54][55][53][21][56][57][52][35] although values of 40%-60% are typically observed. Also results obtained show carbon contents ranging from 20.37% to 64.11%, with an average carbon content of 48.85%. This is a much broader range than the 39.48% to 51% discovered in previous investigations [53][56][21][19][58][52]. Komilis et al [42] believe that this could be due to the inherent variability of the food waste constituents. Alternatively, it may have resulted from errors associated with preparation, sampling and measurement.

The results obtained from this investigation show nitrogen contents ranging from 0.58% to 1.16%, with an average nitrogen content of 0.94%. This compares favourably with results from previous investigations which indicates nitrogen contents ranging from 0.29% to 2.6% [53][56][21][19][58][52]. The results from the carbon content and nitrogen content determination indicate a C/N ratio ranging from 22:1 to 100:1, with an average C/N ratio of 55:1. This ratio is distinctly different to the often documented optimum ratio of 20-30: 1 [59][60][42].

D. Proposed Treatment Options for Institutional Waste

Based on waste characterization and composition data from this investigation, a number of options are available for the management of food waste in particular in the case study area, including; incineration, composting, and anaerobic digestion (AD). Burnley [17] believes that utilizing information related to moisture content and C/N ratio enables waste planners to determine how feasible integrated solid waste management approaches are likely to be. Chang and Davila[19], on the other hand pointed out that waste planners need to bear in mind that the calorific value of waste sample decreases with the increase in moisture content. The relatively high moisture content of food waste samples from the case study area might be indicative of lower calorific values. The implication being that bioconversion technologies, such as anaerobic digestion, are more suitable compared to thermo-chemical conversion technologies, such as combustion and gasification. However, the C/N ratios obtained are too high, implying that decomposition of samples during the AD process may be slow [61]. The waste therefore needs some C/N ratio balancing if AD were to be viable. Kumar et al [62] believe that co-digesting two or more types of organic materials (i.e. food and green waste) can overcome the disadvantages inherent in digesting single stream waste samples. This position is reinforced by [63] who stated that mixed feedstocks are the most appropriate for anaerobic digestion of waste streams that are high in moisture content. A number of UK HEIs have already leveraged AD technology for management of organic fractions of their wastestream. This includes University of Reading, University of Northampton, Harper Adams University, University of Southampton, Queen Margaret University, Wigan and Leigh College and Durham University [64].

V. CONCLUSION

This research has provided an invaluable opportunity to investigate the character and composition of solid waste stream from a typical UK university campus. Results indicate that as much as 73% (by weight) of waste materials are useful resources that could be recycled, 25% could be composted and/or sent for anaerobic digestion, whilst the remaining 2% could be incinerated and/or sent to landfill. Statistical analysis indicate that there was no-significant interaction ($p > 0.05$) between the study area/zones and time of the year in which the study took place. In addition there was a highly significant difference between materials categories ($p < 0.0001$) and a significant difference between results from different sampling points ($p < 0.05$). This study also found out that though the university has put in place a robust waste management strategy, in reality there is a mismatch between the objectives of the waste strategy and actual waste management practices of staff and students. Other notable findings include a significant difference between actual and reported recycling rates as well as level of contamination of recyclates. A range of initiatives focused around public education and development waste management infrastructure are proposed to overcome current barriers constraining sustainable waste management in the institution. Additionally, results from food waste composition analysis indicate a moisture content of 48.8% and a C/N ratio of 55:1. The implication of this result is that with some balancing, the food waste may be amenable to disposable options such as anaerobic digestion. In conclusion, this study provides an example of the tools that can be used to assess waste management in large UK Institutions such as universities. It is hoped that best-practise recommendations, as well as the methodology utilised in this study, can be adapted for the assessment of waste streams from other institutions as well as other sectors

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