CDT Bioenergy
CAPE5970 Team Research Project

Resource and Environmental Assessment of Biological Waste Management Options at the University of Leeds

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Nomenclature

AD	Anaerobic Digestion
AWM	Associated Waste Management Ltd (external contractors)
BAU	Business as usual
CO2	Carbon dioxide
FW	Food Waste
GHG	Greenhouse Gases
GHGE	Greenhouse gas emissions
IVC	In-vessel composting
KWh	Kilowatt hour
Mpg	Miles per gallon
N2O	Nitrous Oxide
NOx	Nitrogen Oxides
WRAP	Waste and Resources Action Plan

Executive Summary

This project assessed the feasibility of the University of Leeds utilising food and other biologically derived waste for on-site treatment, with a particular focus on environmental aspects. This was carried out with a goal to bring about environmental improvements in the way the University treats its' biological waste. The extent of the different waste resources that were produced per annum was ascertained. Following this, a range of technologies were assessed on their environmental credentials. From this, 4 scenarios were formulated. Business as usual was assessed, with food waste being collected by Olleco at £90 per tonne and sent for anaerobic digestion 20 miles away. A 5 year contract with Olleco was put in place in this July (2017), which is set to last until 2022. It is therefore, unlikely that any significant changes to University food waste management could be put in place before 2022. Scenario 1 was to buy a desiccator and desiccate the food waste on-site before collection by Olleco. Scenario 2 was to buy an anaerobic digester, put it at Bardon Grange, a plant nursery, 2 miles away, and use the energy to heat the greenhouses there and the fertiliser to be used at the adjoining Weetwood sports fields. Scenario 3 was to put a composter on campus, compost the waste and use this composter on the sports fields. Finally, scenario 4 included the desiccation food waste on site, with further processing being carried out by Veolia (an incineration plant around 4 miles away) for combustion. An in-depth analysis of the climate change mitigation and other related environmental factors related to each scenario was then conducted, to assess which the best option was moving forward. Recommendations on how to implement strategies to best improve environmental practices in waste management were then stated. Moreover, research gaps and recommended further research were identified.

From the resource assessment section, it was found that the University produced approximately 122 tonnes of food waste per year, 600 tonnes of grass waste and 10 tonnes of wood waste. There was found to be a lot of seasonality, with grass waste only being produced in the summer months and food waste production dramatically reducing during University holidays, in particular in halls of residences over summer. It was also ascertained that improvements in food waste separation in the halls of residences could theoretically lead to

83.5 tonnes per annum of food waste being moved from general waste to food waste. This would bring about notable environmental benefits, as food waste is anaerobically digested locally and general waste is incinerated in Rotterdam and Oslo.

From the technology part of the assessment it was found that the most environmentally friendly option, of those assessed, was scenario 2 and having an anaerobic digester at Bardon Grange. This was primarily due to reduced transport emissions compared to Business as usual. The enhanced climate mitigation potential of this option, compared to business as usual was found to be small and questionable, when simply considering food waste as a feedstock. If grass waste were to be co-digested with the food waste however, the enhanced environmental benefits would be massive, considering anaerobic digestion of grass alone could produce considerably more energy than food waste. Moreover, business as usual is the second best option environmentally, with scenario 3 (composting) performing less favourably, as increased fertiliser production and carbon sequestration was outweighed by its' lack of energy production. Meanwhile, scenario 1 (desiccating and Olleco) performed less well than business as usual, as the reduced transport emissions from desiccation did not come close to offsetting the carbon emissions related to its' high energy usage. Scenario 4 and desiccation with combustion with Veolia was found to be significantly worse for the environmental when compared to business as usual. This is because, although combustion did produce more energy than anaerobic digestion and the transport emissions of the desiccated food were lower, lack of fertiliser production and, in particular, the high energy requirements of the desiccators meant combustion performed poorly. Moreover, significant issues regarding air pollution and hazardous waste production made this option even less favourable.

If the University was to convert to a green grid system and the desiccator was to run on renewable energy however, scenario 1 and 4 should be looked at again. Further to this, it would be beneficial environmentally to utilise the University's waste wood for combustion in a biomass boiler, as the environmental benefits from the heat energy produced would greatly outweigh the compost production and carbon sequestration from the current practice of composting the wood waste. Moreover, behavioural change should be strongly considered, in improving food waste segregation in the Halls of Residences and reducing the amount food waste produced at the University, as this would have enormous climate change mitigation possibilities.

Key recommendations include carrying out a full scale life cycle analysis on waste treatment options at the University and carrying out research on pilot scale versions of the and technologies (composter, anaerobic digester, desiccators and biomass boiler). Moreover, a more comprehensive analysis of biological waste is needed, especially for the green waste. Pilot-scale waste technologies currently owned by the University should be utilised, and pilot scale technologies not owned should be bought, in order to assess the true environmental credentials of each proposed scenario in biological waste management. If the findings of the further research come to the same conclusions then, when the current waste contract is to end in 2022, an anaerobic digester should be bought and installed at Bardon Grange, capable of processing 122 tonnes of food waste and 600 tonnes of grass waste. Furthermore, a biomass boiler for combusting the wood waste should be bought and situated at Bardon grange as soon as is possible. Moreover, efforts should be made to improve waste segregation in the halls of residences, including buying food waste bins for Charles Morris and Henry Price residences. Efforts should be made to amend the cleaning contract in the residences, so that cleaners collect food waste from the apartment kitchens. Additionally, campaigns and research should be carried out, aiming to improve food waste segregation and reduce food waste production across campus.

1. Introduction

1.1 Current practices and problem statement

The University of Leeds produces a very large amount of food and green waste. The food waste is produced mostly in the refectory. The refectory has gross sales of £2.04 million and creates large quantities of food waste each year. Other University cafeterias and two halls of residences (Central Village and Devonshire hall) also produce and separate out food waste. There is also green waste produced from the green areas in the campus, as well as the sports fields. This primarily consists of wood waste, but a significant amount of grass cuttings are produced, as well as a small amount of non-woody biomass. Presently, the green waste is used mostly for composting. The food waste is collected by a food waste management organisation called Olleco, who transport the food for anaerobic digestion (AD) at a site in South Milford, just over 16 miles away. Waste disposal costs £90 per tonne, thus with annual food waste collection costs being approximately £11,000. The heaviness, high moisture content and heterogeneity of the waste are the reasons for the high costs of collection.

The University would like to find a more effective method of managing food waste. This includes, decreasing waste disposal costs, improving environmental friendliness and producing energy from waste, whilst involving a high level of innovation and creating research and training opportunities.

1.2 Previous project

There was a previous project in 2013 to try and improve food waste management practices at the University. This was run by the sustainability services in combination with research staff. Composting was considered as possibility, but anaerobic digestion was believed to be the best option going forward, as it scored highest in criteria set out by the University. Aspects such as environmental friendliness, resource utilisation, as well as economic and social factors were assessed. It was proposed that the University should improve its' food segregation system in the refectory and remove the waste to a small facility on campus. Here, the food would be anaerobically digested, producing electricity and heat and the digestate produced from the AD would be sold as fertiliser.

Sites were identified on campus by the Gryphon sports centre, careers centre and behind the refectory. £200,000 was funded and set aside for the project. A business case was created and it was believed that internal and external funding could be sought. Prohibitively high costs and planning issues related to sighting the AD on campus, as well as a loss of expertise and drivers, due to researchers leaving the UoL meant the AD unit was unable to be bought and situated on campus (CouchPerryWilkes, 2016).

1.3 Food and green waste project waste management options

This project aims to assess the feasibility, appropriateness and desirability of a number of food waste management options to deal with the biological waste created on campus.

A number of technologies are examined in the literature review section of the article. The different waste treatment technologies assessed include anaerobic digestion, composting, desiccation and combustion, using both centralised and decentralised waste treatment options. All of this will be discussed in much greater detail in the proceeding sections.

1.4 Report aims

The aim of this report is to identify and recommend the most environmentally friendly strategy which the UoL can implement to deal with the FW generated on campus. This report will consist of a resource assessment of the waste streams identified at the University. The report then assesses four technologies which can be used to treat the waste on site and will examine the environmental credentials of four possible waste management scenarios that could be adopted. This will be done through carrying out a GHG assessment, as well as an analysis of other environmental factors. Thirdly, based on the findings, recommendations will be made regarding how to achieve optimal environmental sustainability in waste management at UoL, as well as suggestions for where further research should be carried out.

The findings and discussion of this report were the result of an extensive desk-based literature search and through discussions and interviews with staff at the UoL Facilities Directorate, Estates, Cleaning and Catering Services, academics and external waste management contractors AWM.

2. Literature review

2.1 Technological assessment

It is firstly very important to define and describe the technologies that will be assessed for biological waste management.

2.1.1 Anaerobic digestion

As previously mentioned, anaerobic digestion is a technology being considered for waste management at the University of Leeds. Anaerobic digestion (AD) is a process of biochemical conversion involving the degradation of biomass in the absence of oxygen, using microorganisms to drive the reaction. The end products of this process include biogas, digestate and waste water. Of these, the biogas (methane) can be used to produce heat (using a biogas boiler), and/or electricity with a combined heat and electricity (CHP) boiler. Moreover, the digestate can be used as a biological fertiliser. Both of these by-products can be used as to substitute to fossil fuel derived products, thus decreasing GHGEs (LeAF, 2010).

Anaerobic digestion can be fed biological waste as a feedstock. Food waste is mostly appropriate for anaerobic digestion. It needs to be of a certain particle size, moisture content and homogeneity however. Moreover, packaging must be separated from the food waste and it must be ensured that there are no contaminants in the food waste mixture. Moreover, some green waste can be added to the food waste feedstock mixture. This is called co-digestion. Grass cuttings and non-ligno-cellulosic biomass are suitable for AD and co-digestion can improve AD performance. Ligno-cellulosic biomass (woody biomass) cannot be anaerobically digested without significant pre-treatment however, so waste wood is not a suitable feedstock for AD (LeAF, 2009).

2.1.2 Composting

As mentioned in the previous sections, composting is a technology being considered for waste management at the University of Leeds. Composting is the term given to the aiding of the natural process of decaying biological waste (aerobic digestion). In composting, bacteria and worms breakdown the organic material, with the aid of Oxygen and water in a process that produces carbon dioxide and a nutrient rich soil (humus). Water, air and worms can be added to speed up the process. The composting process produces an organic fertiliser (Selincourt, 2008).

With composting, there is a wide range of suitable feedstocks. All food waste and green waste (including lingo-cellulosic biomass) can be used. Moreover, smaller particle size is preferable (for speeding up the decay process), but not essential (Wrap, 2006). Homogeneity is also not a concern. Furthermore, little pre-treatment is needed and feedstock contamination is not as great a concern as with AD for example (LeAF, 2009).

2.1.3 Desiccation

As discussed before in the report, desiccation is a technology being considered for waste management at the University of Leeds. Desiccation can also be referred to as dehydration, or dewatering. It is the process of removing the water from a feedstock through a process of extreme drying, by use of heat, rotation and a desiccating agent. Desiccation can the reduce weight and size of the feedstock by up to 90%. Desiccation produces an energy rich, dense product. If food waste is desiccated it maintains mostly the same level of energy and nutrient content, but decreases in size and density. Moreover, it kills most pathogens and halts the decay process, thus alleviating issues of odour and vermin problems. The end product can be used as a fertiliser, as a feedstock for a bio-boiler, as feedstock for AD (with the addition of water), or for animal feed. Furthermore, as desiccation greatly decreases waste size and weight, it can significantly decrease transport emissions (Dhar, 2016).

Desiccation can take a range of feedstocks. Wet biological wastes can all be desiccated (Neale, 2013). Desiccation would therefore be appropriate for all of the University's food waste that is produced. Alternatively, the desiccated waste could be used as a compost, as feed for a biomass boiler, or as animal feed. Material quality checks and transportation for each option would need to be carried out (Dhar, 2016).

2.1.4 Combustion

As mentioned earlier, composting is a technology being considered for waste management at the University of Leeds. A bio-boiler is a machine that combusts biomass by reacting biomass with oxygen in a process that creates heat energy, carbon dioxide (and other gases) and ash. The heat energy can be used to heat buildings, substituting fossil fuels and thus reduces GHGEs (Moran et al, 2006). The ash can potentially be used added to soil, for nutrient recycling (Obernberger and Supancic, 2009).

Different biomass boilers have different feedstock requirements. Some biomass boilers are more flexible regarding what they can combust and can use wood chips and dehydrated, homogenised food waste (Kim et al., 2013). Food waste that has been desiccated would be suitable feedstocks. Untreated, wet food waste would be unsuitable however (Tidy Planet, 2014).

2.1.5 Business as usual

Another option being considered is that of business as usual and contracting waste out to Olleco for anaerobic digestion. The food waste gets treated at a plant called Maltings organic treatment Ltd in South Milford, just under 20 miles away from the University (one way). They use trucks that can carry 8 tonnes of waste to collect the waste from the University to the site. They use AD to process the food waste and create electricity, to convert used vegetable oil to biodiesel. Moreover, a proportion of the biodiesel produced is used by Olleco lorries, thus greatly minimising transport emissions. Moreover, digestate is produced from AD and is sold as fertiliser, to substitute chemical fertilisers (Olleco, 2017).

2.2 Environmental considerations

There are highly significant environmental impacts related to biological waste production and disposal. Moreover, there is an enormous climate mitigation potential possible through improvements in biological waste management. Vast amounts of bio waste are generated globally. If bio waste is not segregated, or treated specifically, it usually goes to a landfill site. On landfill sites the food waste decomposes, releasing carbon dioxide and methane which contribute towards global warming. Waste can be treated in different ways which are much more environmentally friendly. In total, the UK produces around 10 million tonnes of food waste, almost a quarter of the all of the food that is sold (41 million tonnes sold/post farm). Nine percent of food waste comes from the hospitality and food service (which the University refectory, cafeterias and catered halls are classed under). Seventy percent of food waste comes from household waste (which self catered halls of residence are classed as). Total GHGEs from food waste in the UK are equivalent to 20 million tonnes of CO_2 emitted (WRAP, 2017). If food waste is processed in different ways it can create significant carbon savings comparative to landfill. Land fill produces 1.79 tonnes of CO_2 per tonne of food waste. This can be broken down into 1.75 tonnes of emissions from decay and 0.04 tonnes of CO_2 from the transport of food waste and land filling equipment (USEPA, 2015). Other options can vastly decrease emissions from food waste, or even bring amount a net sequestration of GHGEs from food waste management (Kim et al., 2013).

One area where carbon savings can occur is by using food waste for energy production. Here the energy produced can be used to offset fossil fuel combustion. Using natural gas to produce energy creates 185 Kg of carbon dioxide per MWh from direct emissions and 215Kg per MWh, if you take into account a LCA of the fuel (include fuel production, processing, transport and storage and power generation equipment). Oil creates 264Kg CO_2e/MWh directly, or 313 CO_2e/MWh taking into account an LCA (Forestry Commission, 2006). Alternatively, Carbon Independent (2007) calculates GHGEs related from combusting natural gas to be 203 Kg CO_2e/MWh. Moreover, through processing the biomass by composting, AD and combustion, carbon emissions come mostly in the form of carbon dioxide, as opposed to methane and carbon dioxide. As methane is a much more potent greenhouse gas (around 28 times more potent), this process further mitigates climate change (NYU, 2016). Anaerobic digestion and biomass combustion are examples of energy producing technologies using biological waste. Combustion of the biomass typically produces significantly greater amounts of energy, when compared to anaerobic digestion (Kim et al., 2013).

A further opportunity for climate change mitigation comes in the form of organic fertiliser production from bio waste. This organic fertiliser helps with nutrient recycling into soils and can displace fossil fuel derived fertilisers. Fossil fuel produced fertilisers contribute to a significant amount of GHGEs, thus producing organic fertilisers from waste can significantly help with climate change mitigation. Moreover, composted waste (compost), digestate from AD (Wrap, 2016), and desiccated waste can all be used as biological fertilisers (Dhar, 2016). Compost is a far higher quality fertiliser when compared to digestate. On the other hand, digestate can be composted to create a vastly improved fertiliser (Wrap, 2016). The quality of desiccated waste as a fertiliser is still not fully known (Dhar, 2016). According to the EU average chemical fertiliser results in the emissions of 7.8 Kg of CO_2e per Kg of nitrogen produced, as well as a further 0.1Kg of CO_2e in transport emissions, per Kg of nitrogen in the fertiliser (Yara, 2014). Ash produced from combustion in a bio-boiler can be used as a mineral fertiliser, or added to biological fertiliser to improve fertiliser performance (Obernberger and Supancic, 2009). Moreover, it can also help balance the PH of the soil. It can increase PH levels if the soil is too acidic (Naylor and Schmidt, 1986). Conversely, ash contaminants, or chemical content, in particular heavy metal content, can be a potential issue, so in some cases ash use as a fertiliser is unviable (Obernberger and Supancic, 2009).

A further dimension to biological fertiliser and GHGEs is that, as biological fertiliser contains large amounts of carbon. This can help maintain soil fertility and combat soil desertification. It increases soil carbon content, by directly adding carbon (in the fertiliser) and by improving carbon fertilisation. Peat is a material that is commonly used to combat desertification. Peat mining and application for agriculture in this way creates a great level of GHGEs related to peat decay. 65Kg of peat contains roughly the same amount of carbon as compost produced from 1 tonne of food waste. Moreover, this quantity of peat gives off 55Kg of CO_2 from decay in the soil (Smith et al., 2001). This decay also occurs with the compost, but, as this decay would naturally occur in a landfill site, or with combustion, it can be argued that the emissions from compost decay should not be considered (Selincourt, 2008). Desiccated food, and digestate could also, to a certain extent, would be able to substitute clay, due to the material's carbon content (Dhar, 2016). Conversely, if soil desertification is not an issue on the land where the biological fertiliser is added, or if they do not already apply peat on the land, these aforementioned GHGE reductions cannot be included.

Another factor to consider, regarding GHGEs and biological waste is that of transport emissions. With transporting waste from one site to another, there are extensive GHGEs from transport and fuel usage (typically the combustion of petroleum, or diesel by lorry engines). Local processing of biological waste decreases the amount of GHGEs from transport, from reduced transport distances, as well as waste reduction, due to reduced numbers of journeys transporting wastes. Local processing can include on site AD, composting, bio-boiler combusting and desiccating, here the end products can be utilised on site, or locally (Garnett, 2011). Moreover desiccated waste if transported to another site could be considered as a waste reduction strategy (Dhar, 2016). Another way to reduce waste is behavioural change related waste reduction (Friel et al., 2009).

It is also important to note that different waste treatment technologies do have GHGEs contributed to them related to operational energy use. Desiccation requires a large energy input (Dhar, 2016) and composting can require energy (tidy planet, 2017). On the other hand, anaerobic digesters can often use some of the energy they produce from processing the waste, to power the machines (parasitic load), thus not relying on fossil fuel derived energy (LeAF, 2009). Biomass boilers do not require energy inputs, but do not have a 100% energy conversion level (Damgaard et al., 2010).

There are a number of other, non GHGE related environmental factors that it is important to consider with the different technologies. Combustion of food waste results in the release of a great number of NOx, SOx and PM (He et al., 2004). These create major health issues, such as increasing respiratory problems and cancer frequency among the exposed population (Congialosi et al., 2007). Further to this, the ash produced from combustion can be high in heavy metals and considered hazardous. If this waste leaches into water bodies, it can cause significant environmental damage (He et al., 2004). It is also very important to note that desiccation results in large amounts of water wastage. This can put strains on water treatment facilities and should be considered as a negative environmental impact of desiccation (Dhar, 2016).

2.3 Centralised verses decentralised

As this project will consider both centralised and decentralised waste treatment options and the UoL is looking to decentralise its waste treatment, it is important to discuss the case for decentralising waste management and what effect decentralisation may have on GHGEs.

2.3.1 Benefits of decentralised

Decentralised waste management systems have many benefits as opposed to centralised. Decentralised methods result in environmental benefits such as carbon and economic savings resultant from decreased transportation emissions of the food waste. Moreover any by-products, such as biological fertilisers can be used locally, creating further reductions in transport emissions (NYU, 2016; Reghi et al., 2012). Furthermore, economic benefits can come in the form of cheaper infrastructural costs, as waste is processed locally and perhaps on site, so storage and transportation related infrastructure costs are less (LeAF, 2010). A further point is that in some places transport infrastructure can be inadequate for transporting food waste from a rural area to a centralised facility (Korner et al., 2006). Moreover, decentralised waste management can be very cost effective and can have short payback times for organisations and communities, regarding initial outlays, when compared to having waste contracts by centralised waste management contractors (LeAF, 2010).

Decentralisation can also create socio economic benefits such as by creating local jobs and increasing the energy security of the area, if the waste treatment involves energy production from waste (LeAF, 2010). Furthermore, localised energy treatment can create bio-fertilisers (composting and AD) which can help satisfy local demand and mitigate local resource shortages (Korner et al., 2006). Further benefits include the social benefits of, research opportunities, education, training possibilities and community outreach, such as school visits to see the waste treatment system (Princeton, 2017). This in turn can increase public awareness engagement and support for sustainable waste management practices (Reghi et al., 2012). A further point is that decentralised waste management can allow for the great levels of innovation, regarding technologies and system designs (LeAF, 2009). Another point is that decentralised, smaller scale food waste management can allow for more heterogeneous waste, better segregation and easier extraction of high value chemicals from the waste, such as pectin and D-limonene from citrus peel and spent coffee (Pfultzgraff et al., 2013).

2.3.2 Negatives/barriers of decentralised

On the other hand, there are a number of issues related to decentralised waste management. One issue is that of labour. Typically larger scale waste treatment operations (typical of centralised waste management) require less tasks and a lesser workforce than smaller scale operations (typical for decentralised operation) for the amount of waste treated. This is not much of an issue with simple technologies such as composting, combustion, or desiccation. Conversely, more complicated technology options such as anaerobic digestion has a large range of tasks related to its' operation and maintenance (LeAF, 2010). Furthermore, these tasks are often complex and thus require specialist knowledge and training, which may not be available locally (Korner et al., 2006). Labour can thus be a major barrier to the decentralisation of waste management.

There may be some operational issues related to decentralised, small scale waste management (mostly for AD). For larger scale operations it is more cost effective to invest in training, staff and machines for de-packaging and checking the quality of the feedstock and safeguarding against any contaminants. These factors may present major challenges for smaller scale decentralised operations however (LeAF, 2010).

A further potential issue for anaerobic digestion is that of the waste resources sourced. With large scale AD, there will always be a large, steady stream of diverse waste from a multitude of sources. There will never be key issues relating the quality and quantity of waste feedstock therefore. With smaller scale AD, key changes in waste streams could relate to major problems with AD operations. Seasonal changes in the quantity and composition of waste can lead to major implications on AD productivity, regarding energy and digestate produced, as well as machine maintenance and longevity (LeAF, 2009).

Economic issues can form major barriers. Initial outlays may be prohibitively expensive for many organisations, or communities trying to set up decentralised waste management (Korner et al., 2006). A continuation of contracting out waste management, with smaller continuous fees is often more feasible. In addition, running costs of decentralised AD may be prohibitively high if labour costs are particularly high for the amount of waste treated and benefits that come out. AD for example can have high labour costs, due to the aforementioned high quantity of skilled tasks that need to be carried out (LeAF, 2010).

A further consideration is that of hygiene and health and safety issues. Localised issues of odour, vermin problems and pathogens may arise and cause significant health and safety risks if waste is not effectively managed. These issues concern composting and AD technologies in particular (LeAF, 2010).

Air pollution can also be an issue on a local scale if waste is managed through bio boiler combustion. Regarding combustion, large scale incineration can produce comparatively significantly lower PMs, NOx, SOx, HCl and more (Damgaard et al., 2010). Furthermore, combustion is typically unsuitable for decentralised urban waste management, due to increased air quality regulations (He et al., 2004).

2.4 Previous studies

There have been a number of studies about institutions, including universities, trying to change the way they manage their biological waste to improve environmentally friendliness and effectiveness in waste management. Studying relevant previous research on the topic area, can allow for an improved insight into optimal waste management scenarios for cases such as UoL.

One study was done by New York University (NYU) in 2016. This was a feasibility study into the viability of having an anaerobic digester on campus to process waste. At the time they produced around 180 tonnes of food waste per year. This was going to a farm for composting 230 miles away and waste removal cost 31,500 US dollars per year. They assessed the quantity of organic waste produced, the composition of the waste, power that could be produced, and GHGE reductions. GHGE reductions would come about from converting methane to carbon dioxide (a less potent GHG), producing electricity and heat, that would utilised and substitute fossil fuels combustion, and the production of bio fertiliser (digestate).

They found that 398.9 tonnes of CO2 emissions would be avoided from avoiding any transport emissions. This figure is particularly high, due to the long length of the journey (230 miles round trip), the frequency of the waste disposal trips (312 trips a year) and the relatively high fuel usage of the trucks (3 miles per gallon). They also found that when compared to methane emissions on landfill sites (where there is 1 tonne of CO2 equivalent per tonne of food waste on landfill); there would be a reduction of 166.15 tonnes of CO2 emissions per year (NYU, 2016). They did not do any calculations on the amount of power that would be produced, or the amount of bio fertiliser (digestate) that would be produced and how that would equate to GHGE savings through replacement of fossil fuel combustion and chemical fertilisers.

Princeton University was another University that had problems related to food waste and sustainability. They were producing large amounts of food waste that was being sent to landfill. They decided to invest in a composter (FOR solutions model 1000). This machine is capable of processing 454kg of food per day and processes up to 5000pounds, or 2268kg per week. It produces high quality, nutrient rich compost that is then used on the campus for soil amendment. Research will also be carried out related to food waste management and composting, as part of a living lab programme at the University (Princeton, 2017).

Dhar (2016) from the University of Texas did a study assessing the viability of desiccation as a food waste treatment option. They wanted to assess how well desiccation could tackle the issues of very high GHGEs and economic costs from the disposal of food waste in landfill sites. Desiccation was looked at as an onsite waste treatment option. It was found that it could greatly reduce landfill and transport emissions. In addition, they found that desiccated food had good qualities for use as a fertiliser, as it had an optimal PH and carbon to nitrogen (C/N) ratio. Moreover they found that food waste varied from 63-87% moisture content, with desiccation reducing waste weight by between 53 and 91%. Also, desiccation is economically feasible if it leads to a weight loss of over 53%. Desiccation was also judged to be more efficient and economical than other o-site waste treatment options, such as anaerobic digestion and composting. On the other hand, the waste water produced was tested for reclamation and its' biological oxygen demand was found to be too high and would require BOD removal (Dhar, 2016).

There have been a number of interesting studies doing life cycle analyses (LCAs) on different food waste treatment options. Kim et al. (2013) did an LCA comparing the environmental impact of food waste management options for a municipality in Korea. They assessed the environmental credentials of anaerobic digestion and desiccation and incineration. They assessed power generation from waste, as well as CO2 emissions compared to natural decomposition. They then weighed this up against emissions from collection, transport, treatment and final disposal of the waste. They found that per tonne of food waste processed, drying and incineration reduces carbon emissions by 315kg CO_2e, whereas anaerobic digestion was found to produce a net 33kg CO_2e. Drying and incineration was therefore concluded to be the best option, regarding the environment, for the Korean municipality to process waste.

For this study CO2 emissions from incineration/burning methane was not counted, as the carbon was originally sequestered by the biomass in food production. Although desiccation of the food waste required energy (648.884KWh/tonne), food waste was reduced to 0.24 tonnes, thus trucks could carry more desiccated waste and transport emissions were reduced by 75.9% (% weight reduction). For transport emissions, the average distance to the processing site being 94.4km, with trucks with a fuel efficiency of 4.8km/l and the ability to carry 8 tonnes of waste. Moreover, incineration was seen to be notably more efficient in producing energy. Anaerobic digestion was calculated to be 35% efficient in power conversion, as heat produced was used to heat the digester and 28% of the electricity produced was seen to be needed to power the process. Overall, this meant that incineration was calculated to produce enough energy from 1 tonne of food waste to offset 657 kg CO2e, whereas AD could only offset 178kg CO2e. Furthermore, waste disposal emissions with AD were assessed to be much higher than with incineration, as incineration produces much smaller amounts of solid waste (ash), when compared to AD (digestate).

Although this study is useful in the way that it shows how incineration can have more environmental mitigation potential than AD through reduced transport emissions and increased power generation, an efficiency level of 35% for AD is particularly low and is typically around 60% (Dhar, 2016). Moreover, the fact that AD produces a bio fertiliser that can be used to offset emissions from chemically produced fertiliser is not factored in (Wrap, 2016). Additionally, increased carbon sequestration with AD (digestate) is not factored in to GHGEs with this LCA, as increased CO_2 emissions from combustion are discounted due to the fact that combustion only emits the carbon that was previously sequestered by the crop growing process. Furthermore, the extent of transport emissions reductions for desiccated waste would decrease significantly or entirely for decentralised AD and incineration. It is clear therefore that if these factors were adequately considered, then the figures for anaerobic digestion regarding its' environmental credentials in waste management would be greatly improved.

A further paper, by Worcester Polytechnic University (2009) assesses the environmental credentials of composting and the incineration of garden waste. They found that composting could give a net GHGE saving of 100.73KgCO_2e per tonne of green waste. This study works on the assumption that 1 tonne of garden waste produces 0.35 tonnes of compost. This is broken down into a 12.86KgCO_2 avoided by replacing the carbon in peat and offsetting the emissions from peat decay. A further 12.25KgCO_2 is offset by replacing chemical fertiliser. Moreover, 121 KgCO_2 is offset by the formation of humus. On the other hand, there were net emissions of 33.38 KgCO_2 from processing the compost and 12.02 KgCO_2 from transport. Transport emissions were increased high due to the assumption that compost was sold to multiple buyers and spread on a number of sites, leading to high post sale transport millage. For incineration, they found that a total of 506 KgCO_2 could be offset per tonne of garden waste processed in this way. This was based on the assumption that 1 tonne of garden waste contained 5.5 Giga joules and that 83% of this is transferred into heat energy, 14% into electricity and 3% is lost. Here 4.56 GJ of heat is produced and 346.47 KgCO_2 is offset, 0.79GJ of electricity is produced, offsetting a further 166.78 KgCO_2. Transport emissions are calculated at 8.01 KgCO_2. In total per tonne of garden waste processed, incineration offsets 405.27 KgCO_2e.

For localised processing of the waste, transport emissions should not be factored in however. Also, average transport emissions for chemical fertilisers are not factored into the equation. Furthermore, carbon sequestration is not factored in. As composting retains a large amount of carbon, but incineration converts almost all carbon into CO2, increased carbon emissions from incineration should there for be factored in. On the other hand, peat is used to increase soil carbon in sites where desertification is an issue (Selincourt, 2008). Peat substitution should not be factored in to sites were desertification is not an issue and peat is not being applied. In addition, an incineration efficiency level of 97% is particularly high, as efficiency levels are typically 93% at absolute most (Damgaard et al., 2010).

3. Methods

This research project included the conduction of interviews, with University staff, to understand current practices, alongside a resource assessment focussing on waste types, streams and quantities. Waste treatment scenarios were then formulated and a scenario analysis was conducted, which included a GHG and wider environmental assessment. Recommendations are then given, based on this.

The first step carried out was to ascertain current waste management practices. This was done by conducting meetings and interviews with staff, lecturers, contractors and researchers to collate information and find out all that is known about waste management related issues. Additionally, existing documents on the previous project to have an AD on campus, was analysed to further increase understanding of goals, aims and key challenges.

The next stage of this project was to do a resource assessment on the biological waste produced by the University. This was done by interviewing people to gain any information and data they had. Moreover, official AWM and Olleco food waste data figures were sourced and analysed.

The first part of the resource assessment was to find out what the food waste sources were. The types of biological waste and sites producing said waste were identified from interviews with University staff. After this, the quantities of each type of waste produced were found. There were only food waste production figures for the months of July, August and September for the University refectory and on campus cafeterias this year available (as the Olleco contract only began in July 2017 and prior data was insufficient). The average for the 3 months was calculated to get the monthly average, which was multiplied by 12 to get an average annual figure. Food waste production data for Central Village self catered halls was available for the year of 2017, which was then used as the yearly total food production there. The food waste production figures for Devonshire Hall was available for the years of 2014 to 2017. The average annual food waste production was then calculated. The land area covered in grass at the Weetwood sports fields and campus green spaces was sourced, alongside the dominant species (perennial ryegrass). An annual increment of 12 tonnes of dry silage per hectare for perennial ryegrass in the British Isles was identified in the literature and the annual grass waste mass was calculated using these figures. Moreover, a speculative estimation of the wood waste quantity per year was provided by the estates team.

After this, seasonality was analysed. Tables for how the food waste production differed over the course of the year, on a month by month basis could be created for Devonshire Hall, Central Village residences, as well as the refectory, as there was sufficient data available. Moreover food waste composition was ascertained by carrying out a food waste sampling session at the University cafeteria, milling the waste, freeze drying it and conducting Ultimate and proximate analyses, following British standard practices (Pichtel, 2005).

Potential increases in food waste segregation were based on there being a 10% uptake in FW segregation at Central Village, making up 4% of total waste produced. If 100% of waste were to be segregated, then this would make up 40% of total waste produced at Central Village. Based on this, it is assumed that around 40% of the total waste produced at Charles Morris and Henry Price halls of residences is made up of food.

Scenarios were then formulated based on different feasible options to process the University's biological waste, using the different appropriate technologies.

The next phase of the research was to conduct a GHG assessment. This included assessing transport emissions, energy used in waste treatment, energy produced from each treatment, as well as fertiliser production and carbon sequestration. Transport emissions were based on the shortest distances calculated from the University refectory to the site of treatment using Google maps. It was assumed that food collections were twice weekly and Olleco trucks run at 14MPG (based on data by Olleco). Moreover, it is assumed that 10.15KgCO_2 is emitted per gallon of diesel burnt (U.S.EIA, 2014) and that an average waste collection vehicle would run at 1 MPG (NYU, 2016).

Energy consumption is based on literature analyses of the most energy efficient model for each technology. It is also assumed that mains electricity consumption results in carbon emissions of 0.527KgCO_2 per KWh and combustion of natural gas for heat energy results in emissions of 0.203527KgCO_2 per KWh.

Energy production assumes mitigation levels equal to the aforementioned values per KWh of energy produced from substituting fossil fuels. AD energy production was based on the conduction of BMP tests, using British national standards (Owens and Chynoweth, 1993). Moreover, it was assumed that the AD would have a parasitic load of 8% and the boiler would have an energy efficiency of 90%. Additionally, the combustion energy production figures were based on the value from the proximate analysis of desiccated FW (reduced by 84%

to factor in mass loss due to moisture loss) and an average calorific value of wood chips of 18.6 MJ/Kg (McKendry, 2002) being converted to KWh heat energy (Fiedl et al., 2005) and with a conversion efficiency of 90% (Kim et al., 2013).

Fertiliser production mitigation is based on average nitrogen and phosphate contained in the fertiliser produced. This assumes that 1 tonne of FW goes into 100Kg of compost (Salincourt, 2008). and 1 tonne of GW goes into 330Kg of compost (ADAS, 2007). Moreover, 1 tonne of feedstock anaerobically digested goes into 330Kg of digestate (Dhar, 2016). Moreover, 1 tonne of compost contains 7.5Kg of N and 11Kg of N, for green waste and food waste respectively. Moreover, 1 tonne of GW compost contains 3Kg of phosphates and FW compost contains 3.8Kg, whereas 1 tonne of digestate contains 5Kg of N and 0.5Kg of Phosphates (Wrap, 2016). Further to this, 1 Kg N contributes 9.14KgCO2 emitted and 1 Kg phosphate contributes to 11.27KgCO2 emitted (Fertilisers Europe, 2008).

Carbon sequestration was also calculated for composting. This was assuming that, in a short term period (1^{st} year) around 60% of the feedstock's carbon is converted to CO2 and over a long time period (99 years), a further 30% of the original carbon content of the feedstock is converted lost, thus only 10% of the original carbon content is retained (Salincourt, 2008). Furthermore, the carbon weight is multiplied by a conversion factor of 3.67, as 1 Kg of C converts to 3.67Kg of CO2, due to the additional weight of the Oxygen (Johnson and Coburn, 2010). Moreover, the carbon content of food was calculated to be approximately 50% of the total carbon, with the carbon content of wood chips being taken from the literature and approximately 50% (McKendry, 2002) of the total weight.

Other environmental issues were identified through assessing the literature. Moreover, recommendations based on knowledge gaps, areas where further research is needed and recommendations for how to proceed, in improving biological waste management, regarding environmental aspects, are discussed, based on the research findings.

4. Results and analysis

4.1 Resource assessment

4.1.1 Introduction

This section of the report provides an assessment of the waste resources generated at the University based on information collated from the estates department and operational teams. Data was limited for some aspects of this assessment therefore several assumptions have been made. Where applicable these assumptions are explained and it is recommended that for accuracy future research is conducted to generate a larger dataset.

4.1.2 Waste Streams

The majority of segregated food waste on campus is generated by the refectory and food outlets on site, but it can also be sourced in large volumes from the catered Halls of Residence, Devonshire Hall, and the self-catered accommodation at Central Village.

The Green waste stream on campus includes both grass cuttings and woody waste and is sourced from the University grounds and green spaces. Green waste is an additional waste stream that should be considered for this project as it is possible that some of this waste stream can be utilised and combined with the food waste for optimum use in the technology and enhanced environmental mitigation when compared to utilising food waste alone.

4.1.3 Volumes

Data regarding specific waste volumes is currently limited, however due to a recent change in the waste management contract with external stakeholders AWM; we were able to obtain food waste weight data for the whole campus for the months of July, August and September 2017. The contract is scheduled to continue until 2022; therefore long term waste generation data should be accessible at a later date. It is advised that this data be requested by the University to assess whether food waste volumes and seasonality have changed significantly on an annual basis. This will also provide a degree of validation for the recommendations made in this report where the limited available data has been used.

Similarly, there is currently no recorded data for the green waste generated on campus therefore data shown below has been estimated by the estates team. A future scoping study should be conducted to quantify green waste generation; current estimates were emphasised by the estates team as being purely speculative.

Using the data currently available, Figure 1 is an indication of the averages assumed for the volumes of food waste and green waste generated on campus. It can be observed that the University produces approximately 122 tonnes of food waste per year from The Refectory, cafeterias on campus and the halls of residences where food waste is segregated at source. Moreover, approximately 606 tonnes of grass waste and 10 tonnes of wood waste are produced in green-spaces on campus and at Weetwood sports fields.

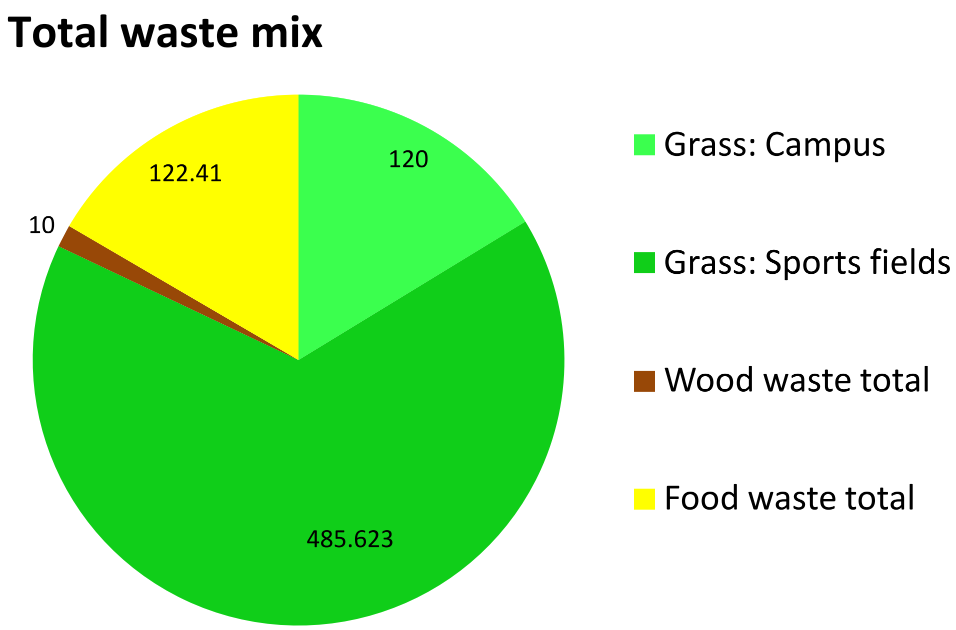

Figure 1 - Average green waste and FW mix generated at the University per annum

4.1.4 Waste sources

University refectory and cafeterias

A large proportion of the University's waste is generated from plate waste at The Refectory canteen on campus, which serves breakfast, lunch and dinner during the week and breakfast and lunch on the weekend. The Refectory is the largest and most frequented cafeteria on campus with gross sales of £2.04 million, serving on average 3,500 covers a day and creating approximately 50 tonnes of food waste a year. The waste is separated at source by The Refectory staff, whereby plate scrapings and kitchen preparation waste are added to food caddies before being placed in dedicated food waste wheelie bins outside.

In addition to The Refectory, there are a large number of cafeterias located around the campus, often situated within each faculty building. Food waste generated here is typically segregated by staff and added to the same food bins as The Refectory waste. In total, the refectory and cafeterias produce an average of 111 tonnes per annum (when taking an average monthly food waste production between July and September, 2017)

Halls of Residences

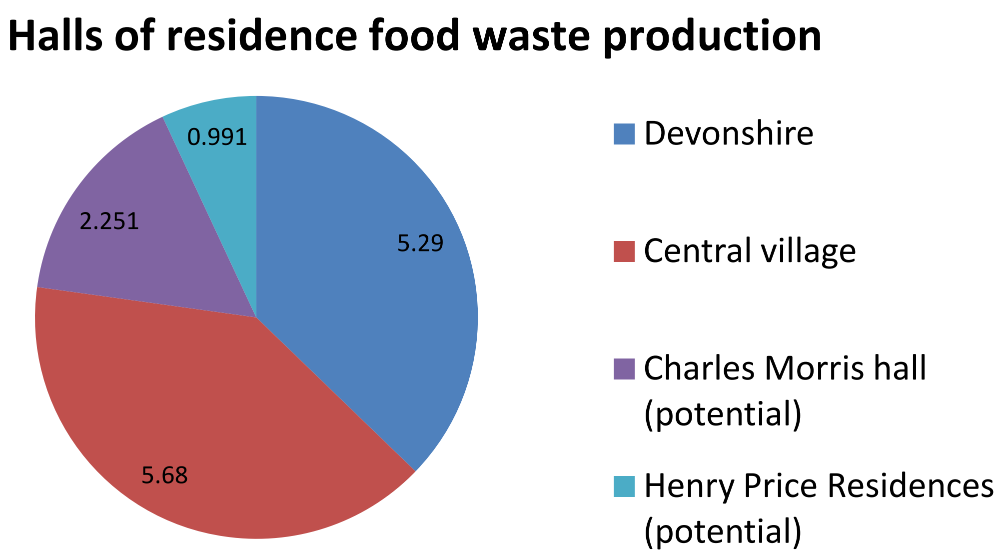

Figure 2 - Average annual FW generation and potential production in all on-campus halls of residences

Devonshire Hall

Devonshire Hall is a 355-person capacity catered accommodation, producing on average 5 tonnes of food waste per annum (Figure 2). At this site the food waste is separated from general waste by kitchen staff and added to specific food waste bins provided by the external contractors Olleco (similar scheme as The Refectory).

Central Village

Central village is a 979-person capacity self-catered accommodation which produced approximately 5.68 tonnes of food waste across the academic year of 2016/2017 (Figure 2) which accounts for 4% of the total waste produced onsite. Food waste bins are provided in shared apartments on an opt-in basis, therefore segregation is optional. The students themselves are responsible for taking the food waste down to a communal food waste bin. Around 10% of students in this accommodation will participate in food waste segregation.

This optional food waste segregation scheme was chosen for Central Village ahead of the other Halls of Residences as it has the greatest number of students residing here and the greatest volume of food waste per head. This is thought to be due to the large proportion of International students who are perceived to cook more frequently with fresh produce than Domestic students.

Charles Morris Hall and Henry Price

Charles Morris and Henry Price Halls are also self-catered accommodation, where waste collection is provided for by the University facilities. Segregated food waste is not collected at these sites however, due to economic and social barriers. Assuming that 4% of the general waste could be separated and collected as food waste (as with Central Village), then, as shown in Figure 2 Charles Morris Hall and Henry Price residences could produce approximately 2.251 and 0.991 tonnes of waste per year respectively. This would increase the volume of food waste being collected by external contractors by 3.2 tonnes per annum and thus decreases the amount of waste being sent for incineration with general collections.

Campus Grounds and Sports Fields

The University sports fields are located off the main campus site, in the suburb of Weetwood and consist of approximately 40.5 hectares of grass. Within the central campus, it has been estimated that there is approximately 10 hectares of grass. Both locations include a large number of trees and shrubs. Combined, they both produce on average 605 tonnes of grass cuttings and 10 tonnes of wood waste. The wood waste is chipped and transported to Bardon Grange (next to the sports fields) where it is composted.

4.1.5 Seasonality

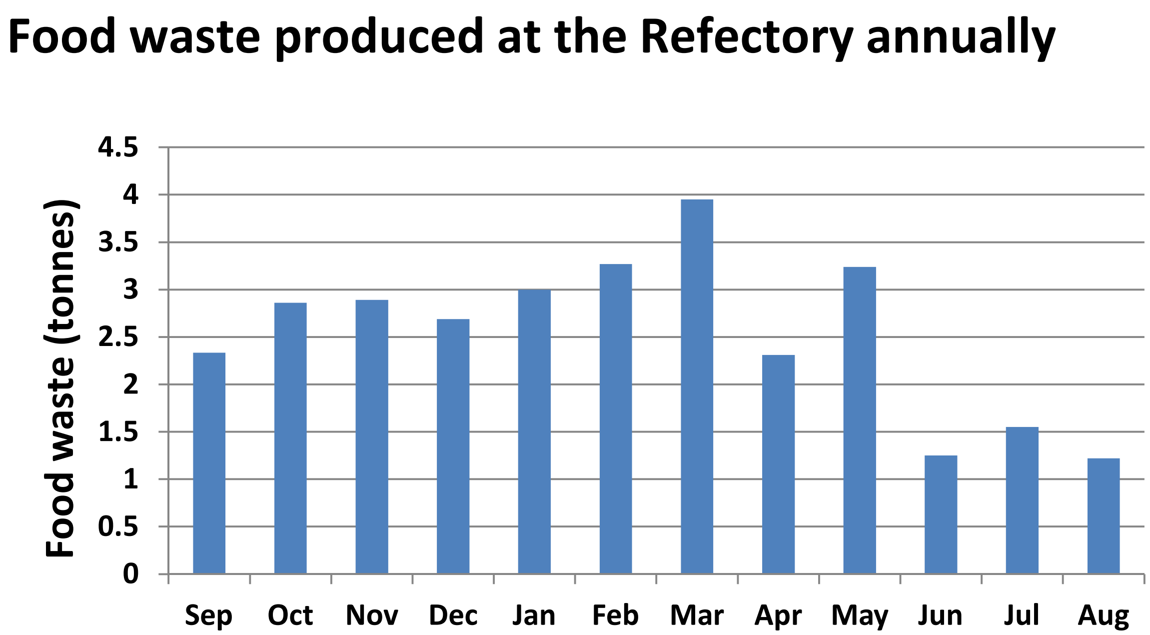

Figure 3 - Annual variation in FW generation at the University Refectory

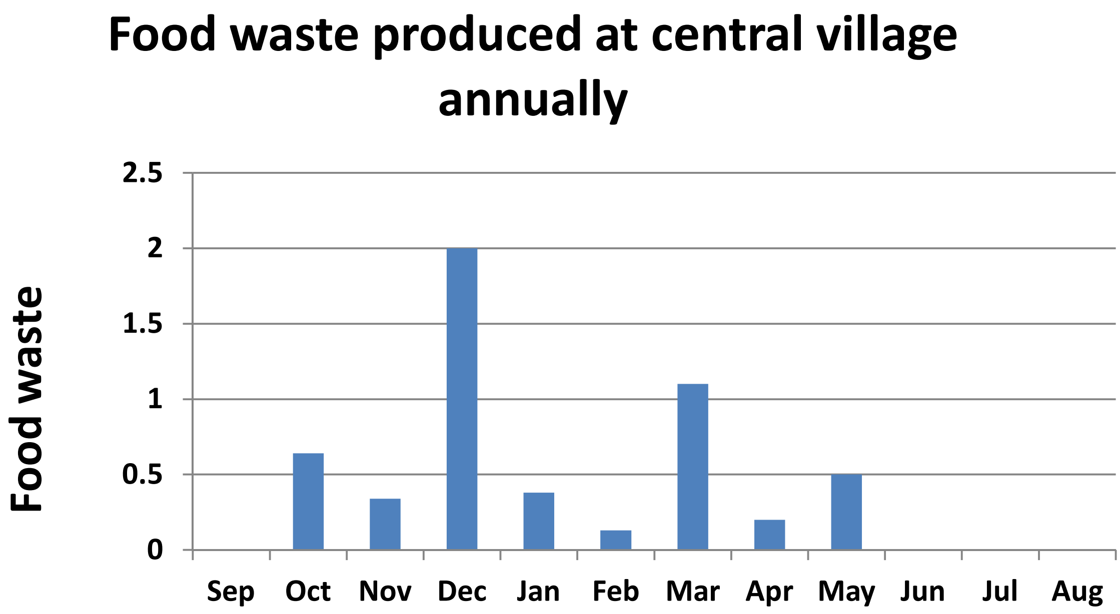

Figure 4 - Annual variation in FW generation at Central Village (self-catered) accommodation

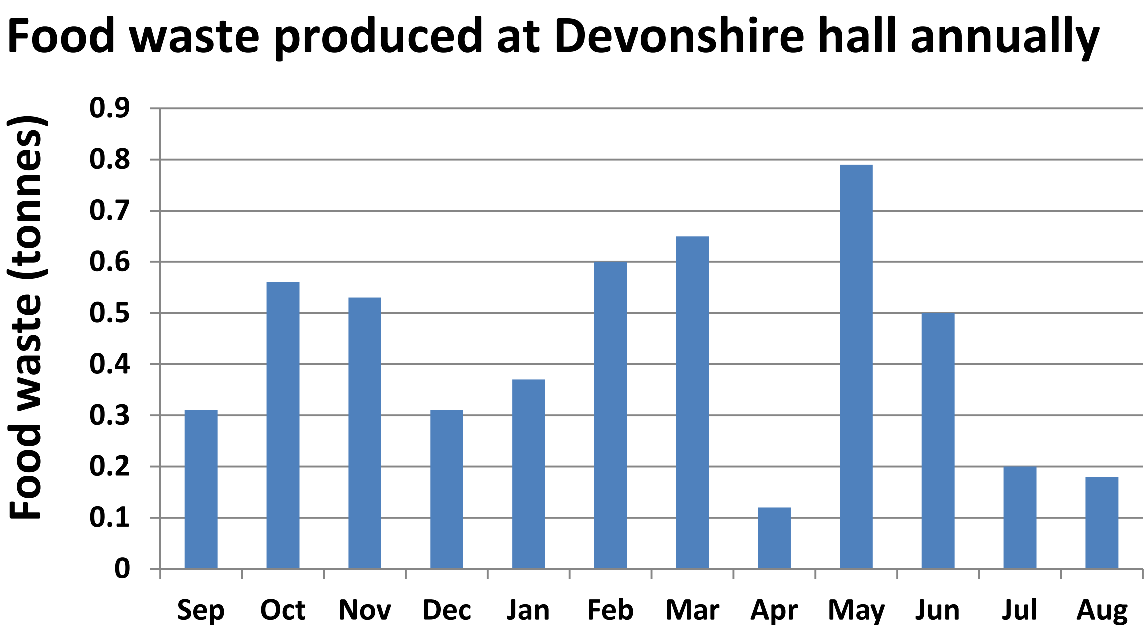

Figure 5 - Annual variation in FW generation at Devonshire Hall (catered) accommodation

Data gathered has shown significant seasonality in the volumes of waste generated throughout the academic year and this can be observed in Figures 3-5.

Food Waste

It can be seen in Figure 4 and 5 that food waste production in both of the halls of residences is highly seasonal, peaking during term time whilst values fall during academic holidays when students typically return home. Figure 4 shows that no food waste has been recorded at Central Village during the summer months, however a small volume is still recorded at Devonshire Hall (Figure 5) as this accommodation is often utilised over the Summer period when large conferences have been organised. Additionally, a large spike in food waste production can be observed at Central Village in December (Figure 4) when an annual scheduled 'deep cleaning' service is conducted by University cleaning staff after the students have left for the Christmas holidays. This deep clean contributes to around one third of the annual food waste produced at Central Village.

Green Waste

There is a significant proportion of green waste generated during spring and summer months when trees, shrubs and grasses are cut back from the green spaces on campus. The volume of green waste therefore declines during autumn and winter months; however, the generation of woody waste remains constant throughout the year.

4.1.6 Current Waste Management Strategy

The University outsources its waste management and has started a new 5-year contract with AWM in July of 2017. This contract involves the separate collection of food waste at several locations by Olleco, who provide resource recovery solutions for food service businesses and organisations.

In locations where food waste is not collected, it is just included in general waste collections, where the waste is transported for incineration with energy recovery. A quarter of the waste is processed locally by The Multifuel Energy Ltd company at the FM1 site in Ferry Bridge, (approximately 21 miles away). The remaining majority of the waste is shipped to incineration sites in Oslo and Rotterdam, which has considerably higher transport emissions associated.

Food outlets in the Students Union

The Leeds Student Union (SU) is classed as a separate business to the University of Leeds and rents the union building space from the University itself, therefore is subject to its own policy and contracts regarding the collection and management of waste generated on site and from the food outlets within.

The SU also has an existing contract with AWM but have chosen to implement source segregation of specific waste streams using recycling bins located across the Union building. Most food waste generated in the SU is being directed by Olleco to their AD facilities. Staff at the SU expressed intent to purchase a composting unit that will be located at the delivery entrance to the SU where source segregated food waste can be treated, although no start date to this new strategy has been confirmed yet. Further to this, the student Union have expressed that they are happy for proposed composter to be used for research and outreach, in-line with the living lab initiative.

Olleco

Olleco have provided the University with dedicated food waste bins which are collected from various locations on campus by the company, on scheduled collection dates twice a week. Once collected, the food waste is taken to an anaerobic digestion plant in South Milford where the waste is used to generate a renewable form of electricity and fertiliser. The fertiliser is sold to local farmers as a replacement to chemical fertilisers and the electricity is used to convert used vegetable oil to biodiesel. Most of this biodiesel is sold to the transport sector, but some is used to power Olleco's trucks used for waste collection and the delivery of their products. This biodiesel improves the efficiency of the vehicles raising average mile per gallon from as low as 3 to around 14mpg (NYU, 2016). The production of biodiesel results in two further by-products; bio-heating oil and glycerol. Bio-heating oil is used to heat boilers and glycerol is sold to cosmetic companies.

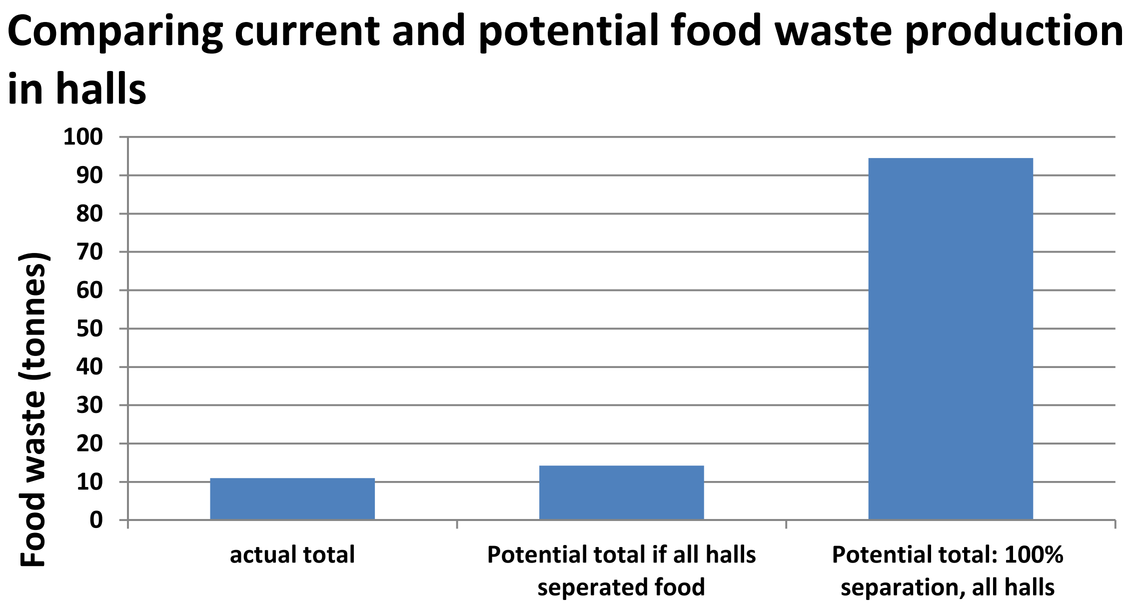

Figure 6- Actual verses potential FW generation in Halls of Residences

Assuming that the 4% of total waste collected as food waste is only 10% of the total food waste generated, you can assume that around 40% of the general waste could be separated out as food waste. As illustrated in Figure 6, if this were the case, the total food waste segregated from all the halls of residences under the University's remit could theoretically total of 94.51 tonnes of food waste a year, an increase of 83.54 tonnes a year compared to present.

There are some key economic and social barriers that would need to be overcome to vastly improve waste segregation practices in the mentioned halls of residences. These include incentivising and educating students to separate their waste, as well as paying cleaners to collect food waste from students' apartments (as is done with the other waste produced) and paying for food waste bins in Charles Morris Residences and Devonshire Hall.

Currently, around 25% of the un-separated food waste gets transported to Ferry Bridge, about 20 miles away (Multifuel energy, 2017) and the rest goes to facilities in Rotterdam and Oslo, where it is incinerated with general waste. This is much less environmentally friendly than AD with Olleco in South Milford; therefore there is a massive scope to have carbon savings through improving food waste separation at the University's halls of residences.

4.2 Scenario assessment

4.2.1 Business as Usual (BAU)

As discussed in chapter 2.1.5, UoL has existing contracts with external stakeholders AWM and Olleco for dealing with the food waste generated on campus. In this 'business as usual' scenario it is assumed that these contracts remain in place for both the contractual 5-year period and is extended thereafter so that food waste is collected and taken offsite to an AD facility in South Milford. An average transportation distance from the University campus to the AD facility of 20 miles has been assumed for this assessment (Figure 7). Additionally, it has been assumed based on information gathered from interviews, that the vehicles transporting the waste have an 8 tonne carrying capacity, operates at 14MPG.

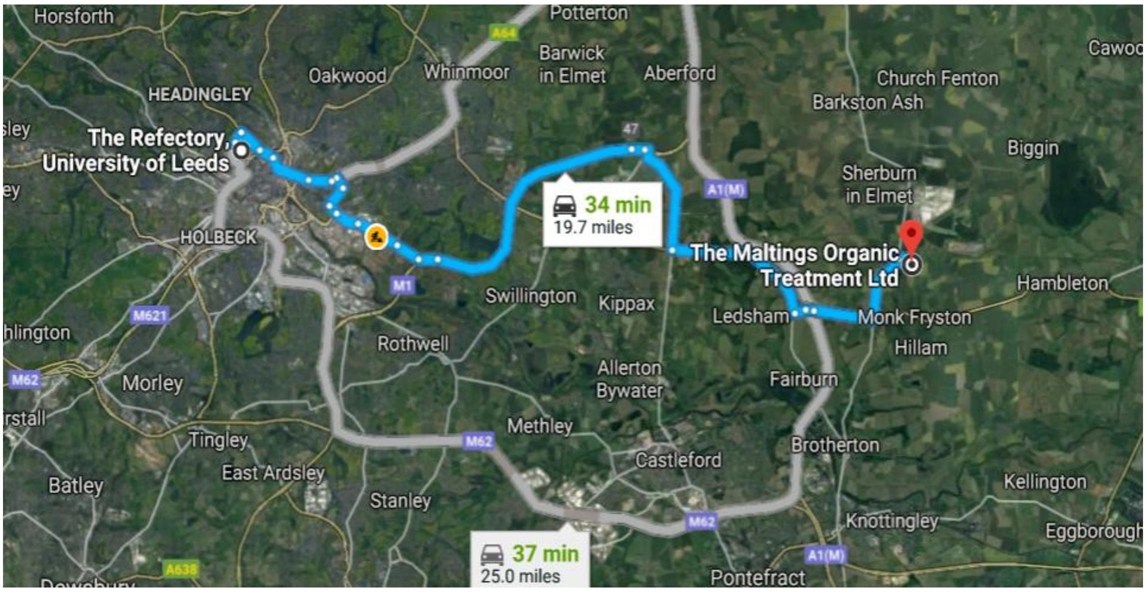

Figure 7 - Possible transport route between UoL and Olleco AD facility (Source: Google Maps).

Environmental Impacts

The BAU scenario appears to do well at reducing the negative environmental impacts of food waste when compared to landfill, particularly so when assessing potential CO_2 emissions from transportation of waste from campus to the AD facility in South Milford. Not only do Olleco try to ensure that their chosen routes from collection to AD are the shortest possible in order to reduce road emissions, they also coordinate FW collections to also collect FW from other institutions en-route, such as Leeds Beckett University. Further still, the company use a fleet of vehicles powered by bio-diesel they produce themselves from waste cooking oil collected from the service sector. As this form of bio fuel is produced from a waste product rather than first generation fuel crops there is the added benefit of avoided GHG emissions from land use change impacts such as deforestation. Moreover, as this vegetable oil is a waste product, using waste oil, as opposed to having specific bio fuel plantations, this system helps avoid added emissions from planting, fertiliser and pesticide use, as well as harvesting. Further to this still, utilising used vegetable oil helps avoid the food verses fuel land use conflict (Gui et al., 2008). The utilisation of waste vegetable oil also helps mitigate plumbing and water treatment issues related to the illegal disposal of oil down drains, or the GHGEs related to landfilling vegetable oil (Kulkarni and Dalai, 2006). It should be taken into consideration that, a fraction of the energy produced from the AD of the University's food waste goes to producing the biodiesel used by the vehicles, potentially reducing the positive environmental credentials of this scenario somewhat. However, this current practice is avoiding GHG emissions associated with landfill and incineration.

The digestate produced by the AD process is used as a replacement for inorganic/chemical fertilisers, being sold to local farmers (Olleco, 2017), thus it offsets the GHGEs associated with the substituted chemical fertilisers (WRAP, 2017). Moreover, in converting vegetable oil to biodiesel, glycerol is produced. This is sold to the cosmetics industry, thus offsetting any emissions related to the specific production of glycerol. Additionally, bio-heating oil is also created as a side product. This is utilised by Olleco as a fuel for powering boilers in their buildings, to produce heat energy. This therefore leads to further GHGEs being mitigated through the substitution of fossil fuels with bioenergy (Olleco, 2017).

When considering food waste disposal and the Olleco system in its entirety, Olleco can be considered as a very sustainable option, through bringing about wide-ranging environmental benefits to society.

4.2.2 Scenario 1- BAU with desiccation as a pre-treatment

Scenario 1 involves a continuation of the existing waste management contract and food waste collection by Olleco explained in the BAU scenario with the addition of on-site desiccation of food waste. The main purpose of using desiccation as a pre-treatment is to remove the water fraction of the food waste (which accounts for up to 84% of the total weight) and will significantly reduce the volume and weight of the waste collected.

This scenario requires the use of an industrial food waste desiccator similar to those implemented in large catering kitchens. It may involve either plate scrapings to be placed in a regular food waste caddy before being taken to the desiccator, or if located within the kitchen itself, plate scrapings could be added to the desiccator directly. During the desiccation process, the food waste is macerated so that the particle size is substantially reduced, after which dehydration occurs to separate the liquid fraction from the solid waste. The liquid is then drained off while the resulting solid waste can be added to a sealable container and stored until collection by Olleco.

Environmental Impacts

The environmental benefits of the BAU scenario, in terms of reduced transport emissions and the AD of food waste, are all applicable for this scenario. When desiccating food waste, there is potential to substantially reduce the number of collections required by Olleco if the waste was to be stored on site, which would improve the efficiency of the scenario and reduce associated transport emissions. Concerns should be raised however, when you factor in the amount of energy that is required to run a desiccation unit to treat the volume of food waste that is generated at the University.

When the amount of energy required is considered 30,800KWh/annum (Somat. (2017), calculations for the equivalent associated GHGEs indicate there is a net increase of 11.25 tonnes of CO_2 equivalent per annum, assuming an average of 0.527kgCO2e/kWh mains electricity (Carbon Independent, 2007). This figure is likely to be higher if you are to consider the emissions that are associated with the production of the desiccation unit as well as the treatment that will be required on the process waste water that is deposited down drains. Despite it not being possible to store desiccated food waste on campus for prolonged amounts of time due to waste regulations and for health and safety reasons, in theory even if waste was stored so that only 3 annual collections were needed, there would only be an additional saving of 0.76 tonnes CO_2 equivalent per annum, meaning scenario 1 would still lead to 10.49 additional tonnes of CO2 being emitted annually.

4.2.3 Scenario 2- Anaerobic Digestion at Bardon Grange

Scenario 2 represents onsite AD of food waste and would require a discontinuation of the contract with Olleco. The food waste would be anaerobically digested at Bardon Grange shown in Figure x. Food waste would need to be segregated at source to avoid any contamination of the AD process, before being transported to the location of the onsite installation. It should be noted that previous attempts have been made to install an AD unit onsite; however there was difficulty at the time in finding a site that could feasibly house the technology.

For the purpose of this scenario analysis, it has been assumed that the AD facility would be situated at University owned Bardon Grange, a plant nursery (Figure 8) approximately 4 miles from the University refectory, in the suburb of Weetwood, with the transport route shown in Figure 9. This assumption has been made as the site has the space and land available to comfortably house an AD unit and store the digestate produced and will allow for calculations to be made regarding transport emissions which will feed into the scenario analysis. Bardon Grange is also in close proximity to the University sports fields where it has been assumed the digestate could be spread to replace the need for inorganic fertilisers. Furthermore, the bio-gas produced from the AD process could be used to heat the greenhouses on site.

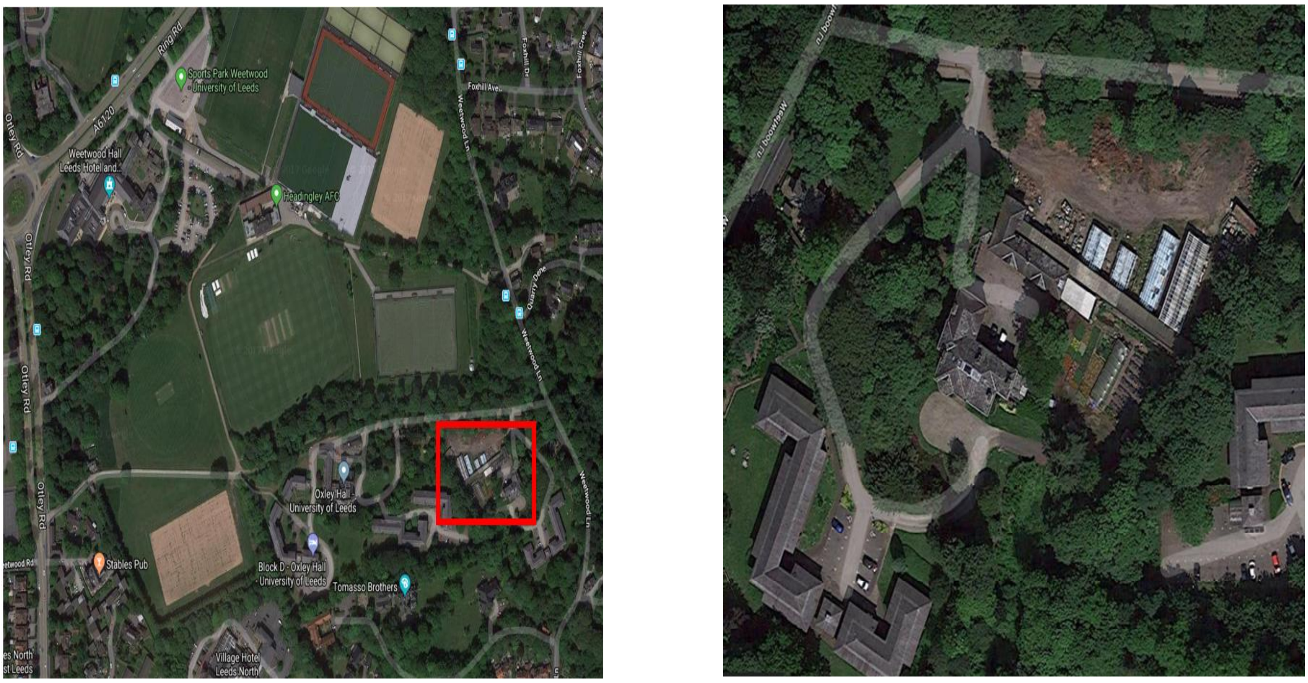

Figure 8 - Possible site for an anaerobic digester at Bardon Grange

Figure 9 - Possible transport route between UoL and Bardon Grange (Source: Google Maps).

Environmental Impacts

Transport emissions are estimated to be lower than those calculated for the BAU scenario due to the shorter distances incurred from using an onsite AD. Furthermore, as AD will produce a replacement to chemical fertiliser and compost, the University will no longer have to have this transported to site from an external producer, thus transport emissions are reduced here too. The digestate produced is also of environmental benefit as it does not involve harmful chemicals. Moreover, the vehicle that would be used for transporting the food waste from the University to Bardon Grange could potentially be converted so that it runs on used vegetable oil produced by the University. If there was a sufficient amount of waste vegetable oil produced by the University, this could greatly decrease transport emissions further (Altin et al., 2001).

In this scenario, all the energy generated by the AD can be used at the University for either heating water or for CHP. Therefore, avoiding GHG emissions associated with the production of electricity from the National Grid which often involves the burning of fossil fuels.

A key benefit to Scenario 2 is that there is potential to utilise the green waste generated on campus in the AD system through co-digestion with food waste. This should have environmental benefits as this waste stream is not being wasted or allowed to decompose on its own.

4.2.4 Scenario 3- Composting

The third scenario included in this report involves the use on a composting system to treat food waste. Food waste would need to be segregated at source so that non-organic wastes and packaging are removed and disposed of separately. In terms of plate waste from The Refectory, this could be conducted by kitchen staff, with food waste being added to a caddy before being taken to the onsite composter.

An example unit which the University could seek to implement would be the 'A1200 Rocket Composter' from Tidy Planet; this unit can process up to 3500 litres of food waste per week, making it suitable for processing all food waste generated each week on the University campus. Once the process is complete, organic compost can be taken out of the composter and can be placed into storage or transported directly to the site where it is to be spread.

Environmental

Transport emissions could be significantly reduced with composting, as waste could be managed on campus. Transport emission reductions would be approximately 6 tonnes of CO_2 a year when compared to the BAU scenario.

Composting would lead to increases in compost quality including an increased amount of nitrogen and phosphate produced, thus increasing GHGE savings from the substitution of chemical fertilisers. Moreover, composting results in an increased level of carbon sequestration when compared to AD, which improves the CO_2 mitigation potential of this scenario. This is likely to be most pronounced in the short term, as compost slowly releases CO_2 over the course of 100 years. Furthermore, high quality composting technology could improve the composting effectiveness of the green waste that is currently left to decompose on a compost heap at Bardon Grange.

4.2.5 Scenario 4- Desiccation and combustion with Veolia

Scenario 4 would be to buy a desiccator and put it on campus, to treat the FW produced, before collection, same as scenario 1. The desiccated waste would, however be transported to Veolia, an incineration plant around 4 miles away, for combustion, with the route shown in Figure 10. The heat produced from combustion would then be utilised for energy production (Veolia, 2017).

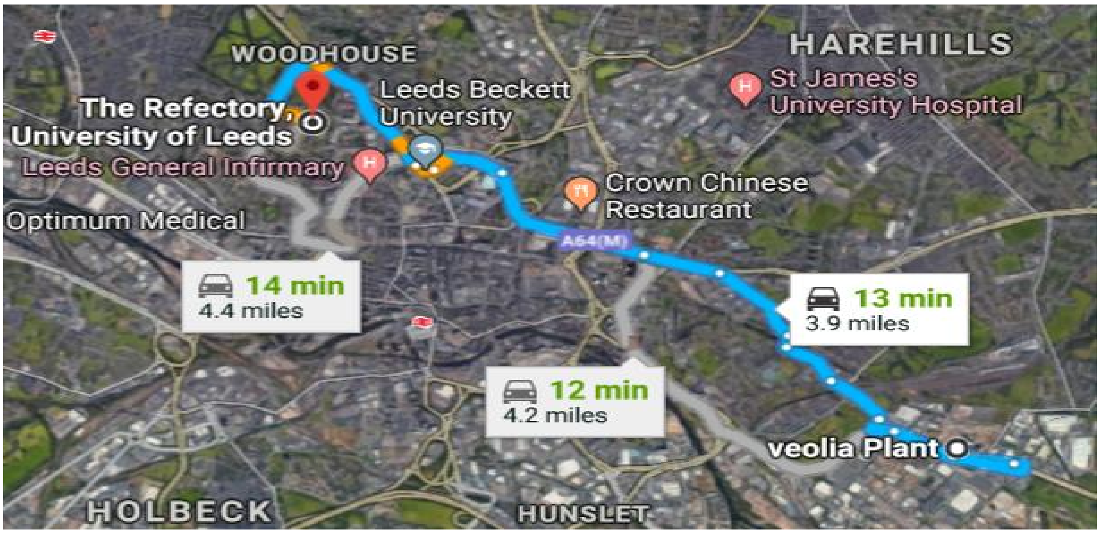

Figure 10- Possible transport route between UoL and Veolia (Source: Google Maps).

Environmental factors

Transport emissions would be significantly reduced, despite the use of less environmentally friendly collection trucks, as desiccation on site would greatly decrease the volume and mass of the food waste, reducing food waste collections by a factor of 5. Moreover, the transport distance is just over 4 miles, thus much shorter than BAU.

Another factor is that combustion produces more energy than AD, due to there being no parasitic load. This results in significant increases in GHGEs mitigated from the substitution of fossil fuel combustion.

On the other hand, combustion does not result in any carbon sequestration, as all of the carbon is burnt and primarily converted into CO2. Moreover, as Veolia incinerates a wide variety of different materials together, it is unlikely that ash could be used as a resource and would instead be more likely to be classed as hazardous waste, which would need to be carefully removed. This would result in further GHGEs from transport emissions, as the ash would likely be transported to a land fill site.

A further significant factor is that desiccation requires very large amounts of energy, which relate to exceedingly high GHGEs when using mains electricity. If the desiccators were to be powered by renewable energy, the GHGEs related to desiccation would be reduced dramatically, meaning that combustion would become a significantly more environmentally friendly option.

A further concern is that of air pollution. The nitrogen in the food waste would be converted into NO_x, the Sulphur converted into SO_x and particulate matter would also be produced, causing the problems mentioned in section 2.2. Furthermore, desiccation results in a great amount of water wastage and a major strain to waste water treatment, again mentioned in section 2.2.

5 Discussion

5.1 Food waste

Table 1 - Comparing the climate change mitigation potential of the different scenarios for food waste processing

Technology	BAU	Desiccation and Olleco	AD Bardon Grange	Combustion with desiccation	Composting
GHGEs production factors (tonne CO_2e/yr)[1]					
Transport emissions	5.96	0.93	5.10	0.70	0
Energy usage (treatment)	Parasitic load from AD	16.2 (mains) 0.14 (wind) (desiccation) and parasitic load from AD	Parasitic load from AD	16.2 (desiccation) (mains) 0.14 (wind)	Minimal-dependant on composting technique
GHGEs offsetting factors (tonne CO_2e/yr)[2]					
Energy produced	16.04	16.04	16.04	-23.39	0
Fertiliser produced	-1.85	-1.85	-1.85	N/A	-6.14
Carbon sequestered	Some, but unquantifiable	Some, but unquantifiable	Some, but unquantifiable	0	-3.99 (15.96 short term)
Total	-11.93	-0.68	-12.71	-6.49	-10.13

[1] Positive figures show Carbon released into the atmosphere
[2] Negative figures show carbon sequestered from the atmosphere

Table 1 shows that scenario 2 has the most climate change mitigation potential of all of the technologies. The emission savings compared to BAU result from reduced transport emissions. This is due to Bardon Grange being a shorter distance away. On the other hand, as Olleco collects food waste on route and food waste would be directly transported to Bardon Grange, these emission savings may be exaggerated. On the other hand, if the University powered the FW collection vehicle with waste vegetable oil (Altin et al., 2001), scenario 2 would have significant reductions in transport emissions, when compared to BAU. Moreover, reduced transport emissions from fertiliser transportation (Bardon Grange to adjacent Weetwood sports fields) would further increase the environmental performance compared to the other scenarios. The greatest opportunity for GHG mitigation regarding scenario 2 would come in the form of utilising grass waste for anaerobic digestion. This will be discussed in the proceeding section on green waste.

As table 1 shows, scenario 3 (composting) is less environmentally friendly, regarding GHGEs, than both BAU and scenario 2. This is as increased fertiliser production, carbon sequestration and reduced transport emissions are outweighed by the power generated by AD. Moreover, in reality the transport emissions of BAU and scenario 2 would be lower (due to reasons previously discussed). Furthermore, some carbon is sequestered with AD, meaning the scenarios using AD would, in reality, have further enhanced environmental mitigation scores. This would make scenario 3 even less competitive, when compared to the other scenarios, regarding GHGEs.

When observing table 1, scenario 1 cannot be justified environmentally, as GHGEs related to the power usage of desiccation massively outweighs any emissions offset by reduced transport emissions. Further to this, the other environmental issues related to water usage and dewatering at the University, only to add the water again at Olleco's AD plant for anaerobic digestion is a major environmental concern. Combustion is also another waste treatment technology that loses its' competitiveness regarding GHGEs, due to the massive GHGEs related to power usage from desiccation. Moreover, combustion has major environmental issues of air pollution, odour and the potential production of hazardous waste (ash). On the other hand, if the desiccator was to be powered by renewable energy, then desiccation could become environmentally viable, greatly increasing the environmental competitiveness of both scenario 1 and combustion. If desiccation was powered by a green grid, scenario 1 would decrease GHGEs attributed to food waste management by around 5 tonnes of CO2 per annum compared to BAU. Furthermore, combustion would decrease GHGEs by around 10 tonnes of CO2 per year. However, the other environmental issues would remain.

It can be seen therefore, that if environmental improvements were to be sought from BAU the only viable option to achieve this would be with scenario 2. Conversely, the environmental credentials of Olleco as a whole should be considered (see section 2.1.5). The environmental benefits of from mitigating water treatment issues from pouring used oil down the drain (Kulkarni and Dalai, 2006), from utilising by-products made from the biodiesel production (Ma and Hanna, 1999) and aversion of land use issues such as deforestation, fertiliser and pesticide use and food verses fuel conflicts related to bioenergy crops (Gui et al., 2008), should be considered. If food waste alone were to be considered, BAU appears already to be very environmentally friendly and little benefit environmentally could come about from setting up an anaerobic digester at Bardon Grange.

5.2 Green waste

Table 2 - Comparing the climate change mitigation potential of the different scenarios for green waste processing

Technology and resource	Wood- combustion	Grass- AD
Transport	0 added (wood already transported to Bardon Grange for composting)	0 added (grass already transported to Bardon Grange for composting)
Energy use	0 added (wood already chipped)	Parasitic load
Fertiliser	0.920	Reduced/lower quality fertiliser
Carbon sequestration	1.84 1.23	Reduced carbon sequestration
Energy produced	-10.10	-60.51
Total	-7.95	<-60.51

Table 2 shows that there is a massive environmental mitigation potential possible if green waste were to be processed in a different way from being decomposed and composted, as is the current practice. Combustion of wood could generate around 50 MWh of heat energy per annum. This is the equivalent of avoiding 10.10 tonnes of CO2 emissions per year, when replacing natural gas combustion (Carbon Independent, 2007). A biomass boiler could be bought and situated at Bardon Grange and used to partially heat the greenhouses there, as was suggested for the anaerobic digester. As composting would result in the sequestration of carbon and some fertilizer production, the enhanced mitigation figure is reduced slightly. With that being said, environmentally, it would be highly beneficial to combust the wood waste in a biomass boiler, as opposed to decomposition based composting. Moreover, it is likely that the ash left from the combusted wood could be added to compost, to increase mineral content, or used to amend acidic soil, assuming the heavy metal content is not too high (Vassilev et al., 2013). On the other hand, combustion of wood waste would lead to a significant amount of air pollution, including PM and NOx production, that could potentially negatively impact the health of the local population (Congialosi et al., 2007)

It is also shown on table x, the even greater enhanced environmental mitigation potential that is possible, if grass cuttings were to be anaerobically digested, as opposed to being composted through natural decomposition. If all of the grass could be successfully anaerobically digested, then over 300 MWh of heat energy could be produced per year. This is the equivalent of over 60 tonnes of CO_2 offset per annum when using a natural gas boiler (Carbon Independent, 2007). When compared to composting, less carbon is sequestered and a lower quality of fertilizer is produced (Wrap, 2016). With this being said, there would be very large amounts of GHGEs mitigated if grass cuttings were to be anaerobically digested at Bardon Grange, as opposed to being composted.

6) Conclusion

6.1 Key findings and recommendations for GHG mitigation

It seems apparent that BAU is particularly environmentally sustainable regarding food waste and Olleco. Typical issues of centralised waste management are not apparent, as transport emissions are low due to 'green' lorries and relatively small distances (20 miles). Moreover, fertiliser is sold to local farmers aiding local nutrient recycling. Furthermore, the previously discussed socio-environmental benefits of collecting used vegetable oil and converting it to biodiesel, whilst utilising the by-products produced adds further credit regarding sustainability.

Combustion, composting and desiccation with a continuation of the Olleco contract all performed less well environmentally than BAU, so can be disregarded. If a desiccator were to be powered by renewable energy, then scenario 1 and 4 could potentially perform better than BAU however and the enhanced environmental credentials of these scenarios should be re-examined. AD at Bardon Grange did perform better than BAU however. Regarding anaerobic digestion at Bardon Grange, the most significant opportunity to improve upon current practices comes from the anaerobic digestion of grass cuttings. This is partially due to the fact that composting through natural decomposition brings about much less environmental benefits than the operation run by Olleco treating food waste. The key reason however, is that, there is such a large quantity of grass cuttings produced on an annual basis, the amount of energy and fertiliser it is possible to produce from the grass waste at the University is a number of times higher than that of food waste. If possible therefore, the University should try to invest in a medium size anaerobic digester capable of processing a total of over 700 tonnes of biological waste (grass and food), when solely considering the environment in optimal waste management practice.

It is clear that there would be environmental benefits regarding GHG mitigation if the waste wood generated by the University were to be combusted in a biomass boiler, as opposed to being composted. To increase environmental mitigation, a biomass boiler capable of processing 10 tonnes of wood per annum should be bought and installed in Bardon grange, so that it can partially heat the greenhouses located there.

Behavioural change is another key area where environmental mitigation could be achieved. As mentioned in section 4.1.6, efforts should be made to increase segregation in the halls of residences on campus. Money should be provided, so that residences can buy food waste bins for the kitchen of each apartment in Charles Morris residences as well as Henry Price Residences. The cleaning contract should also be amended, so that cleaners collect food waste from kitchens also. Furthermore, efforts should be made, such as university-wide behavioural change campaigns to decrease food waste production, as enormous GHGE savings could be made in this area (Garnett, 2011).

Other potential areas regarding food, where environmental impacts can be mitigated include having only locally sourced food products on campus. Moreover, efforts could be made to reduce the sale and student consumption of meat and animal derived food products, in particular red meats (Tobler et al., 2011). Also, retaining carbon rich trees on University grounds and increasing tree planting could further improve climate mitigation at the University of Leeds (Johnson and Coburn, 2010).

6.2 Limitations and further research

There were a number of challenges with this research project and subsequent limitations. Perhaps the most notable issue was that of that of limited data. Total food waste production figures for the refectory and campus cafeterias was only available for the months of July, August and September, meaning that an accurate annual food waste production total was not possible to attain. Moreover, there were no recorded figures for green waste production, thus figures used were vague estimates. Further to this, most environmental calculations were estimates based on figures from the literature, as laboratory research could only be carried out for anaerobic digestion, due to time constrains and not having the equipment available.

Due to the numerous limitations with this research project, a full scale LCA should be carried out. This would ideally be a PhD project, gaining data over the course of a number of years. Food waste production data could be collected over a longer time-scale to gain a better idea of annual waste production and seasonality. Efforts could also be made to better quantify green waste production, composition and the environmental credentials of the current natural decomposition composting practice. Furthermore, composters already present in the sustainable gardens could be used to test the Universities food waste, with the results being assessed to make more accurate environmental calculations. Average quantity of compost produced from a set weight of food waste could be ascertained, as well as the nutrient and carbon content of the compost. Further to this, the University has a pilot scale AD in storage. If a site for this could be located for this unit, research could be carried out to better attain the environmental performance of AD and the feasibility of processing both the University's food and grass waste. Figures regarding energy production and nutrient and carbon content of the digestate produced from the anaerobic digestion of the University's food and grass waste should be researched. Moreover, a small-scale desiccator could be bought, to assess the environmental credentials of the technology. This would include average power usage, water waste, and mass loss of the food and composition of desiccated food. The desiccated food could also be tested for its' qualities as a fertiliser and as animal feed. The environmental credentials of these two applications for desiccated food could then be included in the LCA, as two further scenarios.

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