Biomass Assessments for Local Planning Authorities – A Case Study with Leeds City Council

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In the current global climate, it is important for local planning authorities to try to incorporate locally produced bioenergy into their development plans. Before this can be done, the biomass available must be assessed. This study quantified varying waste biomasses available to the Leeds City Council, as well as the future potential of these resources. A hierarchy of biomass quantification techniques was created in order to do this, with the aim of producing a methodology that other local councils can follow in their own biomass assessments, regardless of the extent of their knowledge base. The technique was successfully applied to Leeds City region, giving an annual current biomass potential of $(55\pm8)\times10^3$ tonnes per annum, equivalent to $(19\pm7)\times10^7$ MJ/year, with a potential future annual mass and energy of $(90\pm9)\times10^5$ tonnes and $(20\pm5)\times10^9$ MJ/year.

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1. Introduction

In order to try to encourage the uptake of renewable energy resources and reduce our global carbon dioxide (CO_2) emissions, the European Union and UK government have employed a large number of policies and directives. Currently, fossil fuels are heavily depended upon by the global energy market. These sources are not considered renewable because they take millions of years to form, and so are finite (Roberts et al., 2015). On top of this, these resources contribute to global warming by releasing vast quantities of CO_2 into the atmosphere. Clean, renewable sources of energy are required to combat these issues, and energy from biomass (bioenergy) is becoming a very important part of the solution (Duku et al., 2011).

Biomass is a term which refers to all biological material originating from living, or recently living, organisms (Roberts et al., 2015). If sourced sustainably, biomass is a renewable carbon neutral fuel, and could therefore make a contribution toward the imposed targets. Biomass is also an ideal fuel for many purposes because of the control over the energy production; it can provide a flow that continually matches the need, with more predictability than many other renewable sources (DECC, 2012).

The uptake of locally-sourced biomass for energy purposes also has additional benefits for small regions such as Local Councils. Lower reliance on externally-sourced forms of energy helps to promote autonomy for Local Councils, giving them more control and prediction over their energy supply, while fossil fuels become increasingly unreliable energy sources (Council, 2010). The utilisation of biomass could give economic savings too, given that it is more cost effective than many other sources, and that the price of fossil fuels is predicted to rise in the future; this would likely cause an increase in the cost of externally sourced renewable energy with it (Roberts et al., 2015). The abovementioned benefits will be even greater with the uptake of waste biomass as an energy source, as the landfill tax would also be minimised (Gronowska et al., 2009). With a well-thought-out plan for the utilisation of biomass within a Council, a more efficient, more holistic approach to the running of Council services can be achieved.

One way of increasing renewable energy usage is by using suitable waste for energy instead of sending it to landfill. Defra (2011) estimated that 3% of all direct UK emissions arise from the waste sector, and so if the material is instead used to recover energy this not only displaces the use of fossil fuels, but also prevents the production of methane that would occur should the material degrade in landfill (Entec, 2011). In 2008, the EU Waste Framework Directive (Union, 2008) gave a framework for the recovery and disposal of waste. This framework sets out a hierarchy of methods for dealing with waste. Firstly it encourages the prevention of the production of waste. Secondly it values the recovery of waste via reuse, and thirdly via recycling. In this context, recycling is the reprocessing of the waste into the same product, or another product (Northwoods, 2008). It places other forms of recovery fourth, which includes energy recovery of the waste. This waste hierarchy acts as a guide to the most sustainable waste management routes as, in general, smaller greenhouse gas impacts occur higher up the hierarchy (Defra, 2011).

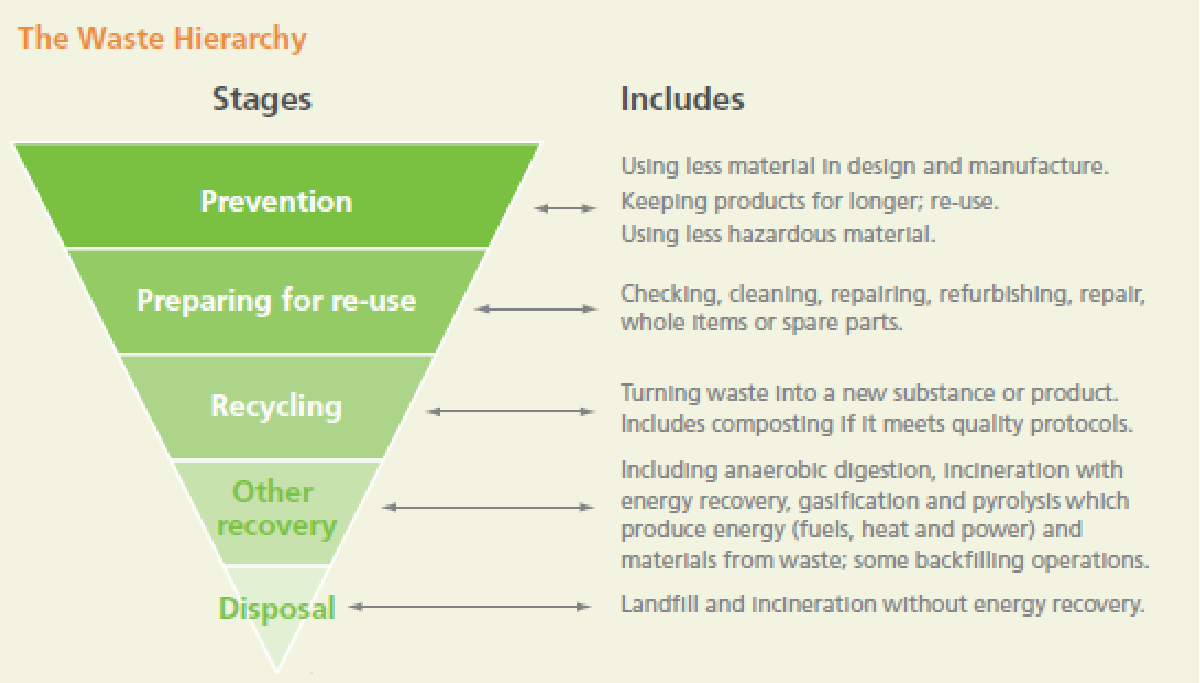

Figure 1. The Waste Hierarchy. Source: Defra (2011)

Before a region can plan to increase its production of bioenergy, it must first have an understanding of the available biomass resource to inform both technology choices and economic decisions (SQWenergy, 2010). A lack of data on waste arisings will cause difficulties determining the appropriate waste infrastructure for a particular region, leading to failures meeting local needs (Defra, 2011).

Local renewable energy planning has been encouraged by a number of Policy Planning Statements. Policy Planning 1: Delivering Sustainable Development (2005) laid the framework for Local Planning Authorities to incorporate sustainability into their planning systems (Council, 2010), while the Supplement to this document established a requirement for Local Planning Authorities to plan for decentralised, locally generated renewable or low carbon energy. An important part of this supplement was the requirement for Local Planning Authorities to have a solid evidence base to inform these policies (Entec, 2011).

The Leeds County Council (LCC), which is the Local Planning Authority for the city of Leeds in West Yorkshire, feels such pressures to incorporate locally sourced renewable energy into the area. Currently, the city is highly reliant on energy sourced from areas outside of Leeds, most of which is derived from fossil fuels, and so a lot of assessment and planning for new infrastructure will be required (Council, 2010).

LCC have done a preliminary assessment of the resources available within the Council domain They have identified various sustainable sources of biomass from management of their substantial woodland and tree stock, as well as major opportunities from the vast quantities of waste materials that are produced by the city. LCC have subsequently decided that some of the main options for increasing use of renewables include small scale biomass and organic waste usage (Council, 2010).

Section 2 will review the types of biomass available to LCC, and analyse the current literature that focuses on biomass resource assessments. Section 3 will outline the method used in this paper to quantify the biomass and energy potential available to LCC and section 4 will present the results from the study. Section 5 will discuss these results and section 6 will conclude the study.

2. Literature Review

2.1. Types of Biomass

According to Meehan and McDonnell (2010), there are two main types of biomass; purpose-grown biomass and residual biomass. Purpose-grown biomass includes energy crops and other biomass which is grown solely for the production of energy, while residual biomass is any biomass that is a by-product of another process (Bowers et al., 2006). This study will only be considering residual biomass resources; those that would otherwise be considered a waste product. There is a very wide range of waste resources that are classed as biomass, and those that LCC would like to incorporate into their development plans are discussed below.

Wood is an invaluable biomass resource, but there is much room for improvement for waste wood utilisation in the UK, particularly within the construction and demolition (C&D) industries (Hobbs, 2003). It was estimated that in 2010 approximately 2.1 million tonnes of C&D waste wood was produced in the UK (WRAP, 2011), with much of it going to landfill because it is overlooked as a potential energy resource. This is also the case in Leeds, where LCC produces large volumes of C&D waste wood from its council construction projects. Despite its potential, there are logistical and financial difficulties with extracting it from the mixed waste stream in which it is usually found (Thornley et al., 2009). A major factor is also the fact that most of this waste wood is contaminated with substances that make its use as a biofuel difficult (Northwoods, 2008, ReNU, 2009). This could be chemicals added to the wood, which become hazardous on combustion, or non-combustible contaminants such as nails and grit, which can damage biomass facilities (WRAP, 2011). However, with 19.3% of construction waste wood being timber in the UK (Research, 2005), the incentive is great to ensure that the maximum possible amount of wood is saved from landfill. Currently, about 50% of the waste wood that cannot be reused for other construction work is recycled (SQWenergy, 2010), for example, in particleboard construction, animal bedding, or horticulture (Research, 2005). These uses are in line with the waste hierarchy, but the wood not suitable for these uses could be diverted from landfill if they were instead used for bioenergy. It should be noted, however, that due to the need to restrict airborne emissions and pollution, such as heavy metals and halogens, most C&D waste wood must be converted at suitably engineered facilities, which are usually of a larger size.

Another major source of potential wood biomass comes from the management of trees. This can include woodland and forestry management residues, as well as those from the management of public roadside trees (arboriculture). Thornley et al. (2009) estimates that 341,000 tonnes of wood arisings from roadside arboricultural management are produced each year in urban areas of the UK, which is a quantity similar to that from forestry residues. LCC has a large stock of trees which have to be managed, producing a lot of wood. This potential source of biomass should therefore not be overlooked.

Over the last 20 years, grass has become increasingly considered as a potential biomass resource in Europe (e.g. Murphy and Power (2009)), and as grasslands in public areas of the Leeds area are actively managed by LCC, there is much potential to utilise this resource for energy. These areas also usually have shrubbery or hedges associated with them, which also provide a potential bioenergy resource.

The Government is encouraging local authorities such as LCC to manage their food waste in a more sustainable manner (Defra, 2011). This is because food waste is a major waste stream: Defra (2011) estimated that 16 million tonnes of food waste is produced in Britain each year, with at least 40% of this going to landfill. The potential for LCC to utilise this resource for bioenergy production is vast. Another waste suitable for anaerobic digestion is animal manure. LCC owns a farm in the Leeds area called Home Farm, and so this represents a convenient animal waste production site. The treatment of these wastes in this manner eliminates odour and produces biogas, which can be used to provide heat and electricity. The by-product is a high quality fertiliser which the farmer can then use instead of artificial fertiliser, thus enabling anaerobic digestion to be high up in the waste hierarchy (Steubing et al., 2010).

2.2. Biomass Analyses

As discussed in the introduction, Local Councils need detailed information concerning the quantity of biomass available to them before they can incorporate bioenergy production into their development plans (Rosillo-Calle, 2007). The quantification of biomass is a complex topic, requiring large amounts of data collection and processing, and usually involving the employment of many approximations (Maithel, 2009). There are many different approaches one can take that have been demonstrated in previous studies, which will be discussed in the following sections.

2.2.1. Image-based Analysis

Many studies assessing biomass utilise mapping software in order to estimate the ground coverage of a particular biomass resource. For example, Van Meerbeek et al. (2015) utilised a Geographic Information System (GIS) to assess the regional non-woody biomass potential associated with the roadsides and conservation areas in Flanders, Belgium. Oettli (2004) also used a GIS-based method, in combination with wood production rate data, to estimate the amount of wood sustainably available within Switzerland. Dagnall et al. (2000) discussed the possibility of using GIS software to map the distribution of animal manure wastes available to regions of the UK for the consideration of bioenergy schemes. However, these studies were done on much larger scales than at the level required for LCC, and so would be less easily applied to this project.

2.2.2. Literature-based Analysis

A vast number of studies that use only secondary sources of information have been carried out in recent years. These papers utilise the results of other studies, in combination with sensible assumptions, to estimate quantities of biomass resources. Meehan and McDonnell (2010) used existing data on land coverage, in combination with assumptions about potential yields and calorific values of biomasses, to estimate the quantity and energy value of biomass available within a 75km radius of Dublin. Duku et al. (2011) conducted an assessment of the biomass resources available in Ghana from forest residues, urban wastes and animal wastes. Although not very geographically relevant, the paper is a good example of a waste biomass assessment, and how important it is to make thorough assessments of the potential in a region before any changes are implemented. This is also the case for Roberts et al. (2015), who assessed the residual biomass available in a small region of Argentina. The residues studied included those from garden maintenance and the trimming of urban trees. Walsh (2008) assessed the forestry residues and urban wood wastes in the U.S. at the county level from national data. Despite the study using U.S. statistics less applicable to the UK, this is a good example of using broader datasets, which are more commonly available, along with assumptions, to get estimates for a smaller region.

There have been various studies that have identified waste wood arisings data. For example Research (2005) quantified arisings for all waste streams within the UK, critically analysing them and using the most reliable sources to quantify what currently happens to the wood waste. Northwoods (2008) quantified wood waste arisings in the North East of the UK, an area geographically and culturally similar to Leeds. They studied various waste wood sources, namely household municipal, C&D and Commercial and Industry (C&I) wastes. They used existing literature to quantify this waste, choosing reliable sources such as the Department of Environment and Rural Affairs (Defra), and the Waste and Resources Action Programme (WRAP). Council (2008) collected data to quantify each of the waste streams within Leeds. This is the closest study to the current paper, and demonstrates some useful methods for estimating various forms of wastes. Sometimes the quantifications were directly accessible, while other times assumptions and calculations were required to estimate the quantities.

2.2.3. Direct contact Analysis

Some quantification studies gather primary information by direct contact with people who are involved closely with the particular biomass resource under consideration. Usually this is people who work to collect the biomass, and the contact could take many different forms such as questionnaires or interviews for example. A recent study that solely used this method of investigation was ReNU (2009), which used telephone questionnaires to quantify the amount of clean waste available in the city of Nottingham from arboricultural, tree surgery and landscaping. Local businesses dealing in these trades were targeted. This is a good example of an appropriate method being used for the number of organisations being questioned, as many other deeper forms of investigation would be too time consuming on such a large scale.

2.2.4. Combined Methods

Many studies use a combination of techniques in order to quantify the biomass in an area. Steubing et al. (2010) assessed the current and future potential biomass available in Switzerland using a combination of expert interviews and literature analyses. A report that is more similar to the present study in terms of location is Entec (2011), which used a combination of direct contact and literature values. It assessed the biomass quantities available to Gloucester County Council from woodland management residues, C&D waste wood, animal manures, and park and gardens management.

Frear (2005) outlined a methodology for quantifying the biomass within Washington State which is equally applicable to small areas of the UK such as Leeds. First, statistics and databases concerning the relevant biomasses were consulted, along with personal interviews with biomass processing leaders, to collate a biomass inventory. The potential energy production was then calculated for the woody matter by determining heat value coefficients, and using these to calculate electrical energy and power at a conversion efficiency of 20%. The wet biomasses were converted into volatile solids, and the potential methane production from anaerobic digestion calculated. From this, the potential electrical energy output was calculated, assuming a 30% efficiency of conversion. This technique is very simple to employ, making it an attractive approach.

Another report, one that is more similar to the present study in terms of scope, is Council (2013). This report consisted of a renewable energy assessment conducted as part of the plan for a new Local Development Framework for Cornwall Council. It included quantifications of various biomasses including forestry residue, waste wood and livestock slurry. Forestry residue was quantified using GIS mapping, while the waste wood and livestock slurry were quantified using existing data and assumptions provided in previous literature. Separate methodologies were given for the different types of wastes, which will be discussed later. However, the use of GIS mapping was more applicable to Cornwall County Council because of the vast land area under consideration. The technique would therefore be less easily applied to the case of LCC.

Another relevant Council study previously done is presented in Ward (2003). This study is in some ways even more relevant because it is a City Council like LCC, rather than a County Council like Cornwall. The biomasses they quantified were from woodland thinnings, arboricultural residues and untreated recycled waste wood. This study utilised interviews, telephone consultations and email discussions with specific relevant people working in the waste management area to quantify some of these waste streams. For the remainder they employed telephone surveys for the large numbers of companies that were producing this waste. Throughout this study, the results of previous literature were employed in order to make assumptions for the information the two previous techniques were unable to find. This method shows that many possible techniques can be combined in a single study order to attain the highest possible amount of data. It also demonstrates the importance of using the correct investigative technique for a given question, in order to get the best results.

SQWenergy (2010) is an energy capacity methodology for the English regions, and sets out a very detailed process to follow in the assessment of many types of biomass resources and their potential energy value. The methodology mainly relies on using literature data values, with some mapping and direct contact with relevant experts. The details of the methodology will be discussed for different types of feedstock, will be discussed in the biomass quantification techniques section below.

2.3. Biomass Quantification Techniques

Specific techniques employed by the different types of studies previously mentioned will now be discussed.

2.3.1. Image-based Analysis

(Das, 2007) outlines a range of remote sensing techniques, including photographic imaging, satellite imaging, radio detection and ranging (RADAR) and light detection and ranging (LIDAR). Aerial photography is suitable for mid-range woodland (few hundred to a few thousand hectares), but can be costly for small-scale projects (Das, 2007). Some image- based methods are able to see to a higher definition than this, but they are even more expensive (Lu, 2006).

Maithel (2009) gives a convenient methodology for the estimation of tree yields. First, one prepares maps that display the extent of the biomass ground cover. This could be satellite imagery or aerial photography. One then uses field data to estimate the sustainable yield per hectare for the particular plant under consideration. Finally, the total sustainable yield for the area is calculated as the product of the previous two quantities. This general technique was followed in Entec (2011), which mapped the distribution of woodlands in Gloucestershire, and then used the Forestry Commission's harvest rate of 4.5 m^3/ha to calculate the potential biomass yield.

Council (2013) used the same technique, but used a value of 2 dry tonnes equivalent yield per hectare per year in their estimations, regardless of the type or size of woodland they were studying. These techniques are useful even if image analysis is not feasible, because the sustainable production rates can be applied to LCC woodland without any need for imaging, provided the area of woodland coverage is known.

Conclusion

Image-based methods are most suited to the quantification of live plant-based biomass, so would only be considered for the tree-based biomass sources studied in this paper. However, it should be noted that due to the high error associated with the image analysis and the assumption of a sustainable yield, the method would become progressively less reliable as the area considered decreases. It is only the ideal choice of method when one is considering vast swathes of fairly homogeneous biomass, which is not the case for most Local Council woodland, including that of LCC. The small sizes of the LCC woodlands would also require these highest resolution techniques, and therefore be costly. However, as discussed previously, the sustainable yields can still be calculated using this information if the area of woodland is known.

2.3.2. Literature-based Analysis

Woodland and Arboricultural Residues

Council (2013) sets out a simple guideline for the assessment of forestry residue:

1. Identify areas of woodland
2. Identify yield per hectare
3. Remove areas considered too small
4. Identify collection boundaries
5. Convert total tonne yield into energy

This is a good guideline to follow in the assessment of woodland resources if estimations from direct contact or databases are not possible. This general technique is also suggested in SQWenergy (2010) in its methodology for the quantification of woodland management residues (often referred to in literature as the DECC methodology). They suggest using the Forestry Commission Research tool to get an estimate of the sustainable yield per hectare, as Entec (2011) did for their mapped woodland.

In order to calculate the energy content of woodland and arboricultural arisings, the individual properties of the different tree species need to be taken into consideration. To get a good estimate, one can simplify the trees into broadleaf (hardwood) and coniferous (softwood). Commission (2014) states that, on average in the UK, the woodland and forest population consists of 65% hardwood and 35% softwood. These proportions can be applied to the forestry and arboricultural arisings when estimating values.

Ward (2003) states that a key aspect of the quality of different forms of wood comes from the moisture content. This is because it affects the useful energy content per unit mass. When burnt, the water not only contributes nothing to the energy content, but also uses some of the useful energy in order to evaporate during combustion. Heating values which take this factor into consideration are called lower heating values, while those that don’t are called higher heating values. According to Centre (2011), the moisture content of hardwood is about 50% of total wet weight, while that of softwood is 55%.

If a quantification of biomass is given as a volume, one has to know what the density is in order to estimate a mass value for this biomass. Different types of wood have different densities, and so these values will always have a large uncertainty. Hogan (2011) gives the densities of softwood and hardwood at different moisture contents, so that the density of the wood on collection can be calculated for the proportions of softwood and hardwood, assuming the green moisture contents given above. This gives a value of 949 kg/m^3, from which the mass can be calculated. Hogan (2011) also gives the energy density of hardwood and softwood for varying moisture contents, so the energy density of the wood on collection can be calculated for the proportions of softwood and hardwood, at the green moisture contents discussed above. This gives an energy content of 7.625 GJ/m^3, or 8.03 MJ/kg. This can be used to calculate the total energy content of the arisings.

C&D and Household Waste Wood

Council (2013) set out a simple guideline for the assessment of waste wood:

1. Identify evidence of availability
2. Identify waste streams containing wood
3. Calculate proportion of wood for each waste stream
4. Compare with other evidence
5. Identify energy content
6. Convert total tonne yield into energy

This is a good general guideline to follow in the assessment of waste woods such as C&D and household municipal waste woods if only secondary sources are available.

Because most C&D wood waste enters the general C&D waste stream (Poyry, 2009), it is important to know what proportion of total C&D waste consists of wood. In order to try to quantify the composition of construction waste in the UK, Research (2005) studied the waste output from 11 large construction projects. They found that on average 25.77% of the composition was wood waste. In a different study, Hobbs (2003) calculated that 17.3% of the total waste produced was timber. This indicates that wood waste consists of mostly timber, along with other forms of wood. It is reasonable to assume that this proportion also applies to household wood waste (Walsh, 2008).

SQWenergy (2010)'s methodology for the quantification of waste wood starts by suggesting the use of national level data for C&D wood waste arisings and assuming a value in proportion for the local housing allocation rate. A similar but slightly different approach was adopted by Entec (2011), which used data published for the South West region on C&D for waste wood quantities, and assumed the quantity in Gloucestershire was proportional to the population. This technique was also employed by Walsh (2008) for both the C&D and the household waste woods. This U.S. study used national data from Falk (2004) for the quantity of both C&D and household municipal wood wastes, and, by assuming that waste wood production is proportional to the population for each region, calculated the quantity of wood waste for that region. Estimations of the quantity of C&D waste have already been completed for the Leeds area. Council (2008) used existing data obtained by Defra (2005) that gave the total amount of waste produced in the Yorkshire and the Humber region. They assumed that the quantity of waste produced is proportional to the construction industry employment rate. They used the ratio between the total Yorkshire and the Humber construction industry employment, and Leeds construction industry employment, to estimate the quantity of waste produced in Leeds to be 1,405,086 tonnes. Although this paper also quantified the municipal solid waste collected by LCC, it did not separately quantify the waste wood content or proportion.

It is also important to estimate how much of this waste wood would be available for bioenergy purposes. To do this, one must first know what the current waste management routes for the waste wood are, and then what proportion of these routes lie on the same level as, or below, the position of bioenergy in the waste hierarchy. Research (2005) categorised the different waste management routes taken for construction waste wood for the year 2001. Table 1 displays these results.

Feedstock	Recycled into production	Re-used internally	Burnt to dispose	Burnt to heat	Recycling Firms	Landfill	Total
Construction	132323	127893	130370	6791	127768	314234	839379

Table 1. Tonnes of wood waste produced by construction in 2001 and the different waste management routes taken. Adapted from Research (2005)

Assuming that re-use and recycling are more valuable destinations than bioenergy, and that landfill and burning are all available for bioenergy, the proportion of construction waste wood in the UK available for bioenergy is 54%, a value that would be applicable to household waste wood too. This value is very close to those of SQWenergy (2010), which suggested that 50% of the wood is of high enough value to be reused or recycled (so not available for bioenergy). Walsh (2008) estimated that the total quantity of waste wood that was too contaminated for reuse for bioenergy was 50%. If these two statistics are combined, this leaves an estimated 25% of total C&D and household waste wood available for bioenergy, assuming that an even proportion of the contaminated wood can be reused or recycled.

In order to estimate the energy potential of the waste wood, one must account for its moisture content. Entec (2011) used a 20% moisture content. This choice of moisture content is corroborated by a range of studies (e.g. Frear (2005), Meehan and McDonnell (2010) and Walsh (2008)). If one uses the dataset provided in Hogan (2011), then it is possible to estimate the energy content of the waste on collection at

20% moisture. If the waste wood is assumed to have equal proportions of hardwood and softwood, then one gets a value of 8.2 GJ/m^3 (14.7MJ/kg).

Green Waste

For park and gardens arisings quantification, Entec (2011) used national statistics for arboriculture under the assumption that this source makes up the majority of these arisings. Only national data was available, so they took the arisings for Gloucestershire to be proportional to the population size. To account for this assumption, they allowed a larger margin for error. The composition of this grass and parkland waste will be composed of wood, leaves and grass. The wood element energy content can be estimated using the same methodology as the woodland and arboricultural arising. Chen (2003) outlines a convenient methodology to calculate the energy content of lawn clippings and leaves, using data from other sources. They use the wet basis (w.b.) moisture content of the waste in combination with the percentage volatile solids of dry waste and the methane yield per mass of volatile solids to calculate the total methane production potential. The values they used are given in table 2.

Feedstock	Moisture content (w.b.)	Volatile solids (% of total solids)	Methane Yield (m^3/kgVS)
Lawn clippings	77%	88.1	0.209
Leaves	30%	88.1	0.123

Table 2. Moisture content, volatile solids percentage, and methane yield for green wastes. (Chen, 2003)

Farm Waste

Council (2013) set out a simple guideline for the assessment of livestock slurry:

1. Identify key slurry producers and determine average daily slurry production
2. Convert the total output into gross and net energy generation capacity
3. Remove proportion that is used for competing uses
4. Convert total installed capacity into annual generation

SQWenergy (2010) provides a more detailed approach that follows the same principles. First, the existing manure and slurry quantity (including bedding) was estimated by using data on the number of livestock and multiplying this by a manure and bedding factor (quantity of manure produced and bedding used per head per day). The methodology then provides values of the biogas yields for cattle and pigs of 25 m^3/tonne and 26 m^3/tonne respectively. It states that all manure biogas has approximately the same calorific value of 20 MJ/m^3. It also suggests applying an average conversion for electrical output of 0.000027 MW/tonne wet organic waste to calculate the potential power output. The DECC methodology in SQWenergy (2010) also has an assessment method for poultry litter. It suggests using data on poultry numbers, and excreta factors from Defra, to calculate the total litter produced per year. It then gives a potential annual power output of 0.0009 MW/tonne wet organic waste, and assumes that 100% of the waste is collectable.

Entec (2011) used this DECC methodology for wet biomass to calculate the manure available in Gloucestershire. The conversion values which they used were discerned and are summarised in table 3.

Feedstock	Arisings per animal (tonnes per year)	Biogas potential (m^3/tonne)	Energy content (MWh/tonne)
Cattle	18.216	20	0.111111111
Pigs	5.481481481	20.06756757	0.111486486
Poultry	0.036567528	N/A	3.744

Table 3. Manure production per animal, biogas potential per tonne and energy content per tonne for various livestock. Based on data from Entec (2011).

A reliable, UK-based source that gives manure production rates for various animals is Dagnall (1995). In this paper the livestock populations, related dry manure wastes produced, and resultant methane potentials were outlined for the UK. Many assumptions were made in the calculations, but these were all detailed in a way that allows extrapolation of the raw production values. These are given in table 4.

Feedstock	Dry Weight of waste per head (tDS/d)	Potential methane per tonne (m^3/tonne)	Potential new electrical energy per tonne (MW/tonne)	Potential annual energy output per tonne (GWh/tonne/yr)
Cattle	0.004672131	200	0.025017544	0.219017544
Pigs	5.06329E-05	2000	0.2475	2.19
Poultry	4.03226E-05[a]	200	0.025	0.219

[a] waste consisting of 70% poultry manure, 30% litter

Table 4. Manure production, methane yield and energy production values for various livestock. Based on data from Dagnall (1995).

A slightly different approach wass presented in (Frear, 2005). Firstly, they presented average production values per day for cattle, calves, pigs and chickens. These are given in table 5, with the values converted into appropriate units.

Feedstock	Production of dry manure per animal (kg/head/day)
Cattle	25.18
Cattle calves	0.63
Pigs	0.41
Chicken broiler	0.16
Chicken layer	0.24

Table 5. Production of dry manure for various livestock. Based on data presented in Frear (2005)

They then converted this into percentage volatile solid content and from this they calculated the methane yield. All of this was done using conversion values taken from literature. The conversion values used within the report, along with the references for each, are represented in table 6 below. This source is a government sponsored report written by members of Washington University, so although (due to differing husbandry practises) the production rates may be slightly different for a small farm in the Leeds area, the values of volatile solids proportion and methane yield are still reliable. The fact that the results are presented as volatile solids rather than being converted straight into a methane production is advantageous because it allows the calculation of methane productions for anaerobic digesters of varying efficiency.

Feedstock	Volatile solids contents (% total solids)	Methane Yield (m^3/kg VS)
Dairy manure	83%	0.21
Cattle manure	85%	0.21
Pig manure	78%	0.33
Poultry manure	76%	0.33

Table 6. Volatile solid contents and methane yields for various livestock manures. (Frear, 2005)

SQWenergy (2010) suggest an 80% collection efficiency as a reasonable assumption, but Entec (2011) instead just added the caveat that only a small proportion of this manure value would actually be collectable due to many animals being kept in outside conditions. This indicates that they believe a much smaller proportion is collectable than SQWenergy (2010). The collectability depends so heavily on the husbandry practices that it is a difficult variable for which to quantify an average value.

It is also useful to quantify the energy content per unit mass of the farm wastes that would be suitable for combustion. Defra (2008) gives energy contents of poultry litter and straw in their report, which they state are more suitable for combustion than anaerobic digestion. These are given in table 7.

Feedstock	Dry Energy Content (MJ/kg)
Poultry litter	13.5
Straw	14.8

Table 7. Energy contents of poultry litter and straw (Defra, 2008)

However, should there be mixed straw and manure, then the proportions of each can be ascertained, and the respective methane potentials summed to give an estimation of the total quantity of methane produced by anaerobic digestion of the waste. The manure methane potential values outlined in table 6 could be used for the animal manure portion. For the straw portion, Moller et al. (2004) calculated a moisture value of 9.46%, a percentage volatile solids value of 84%, and subsequent methane yield of 0.145 m^3/kgVS.

Food Waste

For food waste, SQWenergy (2010) give a DECC methodology. This methodology outlines the following steps for food production assessment: First estimate the food waste production using data from Defra and the Food and Drink Federation. It suggests that an 80% collection efficiency and 50% resource availability (due to competing uses) are reasonable assumptions. The methodology then provides values of the biogas yields for food and drinks of 46 m^3/tonne. To calculate the potential power production, the methodology suggests applying an average conversion for electrical output of 0.000027MW/tonne wet organic waste.

Frear (2005) calculated the food waste available for use as biomass in Washington state using a simple methodology similar to the DECC methodology. Data for the quantity of municipally collected food waste in the state was used, along with various conversion factors taken from other literature, to calculate the potential methane production from food waste. A food moisture content of 80% was used in conjunction with a percentage volatile solids value of 90% and a methane yield of 0.54 m^3/kg to calculate a total methane yield.

This Frear (2005) method works very smoothly once one has a value for the mass of waste food. Assuming that the food wastes produced in the UK are similar in nature to the USA, this is an appropriate method to use in the calculation of the potential energy yield from the utilisation of waste food.

Conclusion

There are a wide range of literature based methods, covering all of the feedstocks assessed in this paper. With well-placed assumptions and reliable data, some examples are the most accurate estimations of the quantity and energy of biomass possible with the available information.

2.3.3. Direct contact Analysis

Many previous biomass quantification studies employed primary investigation methods such as interviews, questionnaires and surveys. ReNU (2009) identified potential sources of clean waste wood, and attempted to contact them. The successful attempts (65% response rate) were then questioned via a comprehensive telephone survey. They then analysed the results and assumed these responses were representative of all potential sources. Ward (2003) also chose to do a telephone survey because, once again, a large number of people/companies were being asked the same questions in order to sum each particular biomasses type available. Steubing et al. (2010), however, chose the method of interviewing experts within the field to give information of certain biomass resources. Frear (2005) also used interviews to develop their biomass inventory. They conducted personal interviews with agriculture and processing leaders in order to quantify the types of biomass involved in the study. From these studies, it seems clear that if one wants to get an idea of the biomass quantity available from many separate sources so that an estimation of the total potential for a specific biomass resource can be calculated, then a broader, shallower method such as a telephone questionnaire should be employed. If, however, one wants specific information for the quantity of a particular biomass one should chose a narrower but deeper form of investigation such as an interview with an expert in the field. The latter is the case for the current paper. Unfortunately, the details concerning the specific types of interviews employed by these studies are sparse, but there is much literature which discusses the merits of different types of interviews (e.g. Drever (1995)).

2.4. Conclusion

From an analysis of various different biomass quantification methods, one can see that there are a wide variety of methods, each with advantages and disadvantages. Generally, those which are most explicit and make the fewest assumptions, particularly with regard to technology conversions for energy calculations, are favoured because they are the most versatile. Those results with a clear similarity to the present study are also favoured.

3. Aims

It would appear that what is missing from current literature is a comprehensive guide laying out a methodical approach to quantitative investigations into the biomass resource available to Local Planning Authorities in the UK. A hierarchy of potential methods is yet to be demonstrated in a single paper, and so this is what the current paper will try to do, for the case study of LCC. The aim of this study is to characterise and quantify the waste biomass resources available to LCC, calculating the annual mass available and the corresponding potential annual energy output from such resources. The potential bioenergy resources currently available, and those that could be possible in the future with further alterations to the strategic running of LCC, will be analysed in this manner. To do this, a hierarchy of assessment techniques will be created, with the specific technique employed for each biomass type in this study will depending on the information available for that biomass. It is hereby the aim of this paper to form a guideline of assessment techniques suitable for other local councils to use in their own biomass assessments. This is to form part of the solid evidence base that is required for Local Planning Authorities to incorporate local forms of renewable energies into their development plans.

4. Methodology

4.1. The Assessment Hierarchy

After investigating methods employed by other studies in their quantification, it is apparent that there are many different approaches, each with advantages and disadvantages. With the purpose of small scale biomass assessments for local councils in mind, a methodology will be proposed that follows a hierarchy of most desirable to least desirable methods. The methodology which is at the highest possible position up the hierarchy will be chosen for each type of biomass, dependent on the information gained during the investigation. An outline of the hierarchy is displayed in figure 2.

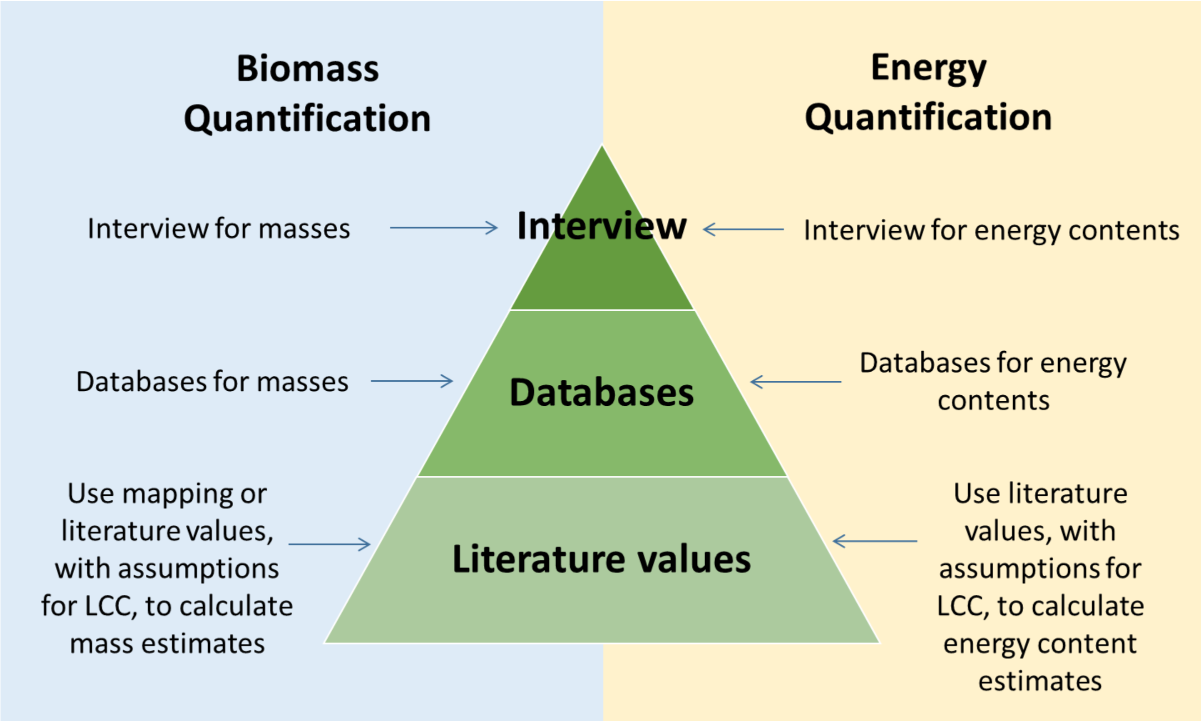

Figure 2. Biomass Resource Method Hierarchy

Ascertaining all of the required information through interviews with relevant experts within each field would be the most efficient and accurate way to get the desired masses and energy contents. Should the required information be found in its entirety within databases, then this would be the next most accurate method. Failing this, getting as much information as possible from the interviews, and the remainder from databases or literature, would allow for reliable estimates to be achieved. If the interviews do not yield any information regarding the masses of the wastes, it would be necessary to entirely estimate them. For growing biomass such as the trimmings from woodlands, one could use knowledge of the surface area (via GIS mapping or, if possible, literature) in combination with literature values for an estimate of the sustainable yield, and then estimate the energy content through the use of appropriate literature values. For the biomass that cannot be estimated through this technique, some database/literature techniques already seen could be employed, such as using national statistics and estimating the proportions applicable to LCC.

4.2. Mass Estimation Methods

4.2.1. Interview

Interviews were conducted with relevant members of LCC. The method of an interview was chosen rather than any of the other methods discussed in current literature. It was thought that, given the small number of people being questioned and the depth of investigation required for each individual, interviews were the most appropriate method, as it was the most likely to yield useful data. The style of a semi-structured interview was chosen, because this allowed the interview to be tailored to the interviewee’s knowledge base. Because much of the information sought after was not necessarily known directly by the interviewee, a certain amount of flexibility in the questions asked was required in order to allow the most accurate estimations of quantities and energies to be made. Drever (1995) was consulted extensively in the interview schedule writing stage. The interview questions were chosen very carefully to be unbiased and open, in order to get the most accurate and detailed answer. Though many questions were possible, those that were definitely required to achieve the aims of a quantification of the biomass and its energy content were favoured.

A copy of the generalised interview schedule is given in the annex. The interviewee was firstly asked about the form of the waste in question. This included questions about the type of waste, its average moisture content and its average particle size. The volume and mass of waste produced per unit size were then asked for, with further questions asked to estimate these values, should the interviewee have been unable to give a direct value. The interviewee was also asked if there was any potential increase in the quantity of biomass that could be collected from a particular source, which if given was categorised as the ‘future potential’. Finally, the interviewee was asked if there was anything more they would like to add, to allow them freedom to give any useful information not considered previously.

The interviews were audio recorded, and then transcribed in full at a later date. From this transcription, the useful information was identified and recorded. Table 8 shows the assumptions made for each type of biomass, if mass estimates were given in the interview. No energy estimates were given in the interviews.

Feedstock	Percentage of total mass available for bioenergy
Woodland and arboricultural arisings	100%
C&D and household waste wood	25% [a]
Green waste	100%
Farm manures	100%
Food waste	100%

[a] SQWenergy (2010), Walsh (2008)

Table 8. Biomass percentage availability assumptions

It was assumed that the green waste was composed of even proportions of wood, leaves and grass. These three substances were then treated as individual waste streams for the mass and energy calculations.

4.2.2. Database

If the required information had been available in complete form on a database, or group of databases, then no further enquiry would have been necessary. Databases include those national ones such as those of the Forestry Commission and Defra, or those specific to the region under assessment. For Leeds, this included the Leeds Data Mill (Council, 2014). Unfortunately no complete biomass quantification data could be found at the time of writing because of insufficient previous work in the field.

4.2.3. Literature Use

Alternative methods of quantification had to be sought for the types of biomass in case the interviews did not reveal the required mass estimates. Once a mass estimate had been achieved, the energy content was calculated from literature using the same method as the section above.

Woodland Arisings

For this waste, the coverage of woodland was estimated from databases or reports. The Forestry Commission's estimated annual sustainable yield for woodland of 4.5 m^3/ha was applied to the woodland arisings to calculate the potential sustainable yield of biomass. In the current work, this methodology acted as a way to calculate the potential yield from under-harvested forests.

Arboricultural, C&D and household waste wood, food and garden wastes

Estimates for the production of these wastes were achieved using regional values proportionately decreased to match the area under assessment. For arboricultural arisings, waste wood, garden waste and food waste, regional values were researched. In general, smaller regions were valued as being more accurate, but only if they included the desired assessment area. It was assumed that waste production is proportional to population size. The ratio of assessment area population to regional population was used to estimate the production rate of the assessment area, as outlined in equation 1. Table 9 displays the regional production rates of the relevant biomasses.

Feedstock	Regional Production Rate (tonnes per year)	Population of Region
Arboricultural arisings	4.44×10^5 [a]	5.26×10^7 [b]
C&D waste wood	5.04×10^6 [c]	6.28×10^7 [d]
Food waste	7×10^6 [e]	6.28×10^7 [d]
Household wood	9.13×10^5 [f,h]	5.26×10^7 [b]
Garden waste	24×10^5 [g,h]	6.28×10^7 [d]

[a] Data from McKay (2003)
[b] Data from Statistics (2013)
[c] Data from Research (2005)
[d] Data from Statistics (2013))
[e] Data from Quested (2012)
[f] Data from Defra (2008)
[h] These are values for the municipally collected mass only

Table 9. The regional production values of various feedstocks.

$$Production\ Rate = \frac{Population\ of\ Assessment\ Area}{Regional\ Population} \times Regional\ Production\ Rate$$

Equation 1. Production rate general calculation

This method was to quantify the arboricultural arisings, household wood waste, garden waste and food waste. The masses available for bioenergy were then calculated using table 8.

For the C&D waste wood estimation, however, it was necessary to account for the fact that LCC is not the sole producer of C&D waste within Leeds. From the C&D production rate in Leeds calculated above, the LCC specific C&D waste production rate was estimated using equation 2 (method 1). The LCC C&D construction waste wood was also calculated using other data for Yorkshire and the Humber (Y&H), using a similar method, but one that did not require the results from equation 2. The method is shown in equation 3 (method 2). Table 10 displays the figures used for both of these calculations.

Variable	Quantity
LCC construction workforce	4600 workers [a]
Leeds construction workforce	62600 workers [b]
Y&H construction workforce	161750 workers [c]
Y&H C&D production rate	108700 tpa [d]

[a] LCC (2014)
[b] Partnership (2012)
[c] (CITB, 2014)
[d] (Poyry, 2009)

Table 10. Values of variables for methods 1 and 2

$$LCC\ C\&D\ Production\ Rate = \frac{LCC\ Construction\ Workforce}{Leeds\ Construction\ Workforce} \times Leeds\ C\&D\ Production\ Rate$$

Equation 2. LCC C&D production rate - Method 1

$$LCC\ C\&D\ Production\ Rate = \frac{LCC\ Construction\ Workforce}{Y\&H\ Construction\ Workforce} \times Y\&H\ C\&D\ Production\ Rate$$

Equation 3. LCC C&D production rate - Method 2

The two values produced for C&D waste wood were averaged, and then 25% of this value was assumed to be available for bioenergy as per table 8.

A future potential biomass calculation was made by considering all of the C&D waste wood produced in Leeds. This was calculated from equation 1. Again, the assumption that 25% of this mass would be available for bioenergy was applied.

Farm Manure

Many studies have calculated average manure production values per head for a range of species. These were used, along with the number of each type of animal present in the assessment area (either from interview or from literature research) to calculate a potential biomass production rate. The collection efficiency of 80% published by (SQWenergy (2010)) was then applied. The most general formula is given in equation 4.

$$Manure\ Production = No.Animals \times Dry\ Waste\ Production\ Rate\ per\ Head \times 0.8$$

Equation 4. Manure production general calculation

Table 11 displays the production values suitable to UK farming methods, for a small range of livestock.

Feedstock	Dry weight of waste per head (dry tonnes per year)
Cattle	0.004672131
Pigs	5.06329E-05
Poultry	4.03226E-05[a]

[a] waste consisting of a representative 70% poultry manure and 30% litter

Table 11. Manure production, methane yield and energy production values for various livestock. Based on data from Dagnall (1995).

The methods outlined above also acted as ways to calculate the potential biomass yield from underutilised resources when necessary.

Conclusion

The hierarchy of methods outlined above were employed in the assessment of the biomass available to LCC. For each type of biomass, the method highest up the hierarchy was used, and this is outlined in the Results section.

4.3. Energy Estimation Methods

4.3.1. Interview

Should the interviewees have been able to give estimates of the energy contents for the particular types of biomass used, then no further quantification techniques would have been necessary. However, in this study none of the interviewees were able to give this information.

4.3.2. Interview with Database/Literature use

Should some, but not all, of the above information been given by the interviewee, then some use of databases or literature values was necessary. If the interviewee was able to give a mass (or volume) estimate and be able to tell the interviewer information about the form of the waste, then this was used in conjunction with standard values to ‘fill in the gaps’ and produce reliable estimates for the remainder of the questions. The precise values and equations used for calculations of the energies for each type of waste will be given below. Once again, any green waste was divided into separate portions of wood, leaves and grass for these calculations.

Wood-based Biomass

If only the wood volume was given during the interview, then the density of the particular type of wood was researched and applied to calculate the mass. If the moisture content was not given during the interview, then appropriate average literature values were adopted instead. The moisture content was then used, along with the type of wood, to estimate the energy content. Again, appropriate values from literature were used. The hardwood and softwood percentage values used for different feedstocks are displayed in table 11, while the moisture contents, density estimates and energy densities on collection are presented in table 12. These are the values that were used if the interview or literature search yielded no more precise values for the particular area under consideration.

Feedstock	Hardwood Percentage	Softwood Percentage
Woodland and arboriculture waste wood	65%	35%
C&D and household waste wood	50%	50%

Table 12. Wood composition percentages for various woody feedstocks

Equation 5 gives the general formula for the calculation of the volumetric energy density

$$Energy\ Density\ \left(\frac{MJ}{kg}\right) = \frac{Energy\ Density\ \left(\frac{GJ}{m^3}\right)}{Density\ \left(\frac{kg}{m^3}\right)} \times 1000$$

Equation 5. Energy density general calculation

Equation 6 gives the general formula for calculating the potential energy on burning a particular type of biomass

$$Potential\ Energy\ (MJ) = Energy\ Density\ \left(\frac{MJ}{kg}\right) \times Bioenergy\ Mass\ (kg)$$

Equation 6. Potential energy general calculation

Type of Wood	Moisture (w.b) [a]	Density (kg/m^3) [b]	Energy Density (GJ/m^3) [b]	Energy Density (MJ/kg) [c]
Woodland and arboriculture waste wood	50%	1016	8.37	4.33
C&D and household wood wastes	20%	558	8.2	14.70

[a] calculated from data in (Meehan and McDonnell, 2010)

[b] calculated from data in Hogan (2011)

[c] calculated from columns [b] (wet basis)

Table 13. Density, Moisture Contents, and Energy Density of Woods on Collection.

For the forestry and arboriculture, it was assumed that all of the arisings could be available for bioenergy. For the C&D and household waste wood, one should assume that 25% of the total collected wood is available for biomass (SQWenergy (2010), Walsh (2008)), and so the mass was decreased proportionately to give a bioenergy mass potential (tonnes/year).

It should be noted that the potential energy stated here is equivalent to the higher heating value of the biomass. This means that this energy value has not accounted for the energy that would be required to evaporate the water content within the biomass. These energy values are therefore slightly overestimated.

If the moisture contents or proportions of hardwood/softwood were revealed in the interviews to be different from those outlined above, then new densities and volume energy densities were sought from Hogan (2011) and used to calculate the mass energy density using the same equations as above. Any such deviations are discussed in the results section.

Wet wastes (Green Waste, Animal Manures, Food Waste)

If only the volume was given during the interview, then the density of the particular type of waste was researched and applied to give the mass. If the moisture content was not given during the interview, then average literature values were adopted. The moisture content was then used, along with literature values for the percentage volatile solids, to calculate the total methane potential yield. Table 14 gives values of moisture content, percentage volatile solids and biogas/methane potential, with references.

Feedstock	Moisture Content (w.b)	% Volatile Solids (of total solids)	Methane Yield (m^3/kgVS)
Green Waste	49.6% [a]	92% [a]	0.143 [a]
Cattle Manure	87% [b]	84% [c]	0.21 [d]
Pig Manure	90% [b]	78% [c]	0.33 [d]
Poultry Manure	74% [b]	76% [c]	0.33 [d]
Straw Waste	9.46% [e]	84% [e]	0.145 [e]
Food Waste	80% [f]	90% [a]	0.54 [a]

[a] calculated from data in Owens and Chynoweth (1993) with 100% conversion efficiency
[b] calculated from data in ASAE (2005)
[c] calculated from data in Subcommittee (1993)
[d] taken from Frear (2005), with 30% conversion efficiency assumed
[e] taken from Moller et al. (2004) with 100% conversion efficiency
[f] taken from Chen (2003)

Table 14. Moisture, volatile solid and potential methane yields of various animal manures.

Equation 7 was used to calculate the total annual Methane potential from a particular biomass. The values of moisture and volatile solids expressed as percentages in table 14 were converted into a decimal equivalent for the calculation in equation 7.

$$\begin{aligned}
&Total\ Methane\ (m^3/year) \\
&\qquad = Bioenergy\ Mass\ (kg/year)\ \times (1 - Moisture)\ \times Volatile\ Solids \\
&\qquad \times Methane\ Yield\ \left(\frac{m^3}{kg}\right)
\end{aligned}$$

Equation 7. Methane production general calculation

Uncertainties were calculated for each bioenergy mass and energy calculation using standard error propagation techniques, as outlined in Annex 2.

5. Results

4.1. Summary

Tables 15 and 16 display the main results for the wood biomasses and wet biomasses respectively.

Type of Waste	Source of Waste	Total Mass Available (tpa)	Mass Available for Bioenergy (tpa)	Energy on Burning (MJ/year)	Future Potential Mass (tpa)	Future Potential Energy on Burning (MJ/year)
Wood	Woodland Arisings	1900	1900±600	$(8\pm3)\times10^{6}$	$(6\pm2)\times10^{3}$	$(26\pm9)\times10^{6}$
	Arboricultural Arisings	3×10^{3}	$(3\pm1)\times10^{3}$	$(3\pm1)\times10^{7}$	$(3\pm1)\times10^{3}$	$(3\pm1)\times10^{7}$
	Construction Waste	7802	1400±300	$(10\pm1)\times10^{7}$	$(16\pm4)\times10^{3}$	$(24\pm7)\times10^{8}$
	Household Timber Waste	1×10^{4}	$(3\pm1)\times10^{3}$	$(4\pm2)\times10^{7}$	$(3\pm1)\times10^{3}$	$(4\pm2)\times10^{7}$
Totals		23×10^{3}	$(9\pm3)\times10^{3}$	$(9\pm4)\times10^{7}$	$(28\pm8)\times10^{3}$	$(3\pm1)\times10^{8}$

Note: Energy values quoted are higher heating values.

Table 15. Results for woody biomasses.

Type of Waste	Source of Waste	Total Mass Available (tpa)	Mass Available for Bioenergy (tpa)	Volatile Solids (kg)	Methane Production (m^3/year)	Future Potential Mass (tpa)	Future Potential Methane Production (m^3/year)
Green Waste	Garden Waste	42×10^{3}	$(42\pm4)\times10^{3}$	2×10^{7}	$(28\pm6)\times10^{5}$	$(42\pm4)\times10^{3}$	$(28\pm6)\ \times10^{5}$
	Parks and Countryside	800	800±80	4×10^{5}	$(5\pm1)\times10^{4}$	$(9\pm2)\times10^{6}$	$(6\pm1)\ \times10^{8}$
	Farm Waste	10	10±1	4600	700±100	10±1	(700)±100
Manure	Pig Slurry	0.66	0.66±0.07	470	150±40	0.66±0.07	150±40
	Mixed animal manure and straw	2000	2000±200	98×10^{4}	$(15\pm9)\times10^{4}$	2000±200	$(15\pm9)\times10^{4}$
Food	Household food waste	1200	1200±100	83×10^{4}	$(45\pm9)\times10^{4}$	$(80\pm8)\times10^{3}$	$(31\pm6)\times10^{6}$
Totals		46×10^{3}	$(46\pm5)\times10^{3}$	2×10^{7}	$(30\pm7)\times10^{5}$	$(90\pm9)\times10^{5}$	$6\pm1\times10^{8}$

Table 16. Results for wet biomasses.

The interview results and subsequent alterations to the methods used to calculate the biomass results are outlined in the following sections.

4.2. Woodland and Arboricultural Arisings

Interviewee 5 said that 1900 m^3 of woodland residues were collected, and that this volume estimate was “reasonably accurate”. They then gave a “conservative estimate” for the total (woodland and arboricultural) arisings of 5400 m^3. From this, an estimate for the arboricultural arisings of 3500 m^3 was inferred. They also estimated that 95% of these were from broadleaf trees. This information implies that 95% of the wood is hardwood and 5% of the wood is softwood. Interviewee 5 stated that the volumes of the woodland arisings would be for the wood in it’s natural ‘green’ state, while the arboricultural arisings were measured in a mixed state, with some of the wood being green, and some being air dried. Table 17 summarises these results.

Feedstock	Volume (m^3)	Hardwood %	Softwood %	Moisture %
Woodland Arisings	1900	95	5	50[a]
Arboricultural Arisings	3500	95	5	40[b]

[a] Wood in a green state is approximately 50% when measured in wet basis
[b] Lower value used to account for some portion of the wood being air dried

Table 17. Results from interview 5

Hogan (2011) was then employed to calculate the results shown in table 18. It was assumed that 100% of this mass would be available for biomass.

Feedstock	Density kg/m^3	Mass (tonnes)	Uncertainty (tonnes)
Woodland Arisings	1264	1900	600
Arboricultural Arisings	843.5	2950	1000

Table 18. Results from the mass calculation

A potential energy calculation was then done using the same method as outlined in equation 5 to give the results displayed in table 19.

Feedstock	Energy Density (MJ/kg)	Energy (TJ)	Uncertainty (TJ)
Woodland Arisings	4.33	8	3
Arboricultural Arisings	10.4	30	10

Table 19. Results from the Energy Calculation

Interviewee 5 stated that the woodland resources are not currently being used to maximum sustainable capacity, therefore there is a larger future potential biomass yield possible. The interviewee was unable to give any more information, and so due to the time constraints involved in this project no potential future bioenergy yield has been calculated for the arboricultural arisings, as the number of trees involved is difficult to estimate. For the woodland arisings, however, the Forestry Commission sustainable forestry yield of 4.5 m^3/ha was applied to the 1300 ha of woodland that Interviewee 5 stated comprised the total estate, to give the potential volume, mass and energy given in table 20.

Feedstock	Volume (m^3)	Mass (tonnes)	Energy (TJ)
Woodland	5850	$(6 \pm 2)\times10^3$	26 ± 9

Table 20. Results from the future potential energy calculation

4.3. Construction Waste Wood

Interviewee 1 could give no mass or volume estimates for the quantity of construction waste wood produced per year from LCC projects. They directed me to a contractor, AWM, for estimates, but attempted contact was unsuccessful. Instead, the technique outlined in the literature mass quantification section of the method was employed, giving the results shown in table 21.

Method	Results (tpa)	Average (tpa)
1	1178	1400 ± 300
2	1545	

Table 21. Results from C&D biomass quantification methods 1 and 2, with their mean

This waste wood mass was then converted into a potential energy using the technique outlined in the methodology. Tables 12 and 13, in combination with equations 4 and 5, were employed for this. However, Interviewee 1 was able to state that the waste wood was “more softwood”, and so the values used were altered slightly from those outlined in the methodology. The new values used are presented with the results in table 22.

Hardwood %	Softwood %	Moisture %	Energy Density (MJ/kg)	Energy (TJ/yr)
20%	80%	20%	14.71	(200 ± 10)

Table 22. Values used to calculate the energy potential

4.4. Household Timber Waste

Interviewee 4 estimated the mass of timber waste available from household waste sites to be 1×10^4 tpa, and so this was used, with the same 25% bioenergy availability as for the waste wood (SQWenergy (2010), Walsh (2008)) to give a mass. The technique outlined in the methodology was employed to calculate an estimated energy potential from this.

Interviewee 4 gave no prediction of increased possible future potential biomass availability, and so it was assumed that the current values are the highest that can be reasonably achieved.

4.5. Arisings from Parks and Countryside

Interviewee 3 gave a figure of 800 tpa for the quantity of green waste collected by the Parks and Countryside unit of LCC. This was all taken from the bowling greens within Leeds and their surrounding hedges. These bowling greens are $35m^2$, and there are approximately 60 of them being cut three times per week for about six months of the year. The calculations of the biomass potential and energy potential followed the techniques outlined in the methodology for green waste.

Interviewee 3 also said that there are 1500 hectares of intensively managed parkland distributed across the city, but that the green waste from these is not collected. There is therefore a potential to increase the quantity of green waste available to LCC if these parks were managed as intensively as the bowling greens are, and the residues were collected. The potential new values of arisings were calculated for each type of waste, using the same techniques as outlined in the methodology. Results are given in tables 15 and 16.

4.6. Arisings from Household Garden Waste

Interviewee 4 estimated the total garden waste collected by LCC each year as “42000 or 43000 tonnes”. This estimate includes the 800 tonnes which Interviewee 3 attributed to Parks and Countryside, and so this was subtracted to give a value of 41700 tpa. This green waste was treated in the manner outlined in the methodology to give mass and energy estimations, which are reported in tables 15 and 16.

Interviewee 4 gave no indication that the quantity of household garden waste will increase in the future, and so it was assumed that the current potential is the maximum potential.

4.7. Arisings from Home Farm

Interviewee 2 gave an estimated two thirds of a tonne of pig waste produced per year, and 2000 tonnes of mixed animal manure and straw per year. They also mentioned that the formal areas of Temple Newsam are actively managed, producing approximately 10 tonnes of green waste per year. This waste was treated in the same way as the green waste, outlined in the methodology, to give the mass and energy results presented in tables 15 and 16. The pig slurry values were treated in the way outlined in the methodology, whereas the mixed manure needed some additional assumptions, which will be outlined below.

Interviewee 2 gave no indication that there could be an increased quantity of green waste collected in the future, and so it was assumed that the current potential also applies to the future potential. The quantity of manure stated above is not the full quantity produced by the animals because not all of it is collected. A potential future biomass quantity for this could be calculated if combined with the average daily manure production rates for livestock, given in the methodology. However, Interviewee

2 was unable to give an estimation of the number of animals at Home Farm, so this calculation could not be performed.

4.7.1. Mixed Animal Manure with Straw

Interviewee 2 stated that approximately 2000 tonnes of cow, poultry, sheep and goat manure mixed with straw was produced at Home Farm each year. The interviewee was, however, unable to provide estimates of the proportional composition. This mixed waste therefore required various assumptions to be made. Firstly it was assumed that the waste consisted of 50% manure and 50% straw. Because cows produce by far the largest volume of manure, the calculation was simplified by assuming all of the manure originated from cows. The energy contents of cow manure and straw were then calculated in the ways outlined in the methodology, and the two values were summed to give the total potential methane yield for the mixed animal manures provided in table 16.

4.8. Food Waste

4.8.1. Household Food Waste

Interviewee 4 estimated the mass of food waste currently collected by LCC to be between 1100 and 1200 tonnes per year. Using the techniques outlined in the methodology, the mass and energy estimates were calculated and presented in table 16.

Only a small area of Leeds currently has its food waste collected. Interviewee 4 gave a value of 12500 properties currently on the collection route, compared to the total number of properties in Leeds of 301614 (ONS, 2001). Wenlock et al. (1980) found that income does not significantly affect the amount of food wastage, with the amount of wastage being proportional instead to the number of occupants. Assuming that the average number of occupants per house is approximately constant over the area of Leeds, it is possible to estimate to total food waste produced by all homes in Leeds. A methane production was then estimated using the same techniques as outlined in the methodology.

4.8.2. Additional Food Waste

Interviewee 4 provided a document which outlined the other sources of food waste potentially available to LCC in the future. These sources included commercial and industrial food wastes, food manufacturing wastes and household food wastes originating from neighbouring Local Authorities. The sum total of these, in combination with the above additional 3×10^4 tonnes from Leeds households, is between 72×10^3 and 88×10^3 tonnes, giving an average value of $(80\pm8)\times10^3$ tonnes/year. The energy potential from this was calculated using methods explained in the methodology, and the results are given in table 16.

4.9. Totals

The total annual biomass available to LCC currently is $(55\pm8)\times10^3$ tonnes. The potential future biomass available if the alterations to LCC methods outlined above were made is $(90\pm9)\times10^5$ tonnes per year. Due to the fact that the dry and wet wastes are converted into useful energy using different conversion technologies, it is difficult to directly compare them. To give an idea of the total potential energy production, the energy density of methane was estimated. A methane energy density of 55.5MJ/kg is given in Elert (1998). This was combined with the density of Methane at normal temperature and pressure according to (Toolbox, 2015) of 0.668 kg/m^3 to give a result of 37.07 MJ/m^3. Using this, the methane volumes calculated were converted into estimates of the energy content. Combining energy contents for the woody and wet wastes gives estimates for the total current potential energy and total future potential energy contents of $(19\pm7)\times10^7$ MJ/year and $(20\pm5)\times10^9$ MJ/year respectively. A summary of the main results for the dry and wet biomasses is given separately below.

4.9.1. Dry (Wood) Arisings

All of the dry matter assessed in this study was wood-based. The total mass of these sources was $(9\pm3)\times10^3$ tonnes/year. The potential energy of this wood was calculated to be $(9\pm4)\times10^7$ MJ/year. With the alterations to the LCC strategic model discussed in previous sections, the potential biomass available to LCC would be $(28\pm8)\times10^3$ tonnes/year. The resulting potential future energy production is $(3\pm1)\times10^8$ MJ/year.

4.9.2. Wet Arisings

The wet wastes assessed in this study consisted of leaves, grass, animal manures and food. The total biomass available to LCC from these wastes is $(46\pm5)\times10^3$ tonnes/year, giving a methane potential of $(30\pm7)\times10^5$ m^3/year. If LCC made adjustments to its strategic model as discussed above, there could be a potential future biomass availability of $(90\pm9)\times10^5$ tonnes. This yields a potential future methane production of $(6\pm1)\times10^8$ m^3.

5. Discussion

The results of this study demonstrate that there is a large amount of biomass currently available to LCC. The hierarchy laid out in the methodology was successfully applied to give these results, with all levels eventually being tested due to the differing availability of information for different types of biomass.

From the results, one can see that approximately equal quantities of dry and wet biomass types are available to LCC, with slightly more of the wet wastes. The largest individual source of woody biomass is garden wood waste, and this subsequently has the highest energy potential. Of the wet biomasses, the green garden wastes (leaves and grass) have the largest masses, and consequently the leaves from garden waste have the greatest methane potential yield. However, it should be noted that these green garden waste values are likely to be an overestimate, because there was no estimation of a proportion of non-organic matter mixed in with the garden waste. The assumption of even proportions of wood, leaves and grass is also a rather crude estimate, which will have inevitably increased the uncertainty.

The future potential biomass availability is likely to be an underestimate, because of the fact that it was not possible to quantify some of the potential biomass availabilities. These were the arboricultural arisings, farm garden waste, household garden waste and farm manure waste. The reasons for this were discussed with the results for each biomass type. From the results at present, it would appear that the woody biomass with the greatest potential future mass and energy is the wood from parks and countryside. The wet wastes with the greatest potential mass are the leaves and grass arisings from parks and countryside, leading to leaves from parks and countryside being the future potential biomass resource with the greatest energy. Of course, collecting this potential biomass may not be economically feasible, but it is outside the scope of this paper to investigate this matter. The full life cycle analysis of the LCC biomass resources and potential biomass resources has not been performed in this study, nor has an economic analysis of the costs involved in using the biomasses. The results presented here are therefore not a full picture of the situation for LCC, and should be taken only as one aspect to inform decisions about planning for renewable energy resources.

The primary and secondary methods employed each have their own advantages and disadvantages. Primary methods such as interview allow the collection of first-hand information and so are often more accurate than secondary information. However, because the methods by which the interviewee collected their information are often unknown, it is difficult to quantify the uncertainty in the results they give. Secondary methods, however, usually have more well-defined uncertainties because the source will provide an overview of the technique employed. The information is usually based on numerous assumptions and generalisations though, leading to higher uncertainties. This paper generally favours primary sources for this reason, ranking these sources further up the biomass quantification hierarchy.

There are large uncertainties associated with most of the results. This is representative of the fact that bioenergy quantification is notoriously difficult (Maithel, 2009), because no single preferred method exists that has a much higher level of certainty associated with it.

As mentioned in the methodology, the energy values quoted for the woody biomass are higher heating values. This means that the energy released on combustion is likely to be slightly lower. Another variation that was not taken into consideration in the uncertainty propagations was the fact that the conversion efficiencies of various technologies vary considerably. For the woody biomass, the potential energy contents are calculated from the matter itself and so the energy values presented are effectively what a burner at 100% efficiency could produce (neglecting the heat required to vaporise the moisture within the matter). The methane predictions, however, were taken from literature and as a result reflect the conversion efficiency assumed by the source. Where possible, these assumptions were given with the value.

6. Conclusion

In this paper, the waste biomass available to LCC has been quantified, and its energy content estimated. The future potential quantity and associated energies have also been quantified for many biomass resources. This information can be used by LCC as it creates its local development plans to incorporate more locally produced renewable energy.

The study serves as a guideline for other local planning authorities to follow in their assessment of biomass wastes available to them. With a hierarchy of methods to choose from, this paper is the first to provide a comprehensive list of approaches for many different kinds of biomass. This means that, regardless of the information available, an estimation of the mass and energy, for each type of biomass, should be achievable.

Due to constraints involved with the project that culminated in this report, this is not a complete analysis of the biomass available to LCC. The waste biomasses quantified in this study do not constitute an exhaustive list, and so it would be beneficial to any future study to quantify the biomass resources missing from this paper. These include, for example, food waste from council commercial outlets and council contracts. Another possibility is utilising wastes produced by other organisations within the Leeds area, such as commercial and industrial waste wood, and manures from other farms. As mentioned earlier in the report, the energy estimates for woody biomass are upper level estimates due to the fact that the energy required to evaporate the moisture content in the material was not accounted for. In order for any future study to more accurately predict the energy outputs, the lower heating values, which account for this, would have to be calculated. In addition, it would provide a clearer, more holistic view of the biomass in Leeds if the resources could be mapped. Therefore, mapping would be an asset to any future biomass assessment. This report failed to quantify the potential future biomass available to LCC from some of the resources, as mentioned in the in the results and discussion. In order to provide a full analysis of the potential biomass availability, all resources with a larger future potential yield should be quantified.

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Annex 1 – Interview Schedule

QUESTION 1 – Briefly, what is your job role at Leeds City Council?

QUESTION 2 – I would like to talk to you about [biomass]. Could you briefly tell me how you are involved with this biomass resource?

QUESTION 3 – Can you tell me what form the [biomass] takes upon collection?

> **QUESTION 3 Prompt 1** – [Further questions specific to biomass type, eg. What was the [biomass] usually used for before it was disposed of – is it contaminated in any way?]
>
> **QUESTION 3 Probe 1** – What is the average moisture content of the waste?
> (If can't answer: How is the [biomass] stored? Is it air dried at all or is it just left outside in open conditions?)
>
> **QUESTION 3 Probe 2** – What is the average size of the pieces of [biomass] that are collected?

QUESTION 4 – Could you give me an estimate of the volume of [biomass] that is produced in a week?

> **QUESTION 4 Prompt 1** – If it's easier you could choose a different timescale such as a day/month/year?
>
> **QUESTION 4 Prompt 2** – Or if this resource is transported by a particular type of vehicle to its destination, could you give me the average load volume and how many trips are required per [week/month/year]?
>
> **QUESTION 4 Prompt 3** – [Further prompts specific to biomass type to determine volume] (Or ask if they can retrieve the info at a later date)

QUESTION 5 – Could you give me an estimate of the mass of [biomass] that is produced in a week?

> **QUESTION 5 Prompt 1-** If it's easier you could choose a different timescale such as a day/month/year?
>
> **QUESTION 5 Prompt 2-** Or if this resource is transported by a particular type of vehicle to its destination, could you give me the average load mass and how many trips are required per [week/month/year]?
>
> **QUESTION 5 Prompt 3-** [Further prompts specific to biomass type to determine mass] (Or ask if they can retrieve the info at a later date)

QUESTION 6 – Finally, is there anything else which you'd like to add?

Annex 2 – Uncertainty Propagation

The uncertainties were calculated using standard error propagation techniques. The general formula is given in equation 8, and the percentage uncertainties that were used for different variables are given in table 23.

$$\Delta f = f \times \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \left(\frac{\Delta z}{z}\right)^2 + \cdots}$$

Equation 8. Uncertainty propagation general calculation

In equation 8 above, Δf represents the uncertainty in result f, while Δx represents the uncertainty in variable x that was used within the calculation, Δy represents the uncertainty in variable y that was multiplied by x in the calculation, and so on.

Variable	Uncertainty
All values given in interviews	10% of the value
[a]Volume of woodland arisings from interview	5% of the value
[a]Volume of arboricultural arisings from interview	20% of the value
Hardwood percentage assumption	10%
Moisture assumption	10%
Biomass availability	10%
Proportioning of green wastes	30% of the value for each type
Proportioning of mixed manure wastes	20%
Error in mass of construction waste wood	23%[b]
Each variable taken from Hogan (2011)	10% of the value for each
Methane Density	10% of the value
Methane Energy Density	10% of the value

[a] Values changed from standard to reflect interviewee confidence

[b] Percentage calculated from difference between construction waste wood values calculated using methods 1 and 2

Table 23. The uncertainties used in error propagation.