Gwent Green Grids cut and collect

Report

Funding Acknowledgement

This report has been commissioned and funded by the Gwent Green Grids Project under workstream 5 of the project; Resilient Grasslands. The Gwent Green Grids Project was funded from the European Agricultural Fund for Rural Development by the Welsh Government.

Declaration

This document contains information and may contain conclusions and recommendations. Every effort has been made to ensure that the information is accurate and that the opinions expressed are sound. However, Severn Wye Energy Agency cannot be made liable for any errors or omissions or for any losses or consequential losses resulting from decisions based on the information.

GRID GWYRDD GWENT
GWENT GREEN GRID

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development: Europe Investing in Rural Areas
Llywodraeth Cymru
Welsh Government

Contents

Table of Figures

1 Introduction

Climate change is a natural phenomenon that is being accelerated by anthropogenic activities [1]. Since 1880 the planets average temperature has risen about 1.02 degrees on average and since 1750 the levels of CO2 in the atmosphere have increased from 280 parts per million to 419ppm as of March 2023 [2]. The increase in temperature and CO2 in the atmosphere is associated with the rise in greenhouse gases. This natural process is what has kept the earth's climate habitable for millions of years. But now greenhouse gas levels are so high and are now trapping heat close to the earth's surface rather than letting it escape into space. As a result, we are seeing more extreme weather patterns, severe heatwaves, droughts, food supply disruptions, increased desertification [3]. Unless interventions are made, long term projections by the IPCC suggest this will happen more frequent and more severe. In 2015, 196 parties adopted an international binding agreement to combat climate change. The agreement aims to limit global warming to 1.5 degrees compared to pre-industrial levels. This must be done by utilizing both preventative measures such as improving energy efficiency and remediation strategies such as carbon capture and storage innovations. Biochar is one of six different carbon capture and storage methods identified by the IPCC special report "Global warming of 1.5°C" [4]. Other methods include Direct Air Capture, Forestation and Bio Energy Carbon Capture and Storage (BECCS) Additionally, a shift towards renewable energy sources instead of fossil fuels must also be at the forefront of this change.

1.1 Scope of the study

The Gwent Green Grids partnership, a new ground-breaking project, that aims to improve and develop green infrastructure – a term used to describe the network of natural and semi-natural features, green spaces, rivers, and lakes that intersperse and connect villages, towns, and cities – as well as provide green job opportunities within the area. Green infrastructure has a crucial role to play in addressing nature, climate change and health emergencies. This project is a collaboration between 5 county councils, Monmouthshire, Blaenau Gwent, Caerphilly, Newport, and Torfaen councils, as well as Natural Resource Wales and us Severn Wye Energy Agency. The project is supported by the European Agricultural fund for rural development: Europe investing in rural areas and is funded by the Welsh Governments Enabling of Natural Resources and Well-being grant. There are 5 dedicated workstreams for this project. Specifically, we are working on workstream 5 Pollinator Friendly Gwent. The work within this workstream is split into two elements, Nature isn't neat and resilient grasslands (Cut and Collect). The cut and collect project will consider the mechanisms needed for the effective management of grasslands addressing barriers and identifying different treatments to utilise grass cuttings. We will be delivering this in partnership with each LA by identifying key locations/strategic sites/areas to improve grasslands for pollinators and design and assist in delivery of the trial.

1.2 Objectives

The focus of this research will address the following:

- Conduct detailed study of each local authority mapping existing green infrastructure, waste streams and land management needs
- Identify a range of opportunities for enriching the local environment by managing natural resources carefully and finding the best way to process green waste sustainably.
- Identification of the barriers to effective management of GI grasslands i.e., availability of suitable machinery for cut and collection and transportation such as location/distance from processor/consumer; contamination by litter/dog faeces; waste regulations etc.
- Identification of potential volumes of grassland for GI Grasslands.
- Identification of the opportunities including local markets e.g., composting, biomass feedstock.
- Identification of which 'treatment' would be suitable for strategic sites e.g., settlements.
- Undertake simple lifecycle analysis and economic appraisal to identify most appropriate use of grass given the local context.
- Undertake a trial/pilot of a range of treatments.
- Maximise the use of an otherwise waste product in a sustainable way; and
- Present findings of study locally and nationally through council meetings, organised workshops, newsletters, press releases and industry networks as part of GGGP Legacy plan.

1.3 Outcomes

On successful completion of this project, we will have achieved:

1. Establishment of a cut and collect working group across the region to include key officers at LA's and other interest groups.
2. A study of cut and collect options for Gwent developed in partnership between public bodies including LA's, housing association, NRW & Severn Wye Energy
3. Sustainable cut and collect mechanisms identified at key locations/strategic sites/areas across Gwent to improve grasslands for pollinators.

2 Background & Literature review

The 5 regions involved in this project all border each other as illustrated in Figure 2.1 shown below. Blaenau Gwent has a total area of 109 square km and according to the population census conducted in 2016 has a population of 69,600. Secondly, Caerphilly has a total area of 278 square km with a population of 180,500 as of 2016. Thirdly, Monmouthshire has a total area of 850 square km with a population of 92,800. The fourth local authority is Newport with a total area of 190 square km. it has a population of 149,100. And lastly, Torfaen, with a total area of 126 square km and a population of 92,000. These 5 regions are all unique in their own topography, landscape, population, and feedstock.

Figure 2.1 County map of Wales

This section is going to analyse all literature relevant to the Gwent Green Grids workstream 5, 'Enabling natural resources and wellbeing, resilient grasslands cut and collect Gwent'.

In the region of Gwent, we are working with 5 local councils. These are Monmouthshire, Caerphilly, Torfaen, Newport, and Blaenau Gwent. These 5 regions are all unique in their own topography, landscape, population, and feedstock. For the sake of this project, Severn Wye Energy will seek to establish a cut and collect operation in the 5 councils while identifying volumes of grass that will be managed and the potential market opportunities possible from it. The key to the success of this project will be the discovery of what feedstock is available to us and the quantity of it, and following on from that, which treatment would be suitable for the feedstock, either anaerobic digestion or pyrolysis or anaerobic digestion with pyrolysis.

2.1 Current situation

European grassland represents 90 million hectares, at least one third of all agricultural land (FA0). These different grasses range from humid to steppic and messic and many more. In the past few years, the decrease of agricultural activities (grazing) led to a continuing reduction of those ecologically valuable, extensively used grasslands. Progressively over time, the attractiveness of formerly open areas will decline. Landscapes lose their open character and certain plant species dominate as these areas develop shrub and woodland vegetation. This leads to a reduction in biodiversity. That is why, as part of this project we must consider all treatment methods to deal with the biomass feedstock.

In the UK there are over 270000km of rural roads and motorways [5, 6] . The grass verges of these roads are cut regularly, and the cuttings could provide an important bioenergy resource. Road verges play many different roles such as access to utility infrastructure, space for pedestrians or an emergency area for cars. The spatial extent of road verges will increase further due to increased urbanisation and a projected increase of 60% in the global road network from 2010 to 2050. Mowing grass is mainly carried out to maintain visibility and safety; with aesthetics a less important factor and the grass cutting are normally left to decompose [7]. The species present on a grass verge relies on many different factors, the soil, geology, current and previous management. However, most UK verges can be classified as type MG1 false oat grass Arrhenatherum elatius grassland, dominated by coarse grasses and tall herbs [8] according to the British Nation Vegetation Classification.

As mentioned above, the grass is usually left on roadsides, although some councils are now beginning to cut and collect some of their biomass. But leaving the biomass turns it into a mulch which increases the nutrient level in the soil and smothers the plants below it. By cutting and collecting it will increase the range of species present in a verge [9]. Biodiversity improvements could be delivered by reduced mowing frequencies, as demonstrated for insects on urban roundabouts [10]. A regime involving two cuts early and late summer, was shown to be optimal for plant and animal biodiversity in non-urban highway verges [9, 11] . Rotational or mosaic cutting, i.e., dividing verges into two longitudinal strips that have a staggered cutting regime, can deliver similar biodiversity benefits, and ensures continuous provision of floral resources [11]. Additional enhancement for herbaceous plant biodiversity may be achieved by removal of cuttings [9, 12].

The potential yield of verge grass is dependent on many factors and is likely to vary significantly from year to year and site to site [13]. The species of plants, soil fertility, incidence of fertiliser run off and herbicide drift, the temperature, rainfall, and management regime (i.e., the timing, and number of cuts and whether grass is removed), will all affect both the yield and moisture content of the grass harvested. The yield from a verge is also dependent on the distance from the road with yield increasing with distance from the carriageway [8] so a wider cut could have a higher yield than a narrow one.

2.2 Ecological benefits of removing cutting/ How removing cuttings affects species richness

The removal of cuttings effectively reduces the nutrient richness in the soil and there is significant evidence of the negative correlation between the nutrient richness of soil and the species-richness of grasslands [14, 15]. Therefore, one method suggested for increasing the species-richness is the removal of soil nutrients. However, the efficiency of the reduction in soil nutrition from solely the removal of cuttings is questionable as only a small proportion of the total pool of nutrients can be removed in any one year. In one study conducted over 10 years on a chalk grassland, the levels of soil phosphorus and magnesium both decreased but the level of nitrogen did not [16]. Similarly, the tests conducted by T. Parr and J. Way found no change in the nitrogen level of the soil after 18 years of the removal of cuttings, however unlike the previous study mentioned the removal of cuttings led to an increase in plant species-richness [15]. This suggests that nitrogen level may not be the leading factor in the correlation between the removal of cuttings and the increasing species richness. There are to other factors resulting from the removal of cuttings that may result in the increased species richness. The first of these is the resulting large mass of cuttings left from cut and leave techniques, has several negative impacts on underlying vegetation. These impacts include reducing light available and therefore photosynthesis, reducing light available for new seedlings causing characteristic growth of long, weak stems and reducing probability of survival of the seedlings and finally creating an environment susceptible to the disease of plants. All these factors reduce the probability of establishment of new plants and therefore favour existing species. The second factor is the partial scarification that occurs during the collection process of cuttings, this creates gaps in the surface layer of soil and turf. The gaps created offer the possibility for dormant seeds to be exposed to light, increasing the chances of their germination, and on a small-scale germination from seed is more likely to result in a new species than spread of an existing species [17].

A further consideration, where nutrient depletion is aimed for, is the importance of removing cuttings as soon as possible after mowing. A study carried out in Holland [18] showed that unless cuttings are collected within one or two weeks, much of the nutrient content may be leached back into the soil.

Cut & Collect is a recognised technique for improving the biodiversity of a grassland primarily by reducing availability of nutrients and facilitating better light and growing conditions for target species. Wildflower and pollinators have a significant impact on biodiversity and importantly, public enjoyment. Guidelines as set out by Plantlife’s best practice guide for management of roadside verges indicates that a two-cut regime is preferable and if not a once cut one as set out in the table below is also beneficial for the reduction of soil fertility and increase in biodiversity.

Management option		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
One cut									full cut				
Two cuts	Summer and autumn cutting							partial cut			full cut		
	Late winter and autumn cutting		full cut							full cut			
	Dry verges (short vegetation)	regular cuts								regular cuts			
	Species-rich verges with mown edge		1m strip							full cut			

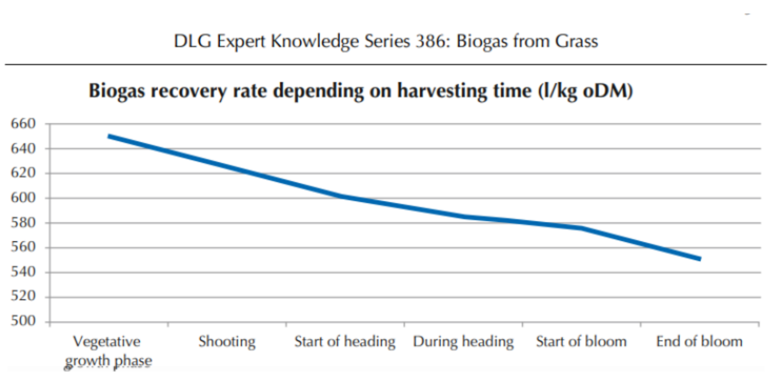


Figure 3: Biogas recovery rate from grassland growth depending on the harvesting time [Lütke-Entrup, Gröblinghoff, 2005]

The challenge is what to do with the arisings form cut & collect and how the practice impacts the practical and economic conditions of the Council. Verges are considered to be low value mixed and potentially contaminated grasslands with limited existing use. Existing opportunities for AD are possible however face key challenges - Harvest for AD & harvest for ecological restoration are often at odds with one another – reductions of 15% in the biogas yield potential can be seen in late cut grasses as can be seen in the graph – left.

2.3 Case Study 1: Lincolnshire case study

This case study examined the possibility of using volumes of grass available near AD plants to see if it is suitable replacement for current feedstock and asses the methane potential and digestion characteristics of grass samples. Lincolnshire is a county in the east of England and the county council are responsible for the maintenance of nearly 8000km of rural roads [19]. LCC currently cuts their verges twice a year to a width of at least 1.1 m, leaving the clippings *in situ*. The first cut is scheduled for between mid-April and the end of May and the second one for September. LCC wished to investigate the potential for harvesting the verge grass for digestion at local AD plants and at the same time enhance the biodiversity of the road network. Initial investigations of the feasibility of the use of grass cuttings for digestion at six sites in Lincolnshire [20] found that the grass was suitable for digestion and that some income could be generated to offset maintenance costs. Figure 2.2 below shows the bespoke harvesting system used to conduct this cut and collect trial which had a

grass cutting head that sucked up the grass and blew it in to a trailer.

Figure 2.2 Verge harvester showing cutting head and suction tube.

The machine collected 5.9 tons of grass from a single cut 4.3km run with a 1.1m swath giving an average fresh yield of 12.5 t/ha in 2016. The pilot in 2018 collected on average 3 tonnes per hour from a 1.2 m swath travelling at 5 km/h giving an average as received yield of 5 t/ha in 2018 was another unusual growing season: a very cold spell from late February to mid-April.

Harvesting cost

The 2018 harvesting vehicle could travel at 60 km/h and harvest at 5 km/h in dry conditions but only 3 km/h in very wet conditions. It had a capacity of 15 t of cut grass and used a 1.2 m swath. The cost per tonne of using one or two vehicles was not significantly different but using two vehicles does provide the option of harvesting more grass in a day. The harvesting costs are very sensitive to yield and speed of harvesting which is in turn influenced by how wet the grass is. The costs for the 2016 fresh yield of 12.5 t/ha and a harvest speed of 4 km/h (a higher yield and average harvest speed) and the costs for the 2018 harvest (with a lower fresh yield of 5 t/ha and the higher harvesting speed of 5 km/h achievable in very dry conditions). In 2016 the grass had a dry matter content of 24% so would expect to achieve a price of £21.60 per tonne, based on the quoted cost of £0.9 per tonne per percent of dry matter. Harvest costs below this level can be achieved even with a 1.2 m cut up to a radius of around 40 km. The harvesting costs suggest that the grass harvested could be an economic feedstock. In 2018 the lower yield resulted in higher harvesting costs, but the significantly higher dry matter content would result in a higher price being achieved. No other data on verge harvesting costs were available in literature for comparison, but previous research has suggested that subsidies may be required for harvesting. Our results suggest that harvesting was economically viable in both 2016 and 2018 in Lincolnshire without subsidies, and costs will not place any constraints on the volume of biomass available for AD.

Market for verge grass

All AD operators said they would consider using verge grass as a feedstock as a replacement for maize or rye assuming that grass was free of chemicals contamination. But litter was a worry as its effect on the digestate they sell, but this could be mitigated.

Conclusion

Road-verge grass has been shown in both lab-scale tests and in use in AD plants to be a technically suitable AD feedstock with digestion characteristics like those of other AD feedstocks. Both fresh and ensiled grass can be added to an AD plant feedstock mix, replacing energy crops such as maize or rye, resulting in reduced CO2 emissions because of reduced fertiliser use. Enhanced verge biodiversity should also result. The use of a waste feedstock is especially attractive to UK operators wishing to source 50% of feedstocks from wastes to qualify for incentive payments. In the Lincolnshire case study, it was found that there was enough verge grass within transportation distances of 20 km of farm-fed AD plants to replace 6% of the county’s AD feedstock demand.

AD operators interviewed were willing to use up to 25% grass in their plants and pay more than the estimated harvesting cost, suggesting that harvesting may be financially viable without subsidies.

2.4 Case study 2: Powys living highways report, 2006

Back in 2006 a practical trial was created to investigate the feasibility of wide scale collecting of cuttings from roadside verges in Powys for use in biogas and compost production

The objectives of the trial were:

- To test the suitability of specialised large-scale harvesting machinery for use on Powys Road verges
- To assess the likely resource inputs required to collect cuttings from Powys Road verges on a wide scale.
- To determine the suitability of road verge cuttings for utilisation in compost and biogas production
- To determine the potential economic benefits of utilising the collected vegetation to produce useful end products (including compost and biogas)
- To draw initial conclusions as to the future potential for collecting cuttings from Powys Road verges

The objectives from the Living Highways report are relevant for the GGG project and thus is a good example of real-life feasibility study which we can utilise the data to form a part of our report.

The trial was conducted over four separate working weeks during the normal cutting season. In Powys, as elsewhere, the timing and frequency of verge cutting is dictated by the road safety requirements balanced against time and budget constraints, while taking account of seasonal variations in growing conditions. Most of the major roads receive two cuts per year, with junctions and other sight lines typically cut three times per year. Minor roads are typically cut only once per year. The trial looked at two different waste treatment methods for the harvested biomass. Firstly, it looked at on farm anaerobic digestion at Bank Farm in Churchstoke for biogas production. And the second waste treatment method was Bryn Posteg in Llanidloes where the biomass was used for compost production.

The harvesting and transportation equipment used for the biomass was a Trilo SG1100 vacuum collection unit which had a 5.5 metre reach Bomford Falcoin Flail arm fitted with a specially adapted 1200 Protrim head, this incorporated a double helix rotor shaft, an auger and extraction pipe. The Falcon Collector was specifically designed for the project and engineered to drive the existing Trilo unit. The Trilo-Bomford machinery was teamed with a Massey Fergusson 6470 Dynashift tractor. The machinery cuts and collects the vegetation in a single operation. In addition to the standard double helix flail rotor shaft, the cutter head also incorporates an auger behind the rotor that moves cut material to the centre of the head, where it is sucked into the accompanying Trilo vacuum collector trailed behind the mowing unit. The vacuum unit is powered from the tractor power take-off (PTO). When full, the load is emptied from the rear of the trailer using a walking floor feature, operated from the tractor cab once the rear door has been opened manually. As part of the study each day a location was chosen as a bulking site which is where biomass would be emptied. Another machine would then be used to transfer the material to a bigger capacity vehicle for haulage.

Figure 2.3 Specialised machinery used to harvest vegetation from Powys Road verges

Figure 2.4 Specialised machinery used to harvest vegetation from Powys Road verges, further image

Figure 2.5 A full load emptied from the harvesting machinery at one of the bulking sites

For the first waste treatment the AD process, the digester was a single staged reactor which is fed with a semi continuously feedstock of chicken litter and small amounts of slurry. For the trial the road verge material was fed into the digester after being chopped with very small amounts of slurry daily. and for the composting process, the roadside verge was composted along with other non-food green waste materials.

Quantities of vegetation harvested

The fresh weight of vegetation harvested per km was greater during the first cut (May/June) than during the second cut (July/August). However, this was linked to a higher moisture content earlier in the year and in fact there was very little difference between the dry weight yield during the first and second cuts. There is even some indication that the dry mass yields per km may be slightly higher in July/August than in May/June. This must be considered for the GGG project as yields will never be the same due to many different variables such as weather, temperature, soil conditions. Annual yields have been estimated using the mean data from each cutting period. The mass yield of vegetation varied considerably between the different locations harvested during the trial. The minimum and maximum annual yields observed during the trial are a good representation of the likely range of road verge productivity that would be observed in Powys, because the harvest locations were deliberately chosen to represent a wide range of characteristics. The greatest potential annual yield indicated during the trial was 642 kg dry mass per km travelled with a flail cutting a single swath width of 1.2 which was cut once. The data from the areas cut twice a year indicate a maximum potential annual yield of 565 kg dry mass/km travelled. The lowest yield recorded during the trial was 78 kg dry mass/km travelled. From the data collected, it is not possible to determine absolute yields from locations, or to extrapolate an absolute potential yield of vegetation from across the whole Powys Road verge network. While the yield range across Powys is likely to be like that observed in the trial, the relative extent of different types of verges may be different. Hence, the trial data do not necessarily represent a quantitative sub-sample of Powys Road verges. In any case, yields would be expected to vary from year to year and may be expected to decline over time in some cases, if harvesting were carried out regularly (in line with nature conservation objectives). Despite this limitation, the data does provide us with base layer information. It suggests that in most cases, mean annual yields could be expected to fall within 300-400kg dry mass for each km travelled with a 1.2m cutter swath. For the calculation a conservative estimate of 300kg dry mass/km verge cut has been used as the expected annual yield.

Figures are expressed as kg dry mass collected per km travelled cutting a single 1.2 swath. Mean % dry mass figures for the relevant samples are shown in brackets.

		Minimum	Maximum	Mean
Verges cut twice a year	1st Cut	110 (18.6)	266 (25.8)	182 (21.85)
	2nd Cut	123 (26.1)	299 (38.9)	219 (32.6)
Verges cut once a year		78 (36.2)	*642 (42.9)	**296 (34.2)

* This value was recorded on a 'Roadside Verge Nature Reserve' on A483
**Only 3 values recorded

Table 2.1 Yield of vegetation from Powys Road verges

An annual yield of 300-400 kg dry mass/ km travelled is equivalent to 2.5-3.3 tonnes dry mass/ha/yr

Analysis of biomass

An analysis of the roadside verge harvested was conducted by a laboratory. The absolute dry matter figures indicate the proportion of the road verge vegetation that is not water. The volatile solids figures are equivalent to the organic matter content, which indicates the proportion of the (dry) material that would be available for decomposition by composting or anaerobic digestion. The moisture content of the road verge vegetation tended to be lower later in the growing season. There were no obvious trends related to weather conditions, although there was very little rainfall during the harvest operation to allow comparison. The volatile solid content of the harvested material was relatively consistent across all the samples and the mean value of 88.3% is therefore considered to be reliable as shown below in Table 2.2.

	Minimum	Maximum	Mean
Dry Matter % mass/mass fresh matter	18.0	46.2	29.0
% Volatile Solids (loss on ignition) % mass/mass dry matter	82.8	91.7	88.3

Table 2.2 Dry mass and organic matter content of vegetation

	Minimum	Maximum	Mean
Carbon % mass/mass dry matter	32.3	44.2	37.9
Nitrogen g/100g dry matter	1.52	2.79	2.03
Phosphorus % mass/mass dry matter	0.14	0.34	0.24
Potassium % mass/mass dry matter	0.54	3.09	1.82
* Chloride g/100g dry matter	0.92	1.95	1.38
Calcium % mass/mass dry matter	0.36	1.12	0.63
* Sodium % mass/mass dry matter	0.09	0.67	0.31
Magnesium % mass/mass dry matter	0.14	0.26	0.19
Sulphur % mass/mass dry matter	0.13	0.26	0.19
Boron mg/kg dry matter	5.81	16.80	9.34
Iron mg/kg dry matter	556	5990	1846
Manganese mg/kg dry matter	71	438	170

Table 2.3 Elemental Constituents

Table 2.3 shows the concentrations of a range of plant macro- and micro- nutrients. There was considerable variation in the elemental composition of the collected plant material. This may be due to the diversity of locations (and hence diversity of soil types, altitudes, etc) from which the vegetation was collected. These factors also have an influence on the plant species composition of the vegetation, all of which results in a heterogenous material. The ratio of carbon (C) to nitrogen (N) in the samples tested ranged from 11.6 to 29.1, averaging 18.7. This is slightly below the ideal range for both compost and biogas production (20-30:1), which suggests that mixing with other relatively Carbon-rich materials may be required to optimise the compost and biogas production process. Such mixing is considered normal practice for these processes. This is important to consider for the GGG project, as we seek local anaerobic digesters in the South Wales region to utilise the biomass. Although there was considerable variation in the C:N ratio between samples, there was no obvious trend of changing C:N ratio through the season.

Table 2.4 shows the concentrations of all the potentially toxic elements listed under BSI standard PAS100 for composted materials, within the samples of fresh road verge vegetation. The concentrations of all these elements fall well within the PAS100 limits, indicating that there is no obvious cause for concern if the material were used to produce compost commercially. However, the PAS100 limits relate to the final composted material, rather than to the raw starting material. The final concentrations of these potentially toxic elements would undoubtedly change during the composting process and it is possible that while some may some may become less concentrated, others may become more concentrated as the volume of material becomes smaller. If this were the case, it may be possible in any case to 'dilute' with other materials to achieve the desired quality. It was not possible, or appropriate to determine the final concentrations of these elements in the compost produced during the trial. If a specific new compost product were developed using road verge vegetation as a raw material, further testing and method development would be required, as with any new compost product. However, these initial results do not indicate any immediate cause for concern regarding potentially toxic elements.

Table 8 Potentially Toxic Elements
(all units are mg/kg dry matter)

	Minimum	Maximum	Mean	BSI PAS100 upper limit
Lead	5.17	19.20	9.85	≤ 200
Nickel	1.30	4.40	2.48	≤ 50
Zinc	37.3	80.5	54.8	≤ 400
Copper	7.97	20.90	11.32	≤ 200
Cadmium	0.16	0.50	0.26	≤ 1.5
Mercury	0.01	0.03	0.02	≤ 1
Chromium	0.95	3.98	2.03	≤ 100

Table 2.4 Potentially Toxic Elements (all units are mg/kg matter)

Economic assessment of roadside verges

Anaerobic Digestion Parameters		
Dry Matter of Crop	%	29
Biogas Yield from Road Verge Vegetation	M^3 per tonne	111.0
Biogas calorific value	MJ per m^3	23.2
CHP Electrical Efficiency	%	33
CHP Heat Efficiency	%	52
Parasitic Electricity	%	3
Parasitic Heat	%	14
Value of Electricity	£ per MW.hr	80
Oil Equivalence of Heat	KW. hr per litre	8.5
Price of Heating Oil	Pence per litre	25
Value of Heat	£ per MW.hr	29
Energy Crop Yield (Wet)	tonnes per km per year	1.03
Value of Solid Biofertiliser	£ per tonne	5
Simple Economic Analysis		
Annual Verge Collection	Tonnes per 100km	103
Total Digester Feedstock	Tonnes per year	103
Biogas Yield from Road Verge Vegetation	M^3 per day	31
Biogas Yield from Other Materials	M^3 per day	0
Total Biogas Yield	M^3 per day	31
Energy Value of Biogas	KW (fuel)	8
Potential CHP Electricity Production	KW (electrical)	3
Potential CHP Heat Production	KW (heat)	4
Process Heat	KW (heat)	1
CHP Availability	%	95
Usage Factor for Surplus Heat	%	30
Gross Electricity Production	MW.hrs per year	23
Net Useful Heat Production	MW.hrs per year	10
Oil Equivalence of Useful Heat	Litres per year	1206
Value of Electricity	£ per MW.hr	80
Value of Heat	£ per MW.hr	29
Value of Gross Electricity Production	£ per year	1848
Value of Energy Production	£ per year	2149
Value of Solid Biofertiliser	£ per year	52
Summary of Economics - £ per year		
Value of Electricity		1848
Value of Heat		301
Value of Solid Biofertiliser		52
Total Income		2201
Total Income per km	£ per km travelled	22.01

Table 2.5 Potential income from Anaerobic Digestion, for an on-farm digester

Table 2.5 shows the estimated potential income from the Anaerobic Digestion of road verge vegetation. The figures have been provided by Greenfinch Ltd, based on current market values, and based on a conservative estimated annual vegetation yield of 0.3 tonnes dry mass per km travelled with a single swath cut of 1.2m. The potential income from Anaerobic Digestion per km cut is £22.01, if all the products of AD (electricity, heat, solid and liquid fertilisers) are utilised

Table 2.6 shows the potential income from compost products using road verge material, based on current market values for different grades of compost, supplied by the Waste and Resources Action Programme (WRAP). The potential income per km travelled with a 1.2m width cutter ranges from as little as £1.24 for low quality compost up to £15.52 for high grade compost sold in smaller quantities. It is considered unlikely that road verge material would be used in the production of high-grade growth media, due to its variable composition, so the maximum value is £12.40 per km for a high-grade landscaping compost.

		Units
Annual fresh yield per km travelled (mean Dry Mass + mean water content)	1.034	Tonnes/km travelled/yr
Annual compost production per km (assuming 40% mass reduction)	0.621	Tonnes/km travelled/yr
Current market price (20mm grade - landscaping)	18-20	£/tonne
Current market price (finer material)	25	£/tonne
Current market price (Agricultural uses)	2-3	£/tonne
Potential income per km (20mm grade - landscaping)	11.17-12.40	£/km travelled/yr
Potential income per km (finer material)	15.52	£/km travelled/yr
Potential income per km (agricultural uses)	1.24-1.86	£/km travelled/yr

Table 2.6 Potential income from Compost Production

Based on these values, road verge vegetation has a potential economic value if used for compost or biogas production. The essential question is whether the value of the end products is high enough to justify the cost of harvesting, transporting, and handling the raw material, along with any costs involved in producing and supplying the end products.

Both these case studies (Lincolnshire and Living highways) are great examples of real-life trials that have been conducted and produced genuine reliable data. As a result, the data collected such as the verge grass analysis and the logistics of the grass is all relevant to the Gwent Green Grids project where we can draw on their findings from the studies and utilise it in our current research. Despite the financial figures being out of date by now, it is still useful to give us a baseline understanding of how such a project could be financed and be profitable.

2.5 Contamination of feedstocks

When using feedstock from roadside verges, sports fields and common land, contamination of vegetation can arise from a variety of sources. Roadside verges are susceptible to contaminants from vehicles such as potentially toxic elements (PTE) and polycyclic aromatic hydrocarbons (PAH). Litter can also pose a problem as well as dog faeces. However, an assessment on PTE and PAH contaminants concluded that while higher levels of contamination were found in roadside verge biomass, the levels were well below those which could cause concern for AD plants and pyrolysis. Verge grass is not classified in EA waste regulation and so it is not currently a permitted feedstock unless a temporary exemption is agreed for feedstock and digestate use.

A German PhD project [21] investigated 16 elements (Ca, K, Mg, N, Na, P, S, Al, Cd, Cl, Cr, Cu, Mn, Pb, Si, Zn) contained in grass collected from roadside verges in the city of Kassel. The study was designed to address the specific issues surrounding the use of roadside verge material, following concerns about anticipated contamination from cars and fuel. It therefore studied elemental concentrations of an increased number of heavy metals. All heavy metals were shown to be within the natural range found in grasslands, and all elements except nitrogen and chlorine were below the limiting values for combustion upon collection. N and Cl content fell below the limiting values after an IFBB washing procedure (hydrothermal conditioning).

Litter contamination

For the arisings from cut-and-collect of the verges to be suitable for use in aerobic digestion any litter present must be removed before cutting when it is easier to sort. Currently the most effective method is still the manual collection by hand so the cost of this will need to be factored into the feasibility estimations. The recommended method according to the Combine report, involved 2 teams of 2 litter pickers accompanied by a safety vehicle to display warning messages [22]. With 6 staff working in this way the estimated length of verge that can be cleared within a day is 10km, this was achieved with the 2 teams starting on the same side of the road but working from opposite ends and moving till they met in the middle, and then moving to the other side of the road and repeating this process.

Soil Contamination

Traditional low cutting heights (e.g., 2.5cm) were found to lead to high contamination (about 40%) of soil within the arisings, so was deemed unsuitable. Recommended cutting heights are 10-15cm above ground. The eco mower (Figure 2.6) was able to maintain lower soil contamination at a lower cutting height, although it was necessary to increase mowing speed, and thus decrease fuel efficiency.

Figure 2.6 Herder "Eco" Rotary Mower with Vacuum pick up [20]

Figure 2.7 Flail mower with vacuum pick up [20]

Purification of arisings

If arisings are contaminated with soil / grit, then washing has been shown to successfully remove contamination prior to processing. This, however, uses energy and also washes out some minerals, so results in less biogas generation. It also decreases dry matter which increases weight and therefore washing is only suitable if the facility is located next to the AD plant so that the biomass does not need to be transported. Alternative techniques which have been shown to be effective in removing contamination from the grass are: sieving using a rotary or star sieve; ballistic separator; or magnets22. In a rotary sieve, fine material passes through the sieve and heavy or larger particles are emitted from the end of the cylinder. A star sieve is a similar process but can also sort medium sized particles. A ballistic separator separates out heavy objects, e.g. stones and glass; the heavy fraction is bounced upwards and the light fraction falls to the bottom. Magnets can effectively be used to remove metal objects.

3 Technologies

3.1 Anaerobic digestion

One of the treatments to process feedstock is anaerobic digestion. This is the biological conversion of organic matter to biogas under oxygen free conditions [23]. This process can generate heat and electricity and it also produces a digestate high in nutrients which can be used as a bio fertiliser. The process produces a gas mixture principally composed of methane (CH_4) and carbon dioxide (CO_2), otherwise known as biogas. AD is most used in the UK for processing animal manure and human waste in treatment plants, nevertheless co-digesting crops with manure can improve the performance of digesters which leads to increase in methane yields. Feedstocks for AD can include energy crops, waste food from processing factories, grass silage and agricultural by products such as straw. A wide range of materials can potentially be processed, but each has varying characteristics with regards the quantity of biogas that may be produced and the period over which this digestion may occur. In addition, some materials may have concentrations of other substances (for example Nitrogen or disinfectant) that can adversely impact the microbiology within the digester and therefore a clear understanding what materials are available is necessary. In addition, whilst some materials may be available with no cost, or even at a fee, other materials will have differing costs to the project which can be subject to a range of factors relating to the market and location of the plant. In all cases it is important to assess the difference between the cost of a material in relation to its value (in terms of the quantity and quality) of biogas produced.

Salter [13], found that using verge grass from principal and classified rural roads in England and Wales to generate biomethane for transport fuel could save up to 24 000 t of CO2 per annum. Using verge grass instead of an energy crop can reduce CO2 emissions from AD energy production as GHG emissions from cultivation and fertiliser use are avoided.

With different regions planning different initiatives such as no mow may etc, councils need to ensure a reliable year-round supply of feedstock. This can be done by ensiling which is a biochemical preservation method widely used in livestock farming which converts fresh crop into silage. Once the biomass is sealed under anaerobic conditions lactic acid producing bacteria (LAB) proliferate. LAB ferment the most readily available organic matter into lactic acid, which accumulates, to decrease the pH of the crop to around 4.0 [24]. The decreased pH prevents the growth of spoilage microorganisms, allowing the crop to be stored for a prolonged period [25].

There are many different feedstocks which can be used in an AD plant. This section will examine the options.

Energy crops

Energy crops can be a valuable addition as feedstock to anaerobic digestion plants as these can provide a predictable and consistent source of biogas. The price these crops are available for is inevitably linked to the agricultural market as growers will make decisions on entering contracting arrangements based on the perceived levels of risk and reward within the commodities market. These markets do vary across the region with soil type, weather conditions and historical land use practices. In addition, environmental designations or limitations have an impact; for example, the availability of irrigation water supplies may limit the profitability of certain crops.

Energy crop types

Supplying an AD plant with energy crops can be an effective method of providing a feedstock mix (recipe) that allows effective and efficient processing that maximises methane production. It is also relevant that materials with high starch and fat content will digest at a faster rate than those with a high level of cellulose or lignin.

Energy crops may be of the following type:

- Energy crops – specifically planted high-methane yielding varieties of crops planted specifically for an AD plant – either as part of rotation or a continuous basis. Examples include varieties of maize, rye, triticale and beet.
- Commodity crops – crops grown for the general commodity market, but where the relative pricing makes it more attractive to send to an AD plant – perhaps as a result of oversupply or market changes. An example might be sugar beet that had not been contracted for sugar extraction, wheat where the selling price is lower than the growing price, or the swap of sugar beet for processed sugar beet pulp.
- Break crops – where the crop is grown as part of rotation to control weeds, e.g. Black Grass or soil fertility - Rye or field beans are often used in this regard, but this could also include grass silage where only one cut is taken in a predominantly grazing system (for example sheep or poultry) in order to control animal health and parasites.

The potential biogas yield across these types of crops can vary widely, as illustrated in the table below. It is important to also recognise that not only do different crops have different yields in the field, but they also have differed dry matter contents and the yield and composition of resulting biogas will vary to give differing gas yields per area of each crop grown.

Crop	Crop Yield (typ.) t/ha	Dry Matter (range) %	Biogas Yield (typ.) m³/t	CH_4 conv. %	CH_4 Yield m³/t	CH_4 Yield. m³/ha	Advantages	Disadvantages
Energy maize	60	27-31	200	53	105	6,300	High methane yield/ha Easy storage and feeding	Relatively slow retention time
Forage maize	45	28-35	200	53	105	4,725		
Ensiled beet	100	22-24	180	55	99	9,900	Highest possible yield per ha Fastest possible retention time	Needs specialised machinery and careful storage
Whole crop cereals (e.g. wheat, triticale, barley)	40	33-36	200	54	108	4,320	High whole crop yield with high DM Acceptable for drought prone areas Good feedstock partner for maize	Needs short chop length at harvest
Hybrid Rye	40	33-36	200	54	108	4,320		
Grass silage	25	25-28	160	53	90	2,250	High DM – but 20% lower gas yields per t fresh weight	Low methane yield per area grown

Table 3.1 Typical Energy Crops and Yields

Commercial, industrial, and other wastes

To enhance the energy yields and community participation of the AD plant, it is proposed that suitable wastes and residues from other sectors of the local economy may be accepted into the plant. The acceptance of such materials can be a valuable addition to the project, as many of these materials have the potential to generate significant biogas yields, however they do bring additional management

The process of anaerobic digestion consists of three steps. The first step is the decomposition (hydrolysis) of plant or animal matter. This step breaks down the complex organic material to usable-sized molecules such as sugars. The second step is the conversion of decomposed matter to simpler soluble organic molecules, including volatile fatty acids (VFA's). Other micro-organisms then finally convert the VFA's into methane. An AD reactor may consist of a single chamber, in which all three stages occur together, or it may comprise two or three consecutive chambers, which allows physical separation of the biochemical stages.

In a single stage reactor, the aim is to optimise conditions for both groups of micro-organisms, but the second group (those responsible for converting VFA's to methane) work more slowly than the first and are inhibited by low pH values. Hence, if for any reason they don't keep up with the first group, the pH falls due to excess VFA production, the rate of conversion to methane falls still further and the process can grind to a halt. A high level of VFA's in a single-stage reactor is therefore an indication of inefficiency (not all the feedstock (raw material) is being converted) and of impending operational problems. On the other hand, a feedstock that produces lots of VFA is a good one for biogas production if the conditions can be controlled. For these reasons, VFA's and pH are often monitored during the process.

Feedstock	Biogas Yield (m3/t)	Feedstock	Biogas Yield (m3/t)
Cattle slurry	*15-25 (10% DM)*	Potatoes	276-400
Pig slurry	*15-25 (8% DM)*	Rye grain	283-492
Poultry	*30-100 (20% DM)*	Clover grass	290-390
Grass silage	*160-200 (28% DM)*	Sorghum	295-372
Whole wheat crop	*185 (33% DM)*	Grass	298-467
Maize silage	*200-220 (33% DM)*	Red clover	300-350
Maize grain	*560 (80% DM)*	Jerusalem artichoke	300-370
Crude glycerine	*580-1000 (80% DM)*	Turnip	314
Wheat grain	*610 (85% DM)*	Rhubarb	320-490
Rape meal	*620 (90% DM)*	Triticale	337-555
Fats	*up to 1200*	Oilseed rape	340-340
Nettle	120-420	Canary grass	340-430
Sunflower	154-400	Alfalfa	340-500
Miscanthus	179-218	Clover	345-350
Flax	212	Barley	353-658
Sudan grass	213-303	Hemp	355-409
Sugar beet	236-381	Wheat grain	384-426
Kale	240-334	Peas	390
Straw	242-324	Ryegrass	390-410
Oats grain	250-295	Leaves	417-453

Table 3.2 Biogas yield and feedstock productivity [26]

The table above shows data on the potential biogas yields of feedstocks commonly used in anaerobic digestion (numbers given in *italics* are taken from an AD calculator produced for NNFCC by The Andersons Centre, all other numbers are from Biogas from Energy Crop Digestion by the IEA [27]). All figures are based on fresh weight unless stated. For the sake of the GGG project, it is important to note that the biogas yield of grass is 298-467 (m^3/t) and leaves is 417-453(m^3/t). The yield of biogas from a particular feedstock will vary accordingly. The purity of the feedstock, length of time in the digester, the type of AD plant, dry matter content and the energy left in the feedstock are variables that can affect the yield of biogas.

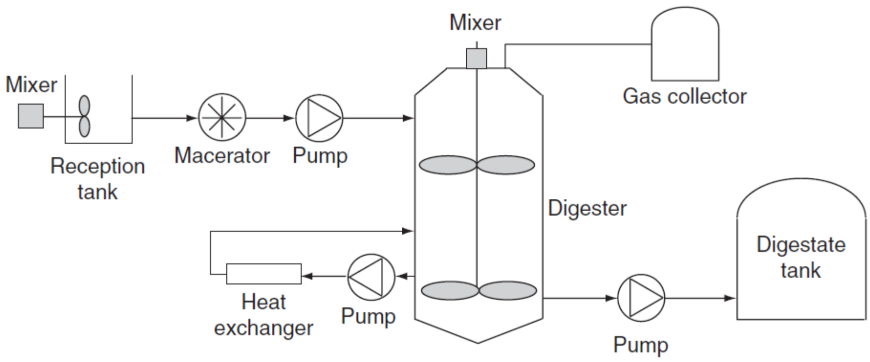


Figure 3.1 A simplified example of an anaerobic digester system

At its simplest as shown above, an anaerobic digester consists of a sealed vessel (the digester) to which a substrate (the material to be digested) is added. When new material is added, a volume of digestate is removed so that the volume of the digester contents remains constant. Digestion usually takes place within one of two temperature ranges: mesophilic (30–428°C) or thermophilic (50–608°C). To achieve these temperatures, the digester is heated by internal or external heat exchangers. To aid the digestion process the digester may be stirred either mechanically or by pumping the biogas back through the digester contents. The digester itself requires electricity for pumps, mixers, and so on, and for heating (both to maintain the digester at the optimum operating temperature and to raise the temperature of the feedstock from ambient to that of the digester).

There are various technologies available for anaerobic digestion. The digester can be wet or dry, mesophilic or thermophilic and a single or multistage. Currently in the UK the most common type is the mesophilic, wet, single style. Generally, AD is conducted in the form of liquid at low total solid (TS) content less than 15% and this is called wet anaerobic digestion. Wet AD is suitable for wastes with low TS contents (and high moisture content). However, to maintain low TS content in the reactor, it requires a large amount of water if it treats wastes with high TS content, such as lignocellulosic biomass, resulting in increase in reactor volume as well as generation of a huge volume of wastewater to be treated. On the contrary to wet anaerobic digestion, operation at TS content of higher than 15% is classified as dry (solid-state) anaerobic digestion. Dry anaerobic digestion has several advantages over wet anaerobic digestion such as less freshwater usage and favourable energy balance. Agricultural waste such as lignocellulosic biomass has high TS content. For example, TS contents of the corn silage, grasses, and straw biomasses are 25–89%. For livestock manure, depending on pre-treatment (solid–liquid separation), TS contents of solid phase are 18–30%. Therefore, agricultural wastes are suitable in dry anaerobic digestion in terms of TS content. Total solid contents of the solid fraction after solid–liquid separation of wet digestate is 23–30%, which are comparable or slightly higher than TS content of the dry anaerobic digestate (TS content in the reactor). Therefore, it would be expected that dry anaerobic digestion would reduce post-digestate treatment such as solid–liquid separation and treatment of liquid fraction, which can reduce energy consumption and cost for plant construction and operation. Therefore, dry anaerobic digestion would have more advantages over wet anaerobic digestion for biorefinery of agricultural wastes.

Although dry anaerobic digestion has several benefits, still wet anaerobic digestion plants have more advantages in terms of energy balance and cost performance in practice. Digestate from the anaerobic digester can be used as fertilizer as it contains nutrient for crop growth or further processed to produce value-added products as noted above. For digestate from wet anaerobic digestion, digestates are subjected to solid–liquid separation [18]. These liquid fraction and solid fraction can be used as fertilizer [18]. Numerous studies have been conducted to evaluate effect of digestate from the wet anaerobic digestion on crop production and environmental risks [15], while digestate from the dry anaerobic digestion has not been well studied. Wet anaerobic digestion systems are designed to process biodegradable feedstock into a digestate slurry with typically less than 15% total solids. For feedstock with high total solids, the mix is diluted with either fresh water, re-circulated process water, or another organic waste with a lower total solid's percentage to the incoming waste stream (i.e. co-digestion).

The differences in wet anaerobic digestion and dry anaerobic digestion are that in wet AD, the feedstock is pumped, heated, and stirred (5-15% solids) and in dry AD it can be stacked (over 15% solids), with leachate sprayed over the top of it which percolates through the material, breaking it down over a longer retention time. Wet systems have a successful track record in treating low solid materials such as human sewage and food waste.

Dry Digestion in full-scale application can be performed in a continuous or discontinuous system. Dry digestion is called discontinuous because biogas production is sequenced with loading and unloading phases. Several digesters will operate in parallel and allow a constant production of biogas over time.

Dry anaerobic digestion is an alternative solution to wet anaerobic digestion to optimize the value of manure. In fact, a wet anaerobic digestion plant is quite limited for the treatment of dry matter-based substrate. Dry anaerobic digestion systems allow the use of substrates with a high content of crop residues, household waste and livestock manure.

Advantages and disadvantages of dry anaerobic digestion	
Advantages	Disadvantages
• Dry matter / total solids 20-40% compared to 20% maximum for wet digestion	• Special technologies for loading and unloading of the digester are necessary
• Low power and heat needs	• Need to manage the variation of biogas and heat production
• Very tolerant system for contaminants (sand, fibres, large particles, etc.)	• Not totally mixed
• Very tolerant system for contaminants (sand, fibres, large particles, etc.)	• In discontinuous systems, the microbial process has to start for each batch
• Management of several digesters simultaneously	• In many cases, lower methane yields compared to wet AD systems
• Less critical equipment (pumps, agitation systems, feeding equipment)	• In many cases, large quantities of structure material is required (a lot of digester space is consumed for structure material)
• Production of land-applied solid digestate similar to manure	
• Low amount of water	

Table 3.3 Advantages and disadvantages of dry anaerobic digestion

Advantages and disadvantages of wet anaerobic digestion	
Advantages	Disadvantages
• Greater flexibility in the materials to be treated	• Need to add liquid to reduce the dry matter of the mixture
• Low investment and operating costs	• Requires robust and costly mixing equipment
• Integrated biological desulphurization	• Significant energy requirements of the facility to run pumps and agitators
	• Production of wet digestate that can modify practices for land application and lead to additional investments (slurry tankers) • Lower dry matter content for the digestate

Table 3.4 Advantages and disadvantages of wet anaerobic digestion

Comparison Criteria	Wet Digestion	Dry Digestion
Input material	maximum 20% dry matter	20-40% dry matter
Water consumption	Dilution may be necessary	Percolat renewal
Process stability	Easier to intervene in the case of biological malfunction	Need to manage several digestors simultaneusly
Heat need	20 to 30% of the heat produced	Lower need for thermally insulated installations
Power need	Pumps and mixers	Low
Fuel need	None, except if dualfuel engine	None, except if dualfuel engine
Digestate	Pumpable	Removed with loader
Manpower need	Possible automation	Important for loading/unloading
Biogas production	Linear production	Sequenced production over time
Security	Plant commissioning = high risk period	Loading/unloading = high risk period

Figure 3.2 Comparison of anaerobic digestion processes (Collective farming grouping)

Key parameters of dry anaerobic digestion

Anaerobic digestion is conducted by anaerobic microorganisms contributing to hydrolysis, acid production, and methane production. Therefore, operation parameters should be considered for their growth and inhibition. For example, manures containing high concentration of ammonia causes ammonia inhibition. In addition, higher TS content in the dry anaerobic digester causes slow mass transfer, resulting in slow decomposition of intermediate. The accumulation of the intermediate will result in inhibition of methane production. In this section, important parameters of dry anaerobic digestion were reviewed.

Total solid content

High total solid (TS) content can reduce reactor volume and capital cost [9]. However, in dry anaerobic digestion, higher TS content reduces methane production. Xu et al. reported that maximum methane production rates were proportionally increased with TS content between 0 and 20% while gradually decreased from 20% TS to 30% TS content in mesophilic digestion of corn stover [33]. For mesophilic dry digestion of empty fruit bunch and oil palm trunk, methane yields at 16 and 25% TS contents were 250–350 mL g−1 VS. At 35% TS content, however methane yields were less than 100 mL g−1 VS with some exception [31]. In semi-batch dry thermophilic co-digestion of pig manure and rice straw, biogas yields were around 600 mL g−1 VS, and no VFAs accumulation was observed between 18% and 27% of TS content in the reactor [16]. However, biogas production was decreased concomitantly with VFAs accumulation when TS content in the reactor exceeded 28% [16]. Therefore, TS content should be carefully chosen and managed.

Over the past 30 years, dry anaerobic digestion process has been developed and marketed by different companies in Europe. Commercial dry anaerobic digestion processes such as Valorga, Dranco, Kompogas, Bekon, and Bioferm are the most prevalent processes for treating municipal solid waste (MSW), biowaste, livestock waste, as well as green waste (Table 1) [10, 39].

Technology			Waste	Temperature (°C)	TS (%)	SRT*/ Digestion period (days)	Biogas yield (m³/t**)	Capacity (1000 tons/year)	Plants***
Full scale	Continuous	Valorga	MSW****	35, 55	25-35	16-35	80-160	10-498	27
		Dranco	MSW	55	20-50	13-30	103-147	3-320	32
		Kompogas	MSW, green waste	55	23-28	15-20	110-130	15-274	25
	Batch	Bekon	Biowaste, agricultural waste	35, 55	Na	28-35	130	4.5-60	60
		Bioferm	Food waste, green waste, agricultural waste	35	25	28	Na	8	9
							Methane yield	Scale (L)	
New case studies	Continuous	Kim and Oh [49]	Food waste, livestock waste	35	30-50	30-100	250 L/g COD	60	
		Zeshan et al. [48]	MSW	35-55	18	13-153	121–327 L/kg VS	690	Na
	Batch process	Meng et al. [51]	Rice straw, pig manure	55	20	40	191 L/kg VS	0.5	

*: Sludge retention time
**: Wet weight base
***: Accessed at 30 December 30, 2019
****: Municipal solid waste
Na: No data

Table 3.5 Performance and parameters of commercial and new case studies of dry anaerobic digestion process. source

To improve homogenization, several different types of continuous dry anaerobic digestion processes such as Valorga (France), Kompogas (Switzerland), and Dranco (Belgium) have been proposed. In continuous digesters, wastes (substrate) are added to the digester at regular intervals, and equal amounts of finished products (digestate) are removed. For example, Valorga process sets a central baffle in the vertical steel tank, and the baffle extends two thirds of the way through the center of the tank. Wastes are forced to flow around the baffle from the inlet to reach the outlet port on the opposite side, creating a plug flow in the reactor. Pressured biogas is provided at the base of the tank at intervals, which promotes the moving up of wastes to the opposite side of the tank and the contact between wastes and mature digestate as shown below in Figure 3.3.

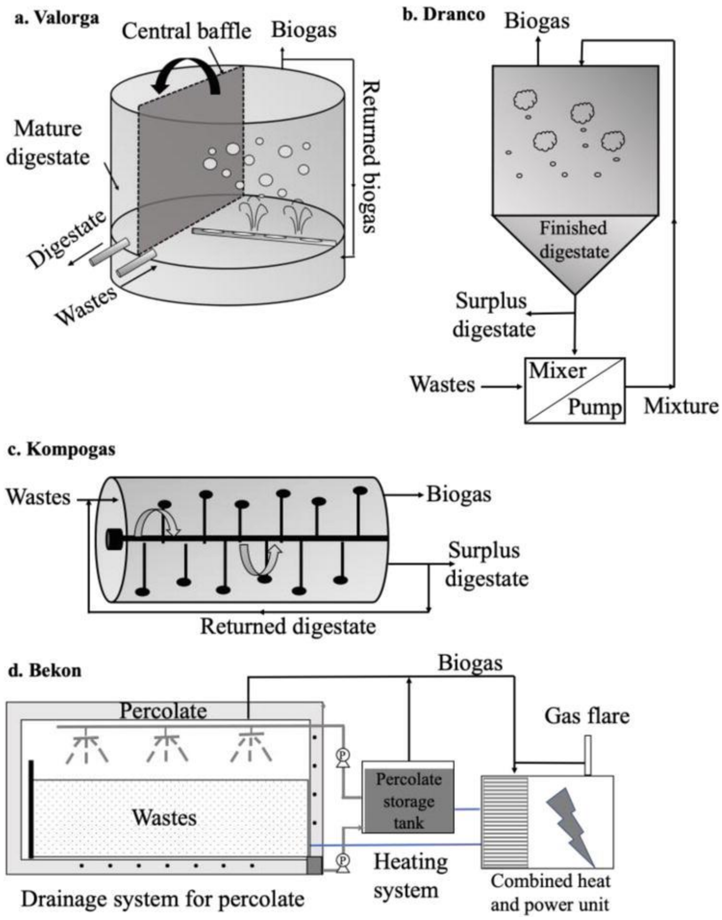


Figure 3.3 Dry anaerobic digestion designs

Like Valorga process, vertical tank is also used in Dranco process. However, different to Valorga process, Dranco process performs the mixing of wastes and finished digestates by a special pump (mix and introduce the mixture of wastes and finished digestates to the pipeline) before introducing the mixture into the inlet located at the top of the tank. Thereafter, introduced mixture moves from the top to the bottom (outlet) by gravity without any internal mixing mechanism during digestion (Figure 1b). Total solid content in Dranco process usually ranges from 20 to 50%, while the SRT ranges from 13 days to 30 days. Approximately 103–147 m3 t−1 of biogas can be recovered.

Different to Valorga and Dranco processes, Kompogas digester is a horizontal steel tank with slowly rotating axial mixers that assist in conveying the material from the inlet to the outlet, keep heavy solids in suspension, and degas the thick digestate. Finished digestates are recycled to inoculate the fresh wastes (Figure 1c). TS in Kompogas process usually ranges from 23 to 28%, and processed water may be added to reduce the solid content, while the SRT ranges from 15 days to 20 days. Approximately 110–130 m^3 t^{-1} of biogas can be recovered [41, 45].

Existing anaerobic digesters in South Wales

As part of this project, we are aiming to see which waste treatment method is most suitable for the feedstock. Therefore, it is important to look at already existing AD plants in South Wales. Data provided by the Welsh Government gives a detailed breakdown of the type and the amount of waste each region is already sending to AD plants in South Wales. Currently the 5 regions provide feedstock to various treatment centres in South Wales. The table below illustrates the figures all the different sites and the amount of feedstock sent from each region. Additionally, we will open dialogue with these different treatment centres to see if they have the capacity to accept more feedstock if each region was to increase their cut and collect capacity. As part of this project, we aim to cover every aspect, and therefore we will also be looking at costings and financial modelling and the feasibility for establishing a completely new AD site as part of the GGG project.

	Biogen AD Aberdare	Parc Stormy AD Bridgend (Agrivert)	Bryn Group AD Gelligaer	Allt yr yn Newport composting centre	Green waste company (Abergavenny)	Agrivert LTD Wallingford
Site Annual Capacity	22,500 tonnes	50,000 tonnes	13,500 tonnes	10,000 tonnes		10,000 tonnes
Newport	3900 tonnes of organic waste			8800 tonnes of organic waste		
Torfaen		3300 tonnes of organic waste	1500 tonnes of organic waste			3100 tonnes of organic waste
Blaenau Gwent		3000 tonnes of organic waste		649 tonnes of organic waste.		3000 tonnes of organic waste
Monmouthshire		5000 tonnes of organic waste			5000 tonnes of organic waste	207 tonnes of organic waste
Caerphilly			11800 tonnes of organic waste			

Table 3.6 Table showing the existing AD plants in South Wales and the current supply of organic matter from local counties

Composting

Compost is a common name for humus, which is the result of the aerobic decomposition of biological material. This is another treatment method to deal with feedstock. During aerobic decomposition (in the presence of oxygen), there is no net production of greenhouse gases. Although carbon dioxide (CO2), a greenhouse gas, is produced, the amount of CO2 released only corresponds to the CO2 that was fixed from the atmosphere into the plant material when it was alive. Hence, there is no net release of CO2 and no net contribution to global warming. During the composting process, decomposition is performed primarily by microbes, although larger invertebrates such as worms and ants contribute to the process. Decomposition occurs naturally in all but the most hostile environments. However, rather than allowing nature to take its slow course, commercial compost producers aim to provide an optimal environment in which decomposers can thrive. To encourage the most active microbes, the compost pile needs the proper mix of ingredients, especially Carbon, Nitrogen, Oxygen, and water. Decomposition happens even in the absence of some of these ingredients but is much slower. (Mention composting in South Wales relevant to GGG)

Verge grass as a feedstock

Studies found that verge grass was suitable for digestion, but problems with available machinery, the safe operation of vehicles during harvesting and year to year variations in yields were encountered, and it was expected that financial subsidies may be needed to support harvesting. Salter [13], found that using verge grass from principal and classified rural roads in England and Wales to generate biomethane for transport fuel could save up to 24 000 t of CO_2 per annum. Using verge grass instead of an energy crop can reduce CO_2 emissions from AD energy production as GHG emissions from cultivation and fertiliser use are avoided, although the level of reduction will depend on the specific crops replaced and any resulting land use changes. Grass is a sustainable source of lignocellulosic material which can be cultivated on non-arable lands, making it non-competitive with other crops for food production [28]

To ensure a reliable, year-round supply of feedstock the grass is usually ensiled. Ensiling is a biochemical preservation method widely used in livestock farming which converts fresh crop into silage. Once the biomass is sealed under anaerobic conditions lactic acid producing bacteria (LAB) proliferate. LAB ferment the most readily available organic matter into lactic acid, which accumulates, to decrease the pH of the crop to around 4.0 [29]. The decreased pH prevents the growth of spoilage microorganisms, allowing the crop to be stored for a prolonged period [30]

3.2 Pyrolysis & Biochar

What is Biochar?

Biochar is a black, carbon-rich, material produced by thermally treating biomass materials in zero- or limited-oxygen conditions using a process called pyrolysis. It is a highly porous product with a very large surface area. Biochar has a high carbon content, more than 60%, and therefore is an effective means of locking away carbon when used in long term applications. When applied to land, biochar is not only a carbon sink, but can act as a soil improver by increasing the water and nutrient-holding capacity of the soil. It may also be effective in demin greenhouse gas emissions from the soil. With the correct calibration, therefore, biochar application could offer considerable benefits in terms of mitigating climate change, improving food security and reducing reliance on chemical fertilisers, all of which could have considerable environmental and economic advantage.

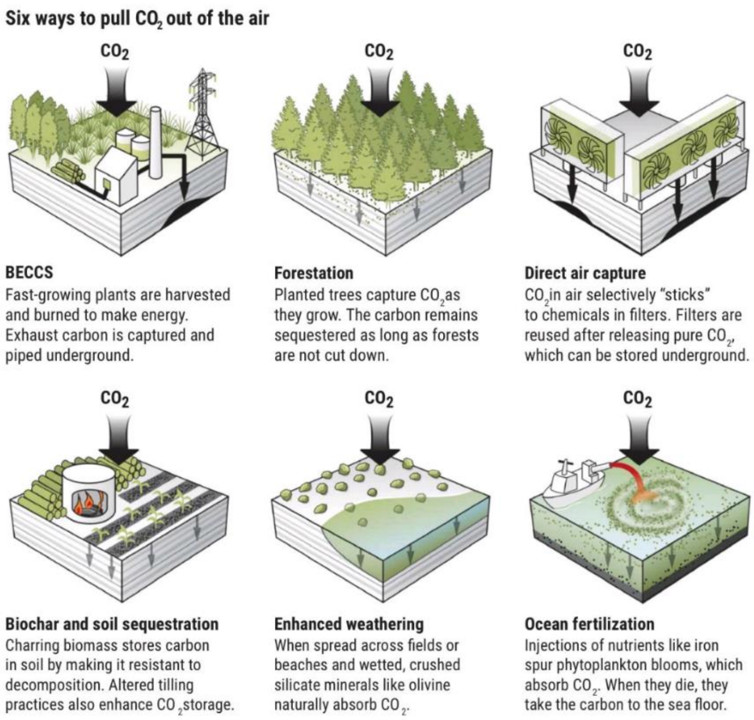


Figure 3.4 Six Carbon capture & storage methods, IPCC Special report

Biochar production, and subsequent sequestration into soil, is one of six Carbon Capture &Storage methods detailed in the IPCC Special Report "Global Warming of 1.5°C" [4], and is recognised by the global carbon trading marketplace, Puro Earth, as one of three carbon removal methods eligible for sale of carbon removal certificates (CORCS). As a result, there are likely to be opportunities to attract environmental payments for carbon sequestration soon, as the new agricultural payments system develop into payment for eco-system services.

It is widely recognised that for every 1 tonne of Biochar produced 3.6 tonnes of CO_2 are sequestered and the whole pyrolysis process is carbon negative as the process is a self-sustaining exothermic reaction.

Pyrolysis

Pyrolysis is the heating of an organic material such as biomass in the absence of oxygen. As a result of no oxygen being present, the material does not combust and the chemical compounds that make up that material thermally decompose into combustible gases and charcoal. Thus, pyrolysis of biomass produces three products: one liquid, bio-oil, one solid, biochar and one gaseous (syngas). The proportion of these products depends on several factors including the composition of the feedstock and process parameters. Figure 3.5 below illustrates the process.

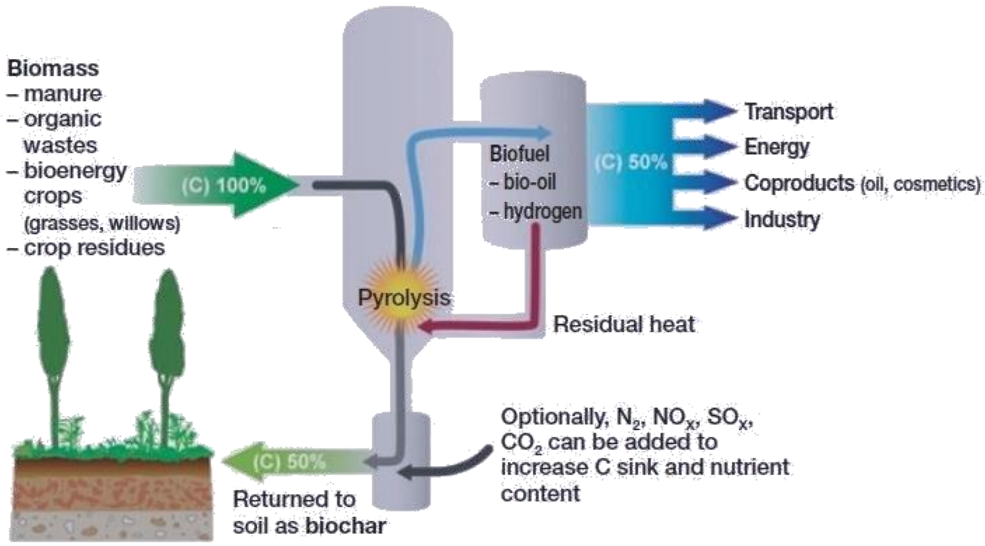


Figure 3.5 Concept of pyrolysis process

Circular Carbon Economy

So, why is biochar so relevant? Carbon is essential for all life on earth- we are in essence carbon-based life forms. Our bodies are 18.5 percent carbon, by weight. Every living thing is built on a backbone of carbon; animals, plants, every living cell, and of course humans rely on the existence of the element know as carbon.

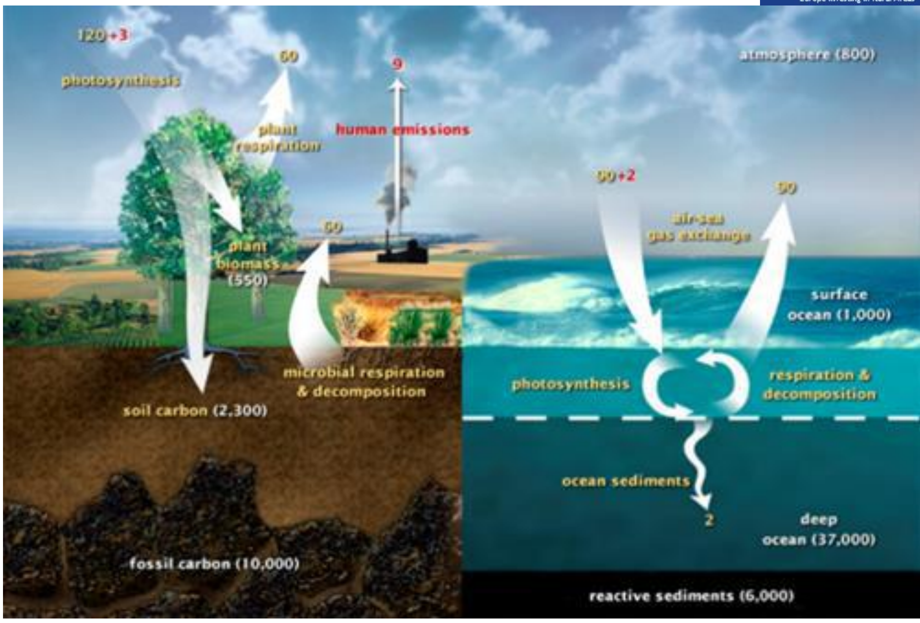


Figure 3.6 Carbon cycle

To place this into context we must briefly touch upon what is known as the carbon cycle, Figure 3.6-. This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans.

Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon. (Diagram adapted from U.S. DOE, Biological and Environmental Research Information System.)

Our issues around climate change arise when the store of fossil carbon is essentially converted into atmospheric carbon, impacting a delicate balance. It is these impacts that are pushing us to try and do more with biomass carbon and less with fossil carbon. This is where the notion of the circular bioeconomy comes into play, and this is why biochar is so relevant. The Circular Bioeconomy and the circular carbon economy share many parallels and in many instances are complimentary.

The bioeconomy operates in principles of cascading uses for a bioresource where the most value and use can be extracted from different streams of the material, ultimately extending the usefulness of a material or resource, allowing for the waste from one process to be used as the input for another and ultimately improving efficiencies of production while minimising the amount of waste in a system. It is within these systems that biochar production and use can play an integral role. A successful and sustainable bioeconomy will rely on a healthy environment and indeed biochar has its role to play in achieving this.

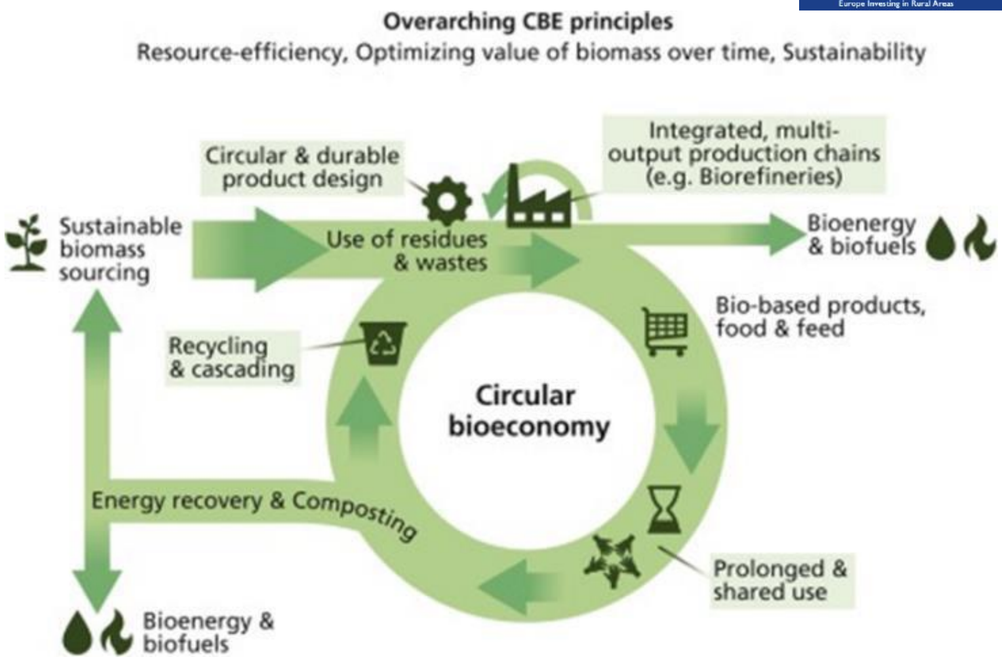


Figure 3.7 Circular bioeconomy [31]

Pyrolysis Technology

Pyrolysis technology broadly sits in three categories: Open/flame cap kilns, Batch kilns and Continuous operation kilns. This section will provide a brief overview of each of these technology types looking at micro scale units up to Macro scale units.

Open/Flame cap kilns

Figure 3.8 Earthly Biochar kiln

Figure 3.9 Kon Tiki Kiln

Open/Flame cap kilns are on the lower tech side of things, such as this Kon tiki kiln pictured Figure 3.9.

Once the kiln is loaded with dry biomass it is lit in a similar fashion to a firepit. Once heat is applied, the biomass begins releasing combustible gases. The shape of the kiln angles this gas to be self-ignited just above the biomass creating a "flame cap". This essentially means the material underneath the cap is receiving low amounts of oxygen, which has the effect of charring the biomass, creating biochar.

The Kiln in figure 3.9 is by Earthly Biochar and costs £697. It is a 25-litre chamber and can produce 10 litres of biochar per burn (1 hour). It heats up to 600°C and comes with a 5-year warranty. It is a small-scale batch process unit which is labour intensive It requires careful monitoring throughout. It also requires a dry biomass feedstock to prevent high levels of smoke and particulates. However, if done correctly, this can produce a good quality biochar.

Another variation of that technology is open fire cone kiln. It is once again on the lower tech side of things and is very labour intensive. The kiln is stacked with wood and is lit from the top. This creates a strong up draft in the stacking wood chimney which pulls in air at the side walls of the kiln. Once the surfaces become hot enough add the first charring layer of wood. From this then build the kiln up layer-by-layer every time the surface of the wood or biomass on the top layer starts to ash. As a result of the vortex system, smoke, vapours, and syngas's mix and burn cleanly. This technology is a batch process and costs roughly £1000-2000.

Figure 3.10 Open fire cone kiln

Batch Kilns

Batch kilns, like the Exeter Retort pictured here, are the next step up from your basic open kilns. Also relatively cheap, generally costing 15-20 thousand pounds, they work in a similar fashion and are also classed as slow pyrolysis but are designed to optimise the process. In this case this is also mobile, with the whole process mounted on a trailer making it particularly suitable for land management of a wide mix of feedstocks. The Exeter Retort is a twin-chambered unit consisting of an inner chamber where the material is heated and an outer "firebox" chamber where the initial kindling feedstock is placed to start the process off. Once ignited the whole unit is sealed and once the process has driven off the water from the feedstock, normally at around 350-400 degrees, the process starts to give off combustible syngas. This gas is then diverted back into the outer firebox chamber and the process becomes autothermic meaning it continues to heat itself. The process takes 6-8 hours and, as with the open kilns, is labour intensive as it requires manually loading/unloading and monitoring. It also needs to be left to cool before it can be opened and emptied (normally overnight) making the whole process a two-day event. Failure to let the chamber cool sufficiently could lead it to auto-ignite when opened.

Figure 3.11 Exeter retort

These retorts are generally larger than the open kilns and can produce hundreds of Kgs of char per run. As well as being fully mobile, other key benefits provided by some of these units are the ability to capture the early gas from the process and condense this into another useful horticultural product, wood vinegar, which has a range of applications ranging from bio-stimulants to biopesticides for plant growth. Some retorts also have the potential to capture both the excess heat and gas from the process. The price of the Exeter retort is around £18000 and can be mounted to a trailer if required.

Figure 3.12 Four seasons retort

Pictured here is the four seasons RTD 1600 charcoal retort. This retort has a conversion rate of 4 tonnes of wood feedstock to 1 tonne of biochar. The labour intensity is high, but this can be reduced massively by using cassettes. This retort costs £47500 and this comes with training and commissioning. This retort has a burn time of approximately 8-10 hours.

The retort works by heating wood in an enclosed cylinder within and the recovering wood gas vapours are given off during the process passing into the firebox and reactive the gases and retorts round the charge drum. The retort requires wood to be cut into 30mm length. It states that one retort using cassettes would produce 2500-2700kgs per 5 working day week and 10000-11000kgs per working calendar.

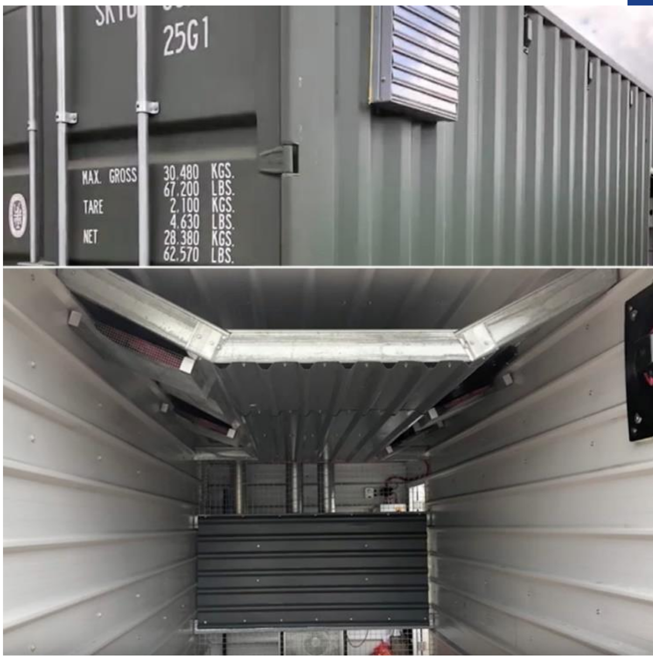


Figure 3.13 Four seasons wood dryer

With the four seasons retort, they also offer a compact wood dryer that will kiln dry 12 m^3 of wood and operates at a temperature of between 70-85°C. The dryer has 6 fans for maximum efficiency. To ensure heat is not lost during the kiln drying process the kiln dryer is fully insulated (including the flooring which has 100 mm of insulation). This will give the option for Rhondda skyline to dry firewood to sell and create a separate revenue stream. The cost of this dryer is £28,000.

Continuous Operation Kilns

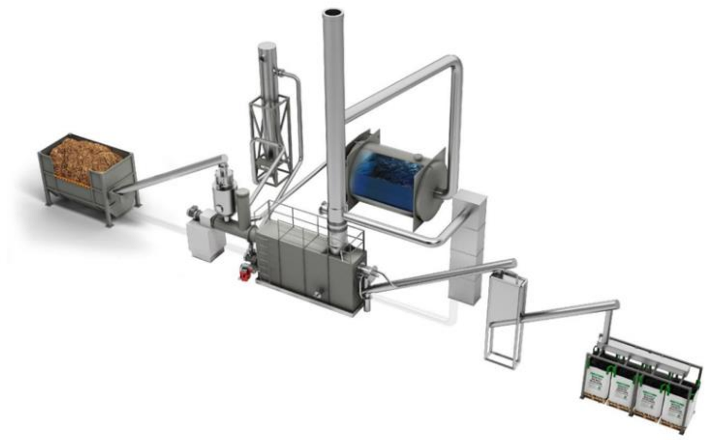


Figure 3.14 Carboflex kiln

The final style of pyrolysis technology is the continuous operation kiln. These are designed for industrial purposes and the jump in cost is significant, into the hundreds of thousands of pounds. However, this is for good reason as the throughput and output of this style is significantly increased and more importantly consistency and replicability are ensured for a product that can be certified.

These units are typically fully automated, with remote monitoring and control. They come fitted with flameless oxidisers or afterburners which oxidises any potential harmful particulates at high temperatures. These units will have a means to utilise the excess heat produced, whether it is to pre-dry new feedstock or, as is the case of the plant pictured by Carboflex in Finland, to provide carbon negative district heating or process heat for industry.

Feedstock data

The cell walls of plants are made up of 4 main components: cellulose, hemicellulose, lignin and pectin, and the arrangement of these components determine the plant's mechanical properties, e.g., strength, flexibility. In general terms, woody plant species have tightly bound fibres and are richer in lignin while herbaceous plants have more loosely bound fibres, and a lower lignin content. For biochar production, a higher lignin content (i.e. woody biomass) will result in a higher quality biochar.

The Re-Direct project investigated a range of ubiquitous, underutilised biomass species from the European partner countries as a feedstock for biochar (and activated carbon) production. Many of these feedstocks are widespread on Welsh agricultural and common land and can pose considerable problems in terms of land management for biodiversity, access, or amenity value.

Untreated biomass	Carbon (%DM)	Lignin (%DM)	Ash (%DM)
Bracken	47.5	32	5.3
Rush (*Juncus effusus*)	47	6.7	3.3
Moor grass (*Molinia* sp.)	48	9	2.6
Rhododendron	NA	19	3.0

Roadside verge arisings	45	7	13
Japanese Knotweed, young	47	13	7
Japanese Knotweed, old	44	23	13
Raspberry pruning	47	12	2.0
Fruit stones	54	42	0.8
Green cut	46	8.3	14
Nature conservation grass	49	6.8	4.5
Horse manure	45	19	11
Communal green cut	44	12.8	7.4
European Gorse	45	25	1.5

Table 3.7 Chemical composition of the investigated untreated biomasses (DM = Dry Matter).

The full list of biomass feedstock investigated (Table 3.7) shows carbon content of all feedstocks to lie within the range of 44% to 54%, with the highest value pertaining to fruit stones. Lignin content has a wider range of values from 6.7% to 42%. The highest value again relates to fruit stones, which suggests these may produce the best quality biochar. This data will be useful for the project by detailing the different properties of biomass that they could potentially use; however, it will mainly be variations of hard and softwood we will be looking at in this project.

Biochar production from Re-Direct feedstocks

During the Re-Direct project, there were some changes to feedstocks supplied and therefore presented for biochar production and analysis. The results of the analysis, therefore, do not contain all biomass feedstocks as shown in the previous section. The biochar produced was analysed for Carbon content, Ash content and molar H/C_{org}. Pyrolyzed matter with carbon content above 60 % constitute a promising material and can be classified as biochar. Pyrolyzed matter with carbon contents below 50 % are not classified as biochar, but as Pyrogenic Carbonaceous Material (PCM), and offer limited benefits for biochar uses.

The ash content expresses the mineral content of the biomass and its pyrolyzed feedstock. Promising materials show an ash content below 10 % DM. When using mineral-rich feedstocks such as animal manure, the pyrolyzed products may contain more ash than carbon. This ash can still be valuable for fertiliser purposes, but does not have carbon sequestration value, and will have limited value for the benefits of biochar.

The molar H/C_{org} ratio is an indicator of the degree of carbonisation and therefore of the biochar stability. The ratio is one of the most important characterising features of biochar, as it represents its long-term carbon sequestration function. Values can fluctuate depending on the biomass and production process used. Values exceeding 0.7 are an indication of nonpyrolytic chars or pyrolysis deficiencies.

The results from the Re-Direct project's biochar analysis (Table 3.8) shows a high-quality biochar product was obtained from the feedstocks where all results are shown in green. Of relevance to the Gwent Green Grids project, are grasses and woody feedstocks. These woody feedstocks, as expected, produced biochar with a high carbon content, low ash content and low H/C_{org} ratio, and therefore offer the most benefit in terms of carbon sequestration and the wide range of benefits as described above in biochar uses.

Other studies have investigated a broad range of wood (tree sp.) feedstock which have shown high quality biochar production due to the high lignin content. Other feedstocks of value include Rush, Moor grass, Rhododendron and Gorse; all of which may be managed in the GGG area. Bracken, grass and roadside verge arisings although showing higher ash fractions, are also promising feedstocks, and other studies have reported successful biochar production and uses from them.

Biomass	Carbon	Ash	molar H/C_{org}
Rush (*Juncus effusus*)	74	9	0.4
Moor grass (*Molinia* sp.)	73	5.2	0.46
Bracken	68	12	0.46
Rhododendron	74	4.2	0.47
European Gorse	80	5.2	0.38
Horticultural waste	30	N/A	0.49
Communal green cut	41	29	0.79
Wood chip	80	3.9	0.4
Wood chip particles	73	8.1	0.45

Green cut	41	29	0.79
Conservation grass	54	16.5	0.61
Horse manure	54	11.5	0.64
Roadside verge arisings	57	21	0.61
Knotweed, young	65	14.3	0.46
Knotweed, old	59	25.8	0.47
Raspberry pruning’s	70	8.2	0.48

Table 3.8 Average concentration of carbon, ash and molar H/Corg ratio for biochar produced from biomass feedstock.

Key		high quality		medium quality		low quality

Of note is that a pre-treatment process to developed in the Re-Direct project to separate the liquid press fluid from the grass feedstocks was successful in creating a dry press cake which created a higher quality biochar.

IFBB, first developed by the University of Kassel in Germany stand for the Integrated Generation of Solid Fuel and Biogas from Biomass. Importantly this process allows for feedstocks such as grass arisings to produce both biochar and a press fluid feedstock for AD. This press fluid has a potential value as compared to the direct grass feedstock and can be easily transported and accommodated into wet AD processes.

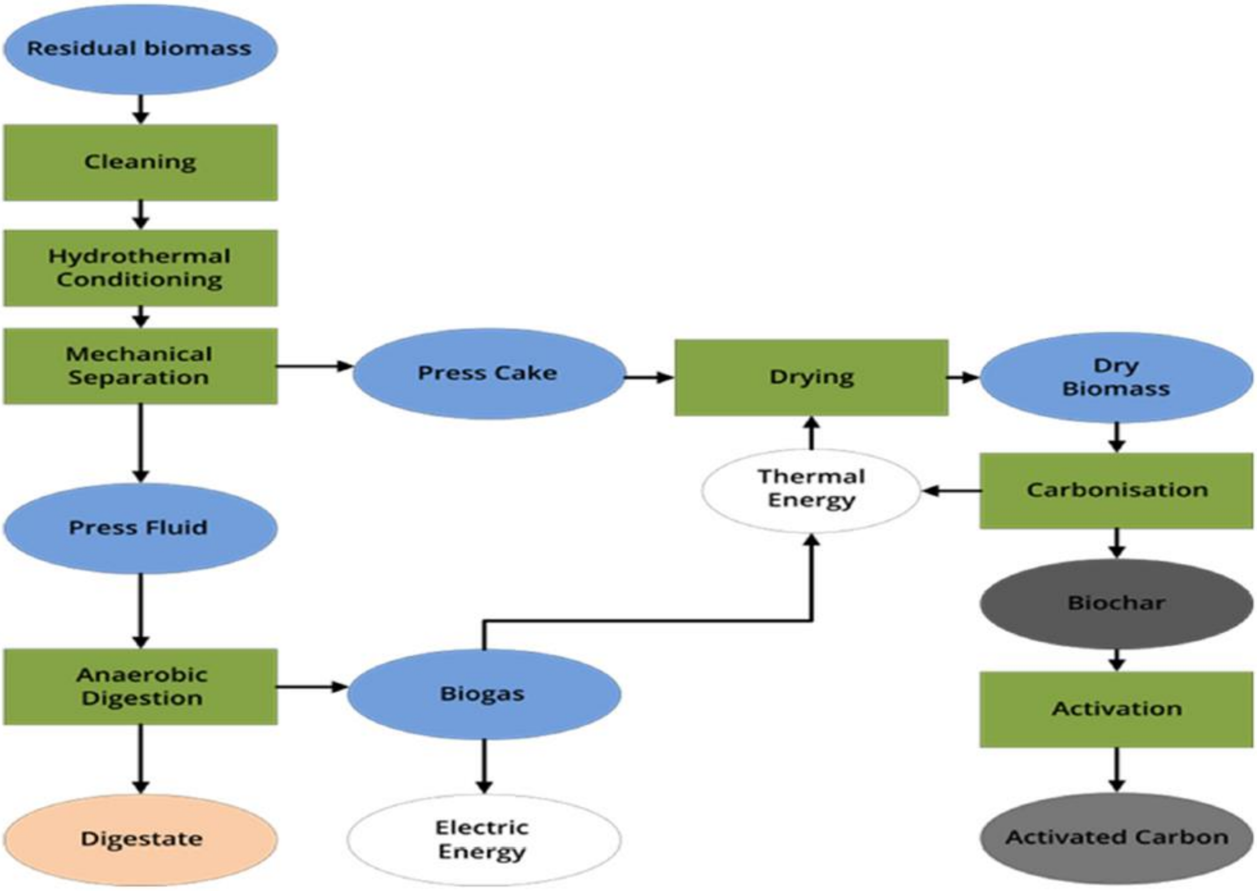


Fig. ……: IFBB schematic. The dried press cake will be further processed, producing Biochar

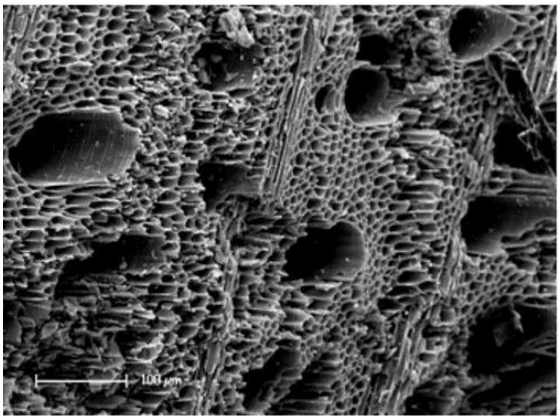
Research overviews

Having conducted detailed research overview the project has identified key industries suitable for development of biochar products during the project. The following sections sets out an overview for a variety of key potential uses for Biochar. As outlined by The European Biochar Industry Consortium's (EBI) graphic (Figure 3.15) the potential uses for biochar are wide ranging with large scale application potential in industry, agriculture, and construction as well as more specialised uses in water treatment, cosmetics, food and medical supplements and even as a key component in bio-batteries.

Figure 3.15 EBI graphic of biochar application

Why biochar?

To gain an understanding of why biochar is so useful in so many different situations, it helps to think of it as a very stable black sponge on the microscale. So, if you were to image it using microscopes, you would see something like the picture here on the right. As you can see, it is full of pores, nooks, and crannies. This in effect means it has a large surface area – 1g of certain biochar's can have the same surface area as an entire football field.



One key aspect is Biochar cation exchange capacity (CEC) is a key property that is central to biochar environmental applications that is based on charge interactions between positive and negative charges. Some biochar's have a capacity for anion exchange, allowing interactions between negative charged particles in the surrounding environment.

These properties are what leads to the retention of soil nutrients in soil amendment and removal of certain pollutants in water-filtration applications. It can bind to heavy metals for instance and immobilise them. In fact, it can adsorb a wide variety of different substances.

Due to the thermal conversion process, biochar becomes extremely stable and will not degrade over time in the same way in which the parent material would have- by decomposition and microbial action for instance. That means in effect the carbon is stored for a long amount of time- anywhere between decades to hundreds of years and potentially, beyond. And as a result, it can sequester carbon, assuming it is not combusted. So, with that large porous surface area and its ability to hold onto moisture and retain nutrients, another way biochar can be of interest to us is its ability to provide a habitat for mycorrhizal fungi and colonies of bacteria. It has been described as a coral reef for soil life and it can help increase soil biodiversity which can have many benefits ranging from nutrient cycling to disease resistance.

So pictured you can see a variety of extreme close ups of different biochar's that have been colonised by different microbes and fungi.

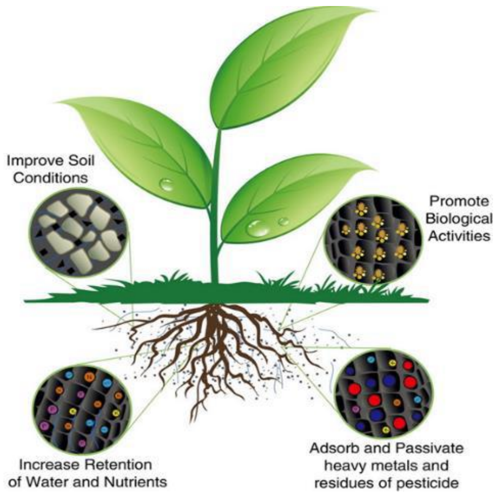


Figure 3.16 Microbial habitats

Biochar can also aid in resistance to drought and can help improve a soils ability to retain water. Biochar can also aid in the retention of nutrients. It can hold on to nutrients and prevent losses from leaching events, perhaps aiding in increasing efficiencies of and fertilisers being applied, or in particular, preventing them from being lost to water courses during high rainfall events.

These properties have been proven to improve the quality of construction materials such as concrete or asphalt, act as a stabilising and absorbent material for animal health, decontamination of air, water and land. The concept of utilising locally sourced, under used and marginalised biomass feedstocks reduce carbon emissions from waste treatment and transportation, whilst the biochar itself often replaces finite, valuable and or harmful materials all whilst improving the quality of the end-products and reducing their carbon outputs.

Most importantly and relevant to this project though is the long term and sustainable nature of carbon sequestration provided by biochar, which locks away carbon drawn straight from the atmosphere by the biomass during its growth and stores it in a stable, recalcitrant form with minimal decay over centuries, all at a relative low cost. It is this use which gives biochar its greatest potential value as we tackle the challenge to bring down global emissions and remove existing carbon from the atmosphere in a sustainable fashion.

Biomass feedstock characteristics

In order to understand why different biochar's might be so variable, it is important to understand that plant biomass or lignocellulosic biomass is largely comprised of 3 main types of carbon containing material:

- Cellulose - The most abundant organic polymer on earth. Its structure is largely crystalline and simply structured
- Hemicellulose - Contains random branched structures and is more complex than cellulose
- Lignin- The most complex in structure, an organic polymer which forms the key structural components of support tissues in plants and is found in cell walls or in wood bark

Different parts of a plant will have variable amounts of these 3 components.

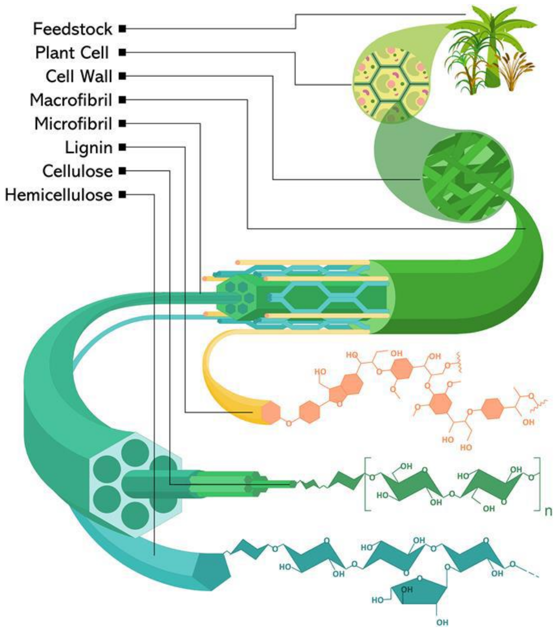


Figure 3.17 Plant cellular structure [32]

When they are converted into biochar, the hard carbon structure that is left behind by the process will be determined by the make-up of the plant biomass on a cellular level.

The next sections highlight the difference from biomass to biomass and how this effects the biochar's produced as a result.

Potential applications

Biochar in agriculture

Along with the horticulture industry, agriculture is the main industry use of biochar. In fact, in 2018 agriculture accounted for 71.1% of the total biochar demand. And in Europe 90% of biochar produced is used in livestock farming [33]. Biochar is mainly used in either agricultural applications such as crops, fertiliser, and bedding, or it is used in livestock farming. Biochar helps to enhance water and fertilizer holding capacity and improves the soil's biological productivity, which provides crop nutrition and accelerating growth [34]. Biochar is a very porous material and therefore has incredible adsorbent potential. Biochar captures nitrogen which stops it from being lost to ammonia volatilization. This ammonia can create unpleasant smells as it volatilizes. Therefore, if retained the N is still useful for fertiliser.

It has been proven that broilers raised on biochar treated litter had better health, performance, and higher productivity [35].In terms of fertilizers the quality and nutrient status of biochar from feedstocks of animal origin such as poultry litter, cow manure, and sewage sludge are higher than biochar made from plants or crop residues which highlights how choice of feedstock along with specific production parameters such as temperature can affects the quality and physical-chemical properties of the biochar [36].

Figure 3.18 Biochar blended cattle feed

Studies shown that feeding 100-400g of high temperature wood biochar (700°C) to livestock specifically cows can bind mycotoxins which result in higher feed intake and improved digestibility which reduces the amount of methane released, which we all know is 30 times more effective at trapping heat and effecting greenhouse gases. Feeding biochar to livestock showed improvement of meat quality and significant reduction in veterinary costs. Also, a reduction in feet diseases due to odour and moisture being adsorbed through biochar litter. Emissions from ruminants account for 81% of total GHG emissions from livestock sector [37]. It is done through flatulence and burping. This is produced through rumen microbial methanogenesis. The production of methane means a significant loss of energy for the animal (from 2% to 12% of the total energy intake; [38]) as the high-energy methane cannot be digested any further and has to be eliminated almost entirely through eructation [39]. The use of biochar as a feed additive has the potential to improve animal gut health thus reducing greenhouse gas emissions and Improve animal husbandry.

Key challenge with current agro-farming systems is to enhance crop yield in more sustainable and environmentally friendly manner. Chemical fertilizers do increase crop yield but also risk the sustainability of the environment [40]. Post green revolution agricultural practices enhance their dependency on organic fertilizer to secure higher crop yield. Biochar has comprehensive environmental use due to its idiosyncratic properties, e.g., large surface area, microporosity, higher adsorption capacity and ion exchange capacity These properties have substantial consequences to its competency and potency in sustainability of the environment. The transformation of feedstock into biochar is a carbon-negative technique and sequesters carbon [41].This not only reduces the problems of waste disposal of agricultural residues but also provides a viable and frugal method of waste transformation into value-added products. Due to its exceptional surface characteristics, biochar shows remarkable efficacy in reducing contaminants such as antibiotics, herbicides, dyes, pesticides, and heavy metals and plays a key role in alleviating global climate change. Biochar is thus a promising way to return lost C into the soil.

Biochar in poultry

Of all the publications on biochar in agriculture, the majority have focussed on its use with poultry. One of most frequently cited studies is [42]who fed two different biochar's, one from corncobs and other from canary tree seeds to broiler chickens at different concentrations 0%-1%per kg feed. Feeding both biochar's up to 0.6% led to greater weight gain. The study is an important indication that biochar derived from non woody biomass may be suitable for feeding. In a later study with the same biochar's, the authors examined whether chickens can, thanks to the biochar supplement, be fed with 20% chickpeas, a feed that is protein-rich but generally difficult for chickens to digest. Surprisingly, when the ash-rich biochar from corncobs was added, the boiled chickpeas could be fed and provided the same weight gain in the broilers as the control without chickpeas [43]. Many studies have shown that by feeding hardwood biochar or other forms of biochar to chickens it leads to higher weight gain, an increase in the quality of meat and strength of eggshells. While importantly for farming production, trials have shown that feeding biochar to chickens can lead to an increase of 5% in egg production [44].

Additionally, by using biochar not only is there an increase in egg production, but the collagen content of the eggs is also increased by 33% with bamboo biochar. Collagen increases the shelf life of eggs which means food can last longer which could lead to a reduction in food waste in supermarkets [45]. Biochar as a bedding is another interesting aspect. It can be used as bedding in barns as it does a good job of reducing ammonia and other odours in poultry houses. Biochar is very effective at capturing nitrogen (N) that is otherwise lost to ammonia volatilization due to its porous structure making it perfect to absorbent. Ammonia creates unpleasant odours in the barn and harms the respiratory health of creatures who breath it. Along with odour and ammonia reduction, biochar leads to fewer flies and pathogens, for improved animal health. Maintaining litter moisture content between 20 and 30% in modern commercial broiler houses is a critical component of house management and important to realizing flock production potential. Elevated litter moisture levels can lead to higher incidences of footpad dermatitis [1–3] and increased ammonia generation that is detrimental to the bird performance and health [4–10]. Biochar as a litter amendment can improve litter quality through increased water absorption.

Biochar in horticulture

Hydroponics is becoming more popular in the horticulture world as it offers several benefits such as improved yield and good-quality products, precise nutrient and disease management, short cultivation times, and safe food and growth environments [46]. But a problem with using substrates is the recirculation of solution provides favourable conditions for algal growth. This is a problem as it influences the water supply system and nutrient uptake by plants leading to a reduction in crop yield [47]. Further, the odour and appearance of crops grown in a hydroponics system containing algae might reduce their value of product, and such algae may also secrete toxins that are harmful to human health [48]. Nevertheless, studies have shown by using biochar in hydroponics it increases plant growth by improving the physiochemical and biological properties of soil and retains soil fertility and it also inhibits algal growth in hydroponics containers. As biochar is a stable and highly resistant to microbial degradation, it is effective as a growth substrate for hydroponics.

The findings suggest that using biochar as a hydroponic substrate, it is effective in improving yield of leafy veggies, up 2-fold. The adsorption capacity, porous structure, and surface area of biochar likely increased nutrient availability to plants and inhibited algal growth in the nutrient solution, thereby improving water quality and enhancing vegetable growth in the hydroponics systems.

Biochar in growing media

Finding high quality, low cost and environmentally friendly constituents is one of the growing media industry's biggest challenges. Growing media are defined as all solid materials, other than soil, that alone or in mixtures can provide superior conditions for plant growth (for one or more aspects) compared to agricultural soil (Gruda et al., 2013). The growing medium must satisfy several main functions, including physically supporting the plant and supplying its roots with nutrients, air, and water. Media such as peat moss and aggregates like perlite and vermiculite are used. But due to decreasing availability, increasing environmental concerns, and the rising cost of horticultural substrates (particularly those made from peat and aggregates), several renewable alternatives like biochar are beginning to be adopted. A life cycle analysis on horticulture GM show nearly all constituents have a negative environmental impact (Schmilewski, 2014). The media with the highest negative impact is coir pith due to long transportation distances from Asia and media with green compost because of processing gas emissions.

Adding biochar to GM can result in several benefits in terms of substrate quality. Biochar generally has a high CEC and a high nutrient holding capacity, thereby reducing nutrient leaching. Biochar can also be considered as a source of nutrients. In general, biochar has a low bulk density and when incorporated in GM helps to reduce the risk of substrate compaction and related problems. the incorporation of fine-textured biochar in GM promotes water retention properties (Bolan, 2016). This property of biochar would be particularly useful in green roofs & hanging basket substrates in which reduced irrigation frequency and controlled nutrient release are desirable. Economically, biochar has a greater potential to replace aggregates than peat in GM mainly due to the high cost of these aggregates compared with peat. This highlights another potential market for this project and shows the diverse properties of biochar and the environmental benefits over other GM such as peat.

Biochar as soil and compost additive

Biochar has also been used as a compost additive to increase the composting rate. A combination of 35% spent mushroom compost with 20% biochar has been shown to reduce the composting time to 24 days compared to the more typical 90–270 days (Zhang and Sun, 2014). The large porosity of biochar can also facilitate microbial growth in the compost pile and therefore accelerate nutrient recycling.

Biochar has been found to be a beneficial additive during composting due to the high porosity and low density of biochar leads to improved composting aeration, thus enhancing microbial activities and the humification process. The high sorption capacity of biochar can reduce the loss of N from the compost while another study stated that biochar can immobilize heavy metals and organic pollutants during the composting process. As well as that, biochar addition to composting can reduce greenhouse gas emissions (Wang et al., 2018).

Meanwhile, many investigations focus on various agronomic benefits of biochar when used as soil amendments. Application of biochar to soils has been shown to enhance soil properties and plant growth, improve soil fertility and sequester carbon, increase crop yield, and alleviate plant stresses, including those induced by drought and salinity. It can also remediate organic pollutant-contaminated soils. Furthermore, it has been demonstrated that combined application of biochar and compost to soils can enhance both their agronomic values and reduce nutrient losses maximumly, which can be a potential alternative to N fertilizer (Kammann et al., 2015). Moreover, biochar addition to compost also accelerates organic matter degradation, reduces the time taken to enter the thermophilic phase, and increases composting temperature, therefore improves composting efficiency and humification process. Based on the above studies, it can be concluded that biochar addition plays an important role in composting acceleration and compost quality enhancement, and more nutrients are retained in the compost following the biochar addition. Porous structure of biochar can decrease the pile density and adjust the particle size, thereby improving the pile structure and aeration. Therefore, biochar is a good additive candidate for composting. Biochar can change the pH of soils, high pH biochar is best for application to acidic soil, whereas weakly alkaline biochar is recommended for application to alkaline soil to lower the pH. Composting and biochar production are both efficient ways to dispose of organic waste, and the combination of them both results in a high value-added strategy when applied to soils. This use bares encouragement as partnerships could be sought with large scale compost producers local to plant sites but also to community composting schemes connected to smaller de-centralised locations.

Biochar in construction

Until now, the main use of biochar has been in agriculture and horticulture because it has been demonstrated that it improves the biological and physical properties of the soil. However, a promising and innovative application of biochar is in construction. As biochar is generally considered a cost effective, sustainable, and eco-friendly material it is now being used in different aspects of construction. Building and construction are responsible for 39% of all carbon emissions in the world (Global Status Report 2017). Therefore, reducing the number of carbon emissions by using sustainable materials could have a significant reduction.

As a result, many studies have examined the possibility of using biochar in various formats in building and construction. Firstly, cement production is a major source of CO2 emission. Due to biochar having low thermal conductivity, chemical stability, and carbon sequestration properties, it is an ideal replacement for cement replacement in building materials. Data shows that biochar content around 2% is shown to contribute to the improvements of mechanical properties of cement (Maljaee, H et al, 2021).

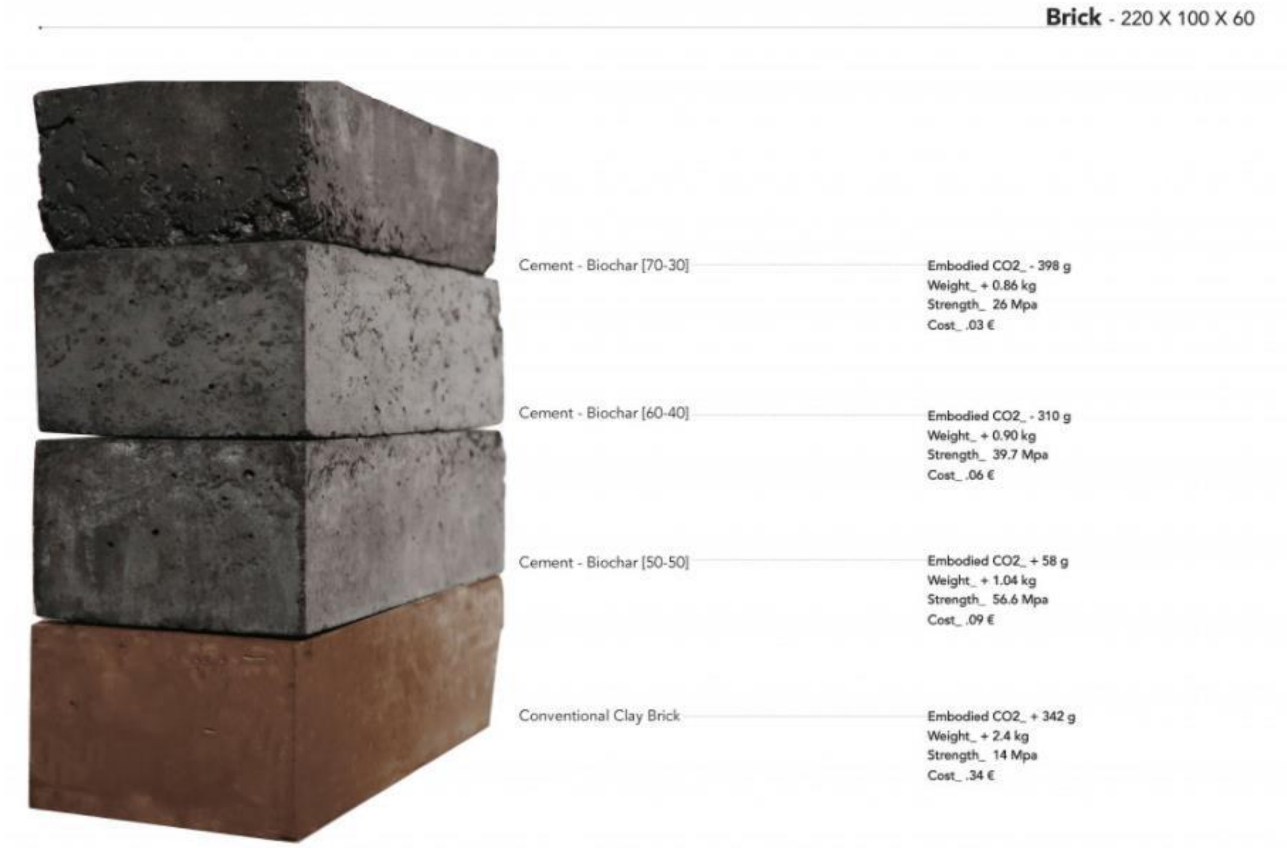


Figure 9 - Biochar brick comparisons

Figure …… from the Cast in Carbon project demonstrates this nicely by highlighting that a brick can be made with 70% biochar which is cheaper, stronger and significantly lighter than a conventional clay brick whilst sequestering just under 0.4kg of CO2 per brick in direct comparison to a conventional brick emitting over 0.3kg of CO2 per brick.

Further research has also explored biochar being used as a filler inside cement paste and mortar composites and as substitute for cement powder in mixes. This research highlighted that biochar is sufficient to increase the strength and toughness of cement and mortar composites by replacing the cement in the mixture, it can still maintain the mechanical properties (Suarez & Restuccia, 2020). Another good property of biochar is its carbon sequestration properties. Because of this biochar has been used in wall plaster and pellets to fill cavities for interior non-structural wall panels. It increased the net carbon dioxide adsorption capability by more than four times (Kua et al, 2017).

Research has highlighted biochar's use to produce geopolymer materials which are low energy consuming and eco-friendly mineral binders. Three different crops were tested, miscanthus, wheat straw and short rotation coppice. The research concluded that biochar from all three crops can be valorised to produce geopolymer materials (Farges, R, et al, 2018).

Biochar is already being widely championed for use in horticulture and agriculture and we predict future trends could lead to the market being saturated. Therefore, we think utilising biochar in construction will be better suited as higher quantities of biochar can be used which will help the industry to sequester more carbon, however, the cost of biochar will be significantly less. Additionally, the EU have signed off on a biochar land application regulation which states the quantity of biochar that can be applied to land and how often this can be done, which gives another reason to pursue biochar uses in construction.

Biochar uses in asphalt

Asphalt is a mixture of aggregates, binder, and filler, used for constructing and maintaining roads, parking areas, railway tracks, ports, airport runways, bicycle lanes, sidewalks, and play- and sport areas. Aggregates used for asphalt mixtures could be crushed rock, sand, gravel, or slags. Nowadays, certain waste and by-products, such as construction and demolition debris, are being used as aggregates, which increases the sustainability of asphalt. To bind the aggregates into a cohesive mixture a binder is used. Most commonly, bitumen is used as a binder, although nowadays, a series of bio-based binders are also under development with the aim of minimising the environmental impact of the roads (EAPA, 2021)

Recently there is more of an impetus on converting organic matter into biofuels. Biochar is considered suitable to be used as an asphalt binder modifier due to its carbon nature and morphology. Studies conducted on switchgrass biochar found that biochar could reduce the temperature susceptibility and significantly increase the rutting resistance. Rutting refers to the permanent deformation of the asphalt surface that accumulates in the wheel paths because of repeated traffic loading (PI,2021). Testing results comparing biochar with commercially activated carbon showed that biochar appears to be a more effective binder modifier with addition of 10wt.% (Zhao, S, et al 2014)

Volatile organic compounds (VOCs) are known to be toxic and carcinogenic (Hangfu et al., 2020), and therefore the VOCs emission from asphalt can cause serious health and environmental issues (Sanchez-Monedero et al., 2019). It is worth mentioning that carbon emission produced by asphalt combustion reached to 3.5 million tons in 2018 (Han et al., 2019). Therefore, the VOCs removal from asphalt has become a popular topic in recent years. A study investigating the effects of three different biochar's, pig manure, waste wood and straw on removing the VOCs emission from asphalt. The results showed that biochar could remove alkanes, polycyclic aromatic hydrocarbons (PAHs) and sulphide compounds because of its intrinsic carbon negativity and porosity. Waste wood-based biochar had the best adsorption performance at a temperature of 500 degrees Celsius due to its amorphous carbon, graphite, and porous structure. Biochar has great potential to be used as VOCs inhibitors (Zhou, X, et al 2020).

Biochar uses in plaster and insulation

Biochar based building materials offers the possibility of carbon negative construction. The first example of this in practice was built in 2013 at the Ithaka institute in Switzerland. The Ithaka institute is an international open-source network for carbon strategies specialising in biochar with its headquarters located in Switzerland. Two of biochar's key properties are its low thermal conductivity and its ability to absorb water up to 5 times its weight. These properties mean that biochar is just the right material for insulating buildings and regulating humidity. In combination with clay, but also with lime and cement mortar, biochar can be used as an additive for plaster or for bricks and concrete elements at a ratio of up to 80%. This blending creates inside walls with excellent insulation and breathing properties, able to maintain humidity levels in a room at 45 – 70% in both summer and winter. Not only does this prevent the air inside the rooms from becoming too dry which is a potential cause of respiratory problems and allergies, but it also prevents condensation from forming around thermal bridges and on outside walls which could lead to the formation of mould.

Biochar-clay plasters adsorb smells and toxins, a welcome property in kitchens and for smokers. Alongside their use in housing, biochar-mud plasters are particularly well-suited for warehouses, factories, and agricultural buildings as well as in schools, universities, hospitals, and other buildings frequented by many people. Improved indoor climate, it can be assumed, has a positive effect on one's ability to concentrate, a welcome property in meeting rooms, libraries, offices, and classrooms. In addition, biochar is a very efficient absorber of electromagnetic radiation resulting from the use of both wireless technology and electricity.

Figure ….. - Ithaka institute demonstrates biochar in practice as plaster on the walls

By using biochar-based insulation material, houses can become very long-term carbon sinks, while at the same time providing healthier indoor climate. And should such a house be demolished later, the biochar-clay or biochar-lime plaster can be directly used as a compost supplement, thus continuing the carbon cycle in a natural way. Biochar plaster can be applied to walls of a building using standard plaster spraying or rendering equipment. Applied at a thickness of up to 20 cm, it can be a substitute for Styrofoam insulation. According to Hans Peter Schmidt, a true pioneer of biochar, that biochar represents a one-to-one ratio of CO2 emissions reduction. For each ton of biochar employed in buildings, one ton of CO2 is kept out of the atmosphere

Sustainability of Biochar

Affordable Negative Emission Technologies (NETs), that actively remove CO2 from the atmosphere are rapidly required to produce large scale quantities of Carbon Sinks (C-Sink). Many of these require large upfront investment or technology creation/development beyond our current capabilities. There are however three accepted methods which could be rolled out in the short and medium term in order to kick off this rapid scaling.

Biochar/Pyrogenic carbon capture and storage (PYCCS), afforestation/reforestation and Soil Organic Matter (SOM) build up are all cost effective methods with the capability to provide high volume C-Sinks.

Figure ….. Below, is a table produced by the European Biochar Initiative Consortium for their 2021 whitepaper; Biochar-based carbon sinks to mitigate climate change

EBI European Biochar Industry	Afforestation, C-centered forestry, material use of wood/biomass	Biochar/ PyCCS	Built-up of Soil Organic Matter (SOM)
C-Sink creation potential	Huge potential in particular outside of Europe	Huge potential	Broad range of expert opinions from huge potential to limited potential
Cost of C-sequestration	Since all these options are not just cost cases but driven by a main benefit, a cost contribution of 50 - 100 EUR/t CO2eq can really change the business case and thus trigger a strong increase of sink creation		
Stability of the sinks	Immanent risk that the sink gets lost (burned); also climate change risk	Stability broadly accepted by science	Stable only if different land management practice is continued; also climate change risk
Quantifiability	Due to risk for stability not easy to quantify	Scientifically robust quantification methodology available	Exact quantification is difficult and costly, at least at the moment
Main/Co-Benefits	Multiple co-benefits including microclimates, water retention, ...	Multiple main/co- benefits depending on application	Improving soil health and productivity, water retention
Ecological risks and negative side effects	From very beneficial (biodiverse forest) to unfavorable (monoculture, water usage, albedo ...)	None when quality controlled and certified biochar is used (e.g. EBC)	None, increase of humus is 100% positive
Carbon efficiency for use of biomass	Long-term material use of biomass has 100% C-efficiency (for the period of use)	Today typically 30 - 60% (less critical due to energetic use of the residual amount); with use of bio-oils up to 70%	if huge amount of biomass is used for area composting C-efficiency is low otherwise it can be very high
Availability and scalability	Practices available even though scaling of larger projects can take time	Quickly scalable, technology readily available	Practical experience available. More research regarding large scale agricultural deployment required.
Use of other ressources	Land and potentially water requirement	Depending on the sustainability of biomass feedstock	No relevant use of energy and water needed

Figure ….. - Affordable Negative Emission Technologies (NETs)

When considering the sustainability of our project methodology, our biochar application and it's C-Sink potential there are some key aspects to take into account:

• **Diversification**: Due to the scales of C-Sinks required it is prudent to actively develop and promote a variety of NET's. Each NET has differing timeframes and land requirements amongst other variables so developing systems which can support and integrate with one another minimises the risk. This is even more important when considering the un-predictable nature of the future climate, economic and technologic position.

• **C-Sink potential/scalability**: The scale of the climate emergency means that rapid scalability is of paramount importance in order to help achieve the estimated requirements of 1 - 5 Gt CO2 per year by 2050. (IPCC 1.5°#4, 2018).

• **Modularity**: Similar to the technology solutions scalability is its modularity which allows for technology to be adaptable and deployable at small, medium and large scales by simply utilising additional modules rather than different technologies.

• **Feasibility and deployment readiness**: The immediacy of the climate emergency means we cannot simply wait for future technologies to be viable. Immediate solutions which have been shown to be feasible and deployable are required immediately.

• **Local adaptability**: Despite the global nature of the climate emergency local solutions are required that can be deployed and maintained to suit individual locations geography, climate, socio-economic and political situations. By doing this it will also safe guard against fluctuations in these situations on a global scale.

• **Carbon-efficient use of biomass and cascading uses**: Biomass is a valuable resource which fluctuates in value and availability and also requires substantial land availability. The traditional school of thought is that you either combust biomass for energy or utilise it for sequestration however Pyrolysis allows for a combination of these factors. Carbon content is key and finding a carbon efficient process which stores enough carbon post pyrolysis whilst still creating a beneficial quantity of energy.

• **Protection of ecosystems**: We must be considerate of the need to safeguard biodiversity, natural habitats and healthy ecosystems when designing these NET's. An over development of monoculture afforestation will not provide a healthy balance and will negatively impact these other elements which in the long term will negate the sustainability of the C-Sink.

• **Costs and added value**: When considering the cost of the C-Sink development it is important to consider all of the added value provided by the process in order to accurately cost the price of sequestration. Cost of NET's are incredibly varied, and their added values and wider impacts also vary making comparison more complex than just cost per tonne of carbon sequestered.

4 Planning, permitting and regulation

4.1 Planning

Requirements for planning can often be off putting, particularly for any projects aimed at tackling new, marginal, or waste biomass streams. However, taking advantage of existing infrastructure in the locality can avoid or mitigate such concerns. In these cases, no planning or potentially simpler planning variations or additional applications on an existing processing site may be required, all of which are less challenging and prone to denial that new applications. It is also of note that small scale, mobile, batch pyrolysis systems will likely not require any planning or permitting as their scale falls within permitted activities.

The development of any processing plant such as Anaerobic digestion or large continuous feed Pyrolysis requires both planning permission from the local authority and an environmental permit from either the local authority of the relevant environment agency (EA for England or NRW for Wales).

The key considerations for determining the planning application will be national planning policy, the local development plan and the principle of development, siting, design and impact on the landscape, highways, heritage, amenity (odour and noise), landscaping, biodiversity, drainage and agricultural/business need.

Planning for any development of this nature can be challenging due to the public perception of the technology. AD does not normally suffer too greatly from negative perception, but plant development applications often receive complaints about odour and due to the explosions at an AD facility on a water treatment facility in 2022 there are added public challenges at the moment. As for Pyrolysis, this is a relatively unknown technology and could easily be mistaken for an incineration plant by the public when an application is made. Generally speaking, incineration plants tend to attract a string public response and for this reason any planning application needs to have a well-planned information and community engagement campaign to accompany it. Despite these challenges with this simple mitigation is not expected an application for development of either technology would face any insurmountable hurdles.

The planning process varies from authority to authority, but the following is a rough timeline of the required actions to achieve planning for such developments:

Action	Notes	Time
Pre-Planning application	A service offered by most authorities. Provides and early opportunity for guidance and feedback. Allows for an informed decision about progressing to a full planning application.	1 week
Environmental risk assessment	Site specific requirements if needed. A key aspect of planning and permit applications.	2 weeks

Flood risk and drainage study	Site dependant but most likely required	2 weeks
Air quality study	Site and location specific – often includes dispersion modelling which informs key information such as a flue height.	2 weeks
Noise study	Site and equipment specific	2 weeks
Transport study	Based on design and specification of development, key issue for planning and with community is often additional movement of traffic, particularly large vehicles such as lorries and tractors.	2 weeks
Asbestos study	Site dependant (pre-existing buildings)	2 weeks
Ground contamination report	Site dependant, unless the site is on an existing industrial site or large concrete pad this is often required.	2 weeks
Full planning application	Application to include study results as identified as well as detailed RIBA stage 4 design and site drawings.	2 weeks
DNO application	Required if electricity is to be exported to the Grid.	2 weeks
LA Decision	Additional time to be factored in for any appeal process should planning be unsuccessful.	12 weeks

Broadly speaking the studies required to inform planning can run concurrently however some will inform one another and all will potentially inform the technical design and site layouts required for the application. In total it is wise to factor in 6 months for a planning application process with additional time should planning be unsuccessful and an appeal is required.

4.2 Permitting

The development and operation of AD or pyrolysis plants in England & Wales is regulated by the EA & NRW respectively through the Environmental Permitting Regulations. Other than small scale pyrolysis both processes will require either a Standard Rules or Bespoke Environmental Permit. Most pyrolysis applications will be bespoke, due to the lack of precedent in most areas with only a handful of existing sites in the UK.

The site, locations and proposal all impact the classification of the application.

The requirement for a bespoke application should not be considered a barrier to development. There are however increased costs and more detailed application requirements in order to assure the regulators of the plants technical and managements capabilities to prevent an un-acceptable level of risk to the environment.

It is worth noting that small pyrolysis installations can either be categorised under low-risk exemptions or under the small plant industrial emissions directive (IED) which would require no permit or and IED permit from the local authority respectively. In addition, any pyrolysis plant developed under an R&D pilot project would be entirely exempt from permitting under existing regulations up until commercial operation at which point the relevant permit would be required.

4.3 Regulation

In addition to the operation of such sites the regulations governing the sources and use of the site feedstocks are key as these also have implications on the end use of the products produced.

Waste classification of roadside verge arisings as well as other feedstocks of interest to this report is conducted by using the Classification and Assessment guidance (1) issued jointly by EA, NRW, SEPA and NIEA. Arguments can be made that some will not be classed as a waste at all but for ease of development we are assuming all would be a waste and will need classifying under the guidance. Key is the want for feedstocks to fall into category 2; Absolute non-hazardous (AN). If a waste is given a AN code, then no further assessment of that waste is required at this stage unless the user believes that the waste may display hazardous properties. In this case the onus is on the user to carry out assessments of the waste contaminants.

Following the guidance waste codes have been assigned to the relevant feedstocks in the table..... below:

Feedstock	Waste category	Code
Green garden waste	Municipal wastes; garden and park wastes - biodegradable waste	20 02 01 AN
Grass cuttings (domestic and LA)	Municipal wastes; garden and park wastes - biodegradable waste	20 02 01 AN
Forestry woodchip	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - wastes from forestry	02 01 07 AN
Rhododendron	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - wastes from forestry	02 01 07 AN

	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste	02 01 03 AN
Bracken	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste	02 01 03 AN
Gorse	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste	02 01 03 AN
Fruit plants such as raspberry canes	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste	02 01 03 AN
Rush	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste	02 01 03 AN
Nature conservation grass/hay	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing - plant-tissue waste Municipal wastes; garden and park wastes - biodegradable waste	02 01 03 AN 20 02 01 AN
Fruit stones	wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing - materials unsuitable for consumption or processing	02 03 04 AN
Roadside verge cuttings	Municipal wastes; garden and park wastes - biodegradable waste Other municipal wastes - municipal wastes not otherwise specified	20 02 01 AN 20 03 99 AN*

* NRW have suggested in initial discussions that Roadside verge horizons would fall into the Municipal waste category along with bio-degradable garden and park waste however this goes against the advice from the EA to the Lincolnshire Councils Sustain project.

Table …. – Relevant feedstocks & there waste classification codes

Of the exemptions under the Low Risk Waste Guidance, the ones of relevance are LRWP 60 & 61. These dictate the permissible waste feedstocks that can be stored and treated to produce biochar without an environmental waste permit and the amount of biochar that can be stored and spread to land without a permit. They stipulate an application rate of up to 1 tonne per hectare annually with a 10 tonne storage limit. The exemption must be registered but that is the only stipulation. It should be noted that waste regulations must still be adhered to when it comes to transporting the waste product even if the exemption applies to its use.

End of waste

There are two key uses of waste which are of relevance as defined in Article 3(15) & (17) of the WFD:

1) Recovery - "…any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy".
2) Recycling - "… any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations".

Under Article 6(1) and (2) of the WFD there are 4 criteria a product must meet to qualify for and end of waste status. They are:

(a) The substance or object is commonly used for specific purposes;

(b) A market or demand exists for such a substance or object;

(c) The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and

(d) The use of the substance or object will not lead to overall adverse environmental or human health impacts.

There are numerous quality protocol's set out to define how to convert a waste into a non-waste product. The process is specific to the output product, not the input feedstock or the method of production. There is no existing protocol for the production of biochar although work is ongoing with regulators to create one. Where there is no protocol an end of waste test must be conducted. The Court of Appeal OSS end of waste test generally represents all the case law requirements for the end of waste test.

This test assesses whether:

- the waste has been converted into a distinct and marketable product, this means:
  - the waste has been turned into a completely new product, for example a playground surface is produced from waste tyres
  - the new product is different from the original waste (minor changes to its composition may not be sufficient), for example non packaging plastic recycled material is processed to make new plastic products
  - there is a genuine market for the material so it will definitely be used – if it's stored indefinitely with little prospect for use the material remains waste
- the processed substance can be used in exactly the same way as a non-waste
- the processed substance can be stored and used with no worse environmental effects when compared to the material it is intended to replace

Existing protocols of relevance are for Compost and anaerobic digestate.

Both of these detail the feedstocks which can be used to achieve a non-waste product as defined by the LoW codes of which all of those included in the table above qualify.

Compost production is regulated and accredited by PAS100 with digestate production by PAS110.

The guidelines state that generally the protocols must:

- ensure the product made from waste does not pose an unacceptable risk to human health or the environment
- increase market confidence in the quality of products made from waste and their potential value
- encourage greater waste recycling and recovery

Biochar quality

Under the exemptions specified by LRWP 60 & 61 and wider EA regulation there is limited quality requirements on biochar spread to land as set out in table..... below.

Limits for quality biochar

	As	Cd	Cr	Cu	Pb	Hg	Mn	Mo	Ni	Se	Zn	PAHs (sum of USEPA16)	Dioxins/ furans	PCBs
	mg/kg												ng/kg	mg/kg 1-TEQ
Maximum limit suggested for high grade quality biochar	10	3	15	40	60	1	3,500	10	10	5	150	<20	<20	<0.5
Maximum limit suggested for standard grade quality biochar	100	39	100	1,500	500	17	Limits set by regulators	75	600	100	2,800	<20	<20	<0.5

Notes: Source: Shackley et al. (2013)
TEQ = toxic equivalence

Table ….. – limits for quality biochar

However, work is ongoing with regulators to update this and a fair estimation of the route they are going can be seen in the EU with amendment to Annexes II, III and IV of Regulation (EU) 2019/1009 are coming into force in summer 2022. These amendments specifically tackle the addition of pyrolysis or gasification materials as a component material category in EU fertilising products. These use more stringent quality standards as set out by the European Biochar Certification scheme, one of the leading certification schemes which bring added value to the product and also link in to carbon trading platform Puro with a carbon sequestration verification scheme running in tandem which again brings quality re-assurance and added value via the ability to sell carbon credits.

Below, table …… sets out the most recent EBC standards which define both quality and recommended end use application.

EBC -Certification Class		EBC-FeedPlus	EBC-Feed	EBC-AgroOrganic	EBC-Agro	EBC-Urban	EBC-ConsumerMaterials	EBC-BasicMaterials
Elemental analysis	Declaration of Ctot, Corg, H, N, O, S, ash							
	H / Corg	< 0.4		< 0.7				
Physical parameters	Water content, dry matter (as received and @ < 3mm particle size), bulk density (DM), WHC, pH, salt content, electrical conductivity of the solid biochar							
TGA	Needs to be presented for the first production batch of a pyroylsis unit							
Nutrients	Declaration of N, P, K, Mg, Ca, Fe							
Heavy metals	Pb	10 g t^{-1} (88%DM)	10 g t^{-1} (88%DM)	45 g t^{-1} DM	120 g t^{-1} DM	120 g t^{-1} DM	120 g t^{-1} DM	declaration, no limit values for certification
	Cd	0.8 g t^{-1} (88% DM)	0.8 g t^{-1} (88% DM)	0.7 g t^{-1} DM	1,5 g t^{-1} DM	1,5 g t^{-1} DM	1,5 g t^{-1} DM	
	Cu	70 g t^{-1}DM	70 g t^{-1}DM	70 g t^{-1}DM	100 g t^{-1} DM	100 g t^{-1} DM	100 g t^{-1} DM	
	Ni	25 g t^{-1} DM	25 g t^{-1} DM	25 g t^{-1} DM	50 g t^{-1} DM	50 g t^{-1} DM	50 g t^{-1} DM	
	Hg	0.1 g t^{-1} (88% DM)	0.1 g t^{-1} (88% DM)	0.4 g t^{-1} DM	1 g t^{-1} DM	1 g t^{-1} DM	1 g t^{-1} DM	
	Zn	200 g t^{-1} DM	200 g t^{-1} DM	200 g t^{-1} DM	400 g t^{-1} DM	400 g t^{-1} DM	400 g t^{-1} DM	
	Cr	70 g t^{-1} DM	70 g t^{-1} DM	70 g t^{-1} DM	90 g t^{-1} DM	90 g t^{-1} DM	90 g t^{-1} DM	
	As	2 g t^{-1} (88% DM)	2 g t^{-1} (88% DM)	13 g t^{-1} DM	13 g t^{-1} DM	13 g t^{-1} DM	13 g t^{-1} DM	
Organic contaminents	16 EPA PAH	6±2.4 g t^{-1} DM	CSI-declaration	6±2.4 g t^{-1} DM	6.0+2.4 g t^{-1} DM	CSI-declaration	CSI-declaration	CSI-declaration
	8 EFSA PAH	1.0 g t^{-1} DM						4 g t^{-1} DM
	benzo[e]pyrene benzo[j]fluoran-thene	< 1.0 g t^{-1} DM for each of both substances						
	PCB, PCDD/F	See chapter 10		Once per pyrolysis unit for the first production batch. For PCB: 0.2 mg kg^{-1} DM, for PCDD/F: 20 ng kg^{-1} (I-TEQ OMS), respectively				

Carbon credits

Across the world, there is strong focus on reducing GHG emissions and expanding activities which help to store and remove GHG (principally carbon) from the atmosphere. In carbon markets, those whose activities avoid/reduce emissions or sequester carbon receive payments and those who have to/wish to decrease their carbon foot print can buy carbon credits to offset their emissions. This process is called "carbon offsetting".

Carbon credits are units purchased on a "buy and hold" basis or traded on carbon markets. GHGs are converted to CO2 equivalents CO2e for this purpose, so that one carbon credit equals one tonne of CO2.

Offsetting credits verified under the carbon standards help mobilise significant amount of finance through the voluntary offsetting markets.

Carbon standards exist to define what a good quality carbon credit looks like by setting out requirements for monitoring, reporting, verification and certification of carbon projects. The standards are based on key principles which aim to ensure that the reduction of emissions offered by certified carbon credits is real:

- Additionality – ensuring the offsetting activity financed through the sale of carbon credits is not already funded from a different source.
- Permanence and – ensuring the benefits of the emissions reduction/removal are not going to be reversed at a later stage and that
- Leakage - ensuring the carbon offsetting project it does not cause an increase in emissions elsewhere.
- Unique claims – ensuring the carbon credits are not double-counted and the same credits sold to multiple buyers.

Baseline methodologies against which additionality is being determined and procedures for validating the emission reduction/removal are developed and formalised in the design and early implementation phase of a project.

Monitoring, reporting, verification, and certification rules ensure that offset projects perform in line with their design documentation and the credits issued by the project are linked to genuine, measurable GHG reductions. This enables the credits to be sold in the carbon market.

The requirement for unique claims made by carbon credits is addressed through clear registration systems. A carbon registry is used for storing and tracking carbon credits: their issue (post independent validation, as described above), ownership, sale and retirement. All carbon projects must use a publicly available registry, provided by one of the main platforms such as the previously mentioned Puro.

Agricultural payments

UK governments are investigating and testing proposals to introduce environmental payments, or payments for ecosystem services, to replace EU based agricultural payments systems.

In England, the Environmental Land Management schemes (ELMS) and in Wales, the Sustainable Farming Scheme will include the Sustainable Farming Incentive, Local Nature Recovery, and the Landscape Recovery scheme, which will offer payments for environmental improvements to agricultural land including tree planting and habitat restoration. The schemes aim to support progression towards achieving the goals of the 25 Year Environment Plan and the commitment to net zero emissions by 2050, and activities eligible for payments are likely to include improvements to: water and air quality; plant and wildlife ecosystems; and reduction of and adaptation to climate change. Biochar can contribute towards all of these goals and is likely to become a valuable resource for farmers and agricultural landowners.

5 Local Authority Survey

In order to gather baseline information on the practices of the partners as well as areas of development already being considered as well as any limitations, a survey was distributed to all the councils and interviews conducted to discuss responses.

All responses are included in the appendix (Appendix-A Survey Responses), however a more summarised look into the lessons to be taken from the survey is included in this section.

1. *Which of these green spaces do you currently manage?*

	Monmouth	Torfaen	Newport	Blaenau Gwent
Community gardens (Allotments)			✓	
Parks	✓	✓	✓	✓
Common land		✓ (some)		
Roadside verges	✓	✓	✓	✓
Cemeteries	✓	✓	✓	✓
Social housing	Some	✓		
Schools	Some	✓	✓	✓
Playing fields	✓	✓	✓	✓
Sports clubs pitches (Rugby, cricket, pitches, etc)	Some	✓	✓	✓
Woods	Some woodland		✓	
Other	NHS land under contract		✓	

2. Are these areas cut and collect or cut and leave? (Please tick a box

	Monmouth		Torfaen		Newport		Blaenau Gwent	
Areas	Collect	Leave	Collect	Leave	Collect	Leave	Collect	Leave
Parks	22%	78%	100%	0%	2%	98%	0%	100%
Roadside verges	0%	100%	0%	100%		100%	Some small trial areas	100%
Cemeteries	35%	65%	60%	40%	2%	98%		100%
Social housing	38%	62%	80%	20%				NA
Schools	0%	100%	0%	100%	5%	95%	-	100%
Playing fields	0 %	100%	70%	30%		100%	-	100%
Sports clubs pitches (Rugby, cricket, pitches, etc)	0 %	100%	0%	100%		100%	-	100%
Other	Open spaces 34%	66%			100%			

Questions 1 & 2 were used to gather baseline information on the current management practices.

6 Cut and Collect trial

6.1 Planned trial

As a part of the Resilient Grasslands workstream, a trial was conducted in coordination with the county councils in order to analyse the potential biomass that can be harvested through cut-and-collect management and its suitability for anaerobic digestion. A manual for the sampling of biomass was produced and distributed to the councils involved in the trial, this can be found in the appendix (Section 14.1).

The manual described the work to be conducted by local authorities to ensure all samples that were collected and sent for analysis were collected and stored consistently. There were five steps given to local authorities:

1. Identification of Biomass samples
2. Agreement on the Biomass samples
3. Harvest or Collection of the samples
4. Ensiling the Samples
5. Transporting the Samples

6.2 Location of collections

#	OWNER	SITE	DATE COLLECTED
01	NRW	Outfall Lane	04/10/2022
02	NRW	Rogiet MOD range	12/10/2022
03	NRW	NRW1 - Peterstone	No date provided
04	MCC	Highbeech 1*	07/07/2022
05	MCC	Highbeech 2*	07/07/2022
06	MCC	Highbeech 3*	07/07/2022
07	MCC	Larkfield 1	02/09/2022
08	MCC	Larkfield 2	02/09/2022
09	MCC	Larkfield 3	02/09/2022
10	MCC	Fairview NIN 1	16/08/2022
11	MCC	Denby Drive	16/08/2022
12	MCC	Fairview NIN 2	04/11/2022
13	MCC	Larkfield 1 NIN	04/11/2022
14	MCC	Larkfield 2 NIN	04/11/2022
15	MCC	Larkfield 3 NIN	04/11/2022

Table 6.1 Sites of cut and collect sampling

Figure 6.3 shows the locations of the collection of samples taken within Newport and Monmouthshire, in total 12 locations were sampled with 4 of those having collections at two points during the year. *Highbeech 1,2,3 are early cuts in the same location as Larkfield 1,2,3 respectively.

The locations were selected to be representative of the varying types of grassland that the partners will manage, some abnormal locations such as Outfall Lane, as this is representative of a less managed location that councils may wish to reclaim in the future.

Figure 6.1 Cut location 14 -Larkfield 2 NIN

Figure 6.2 Cut location 12 -Fairview NIN 2

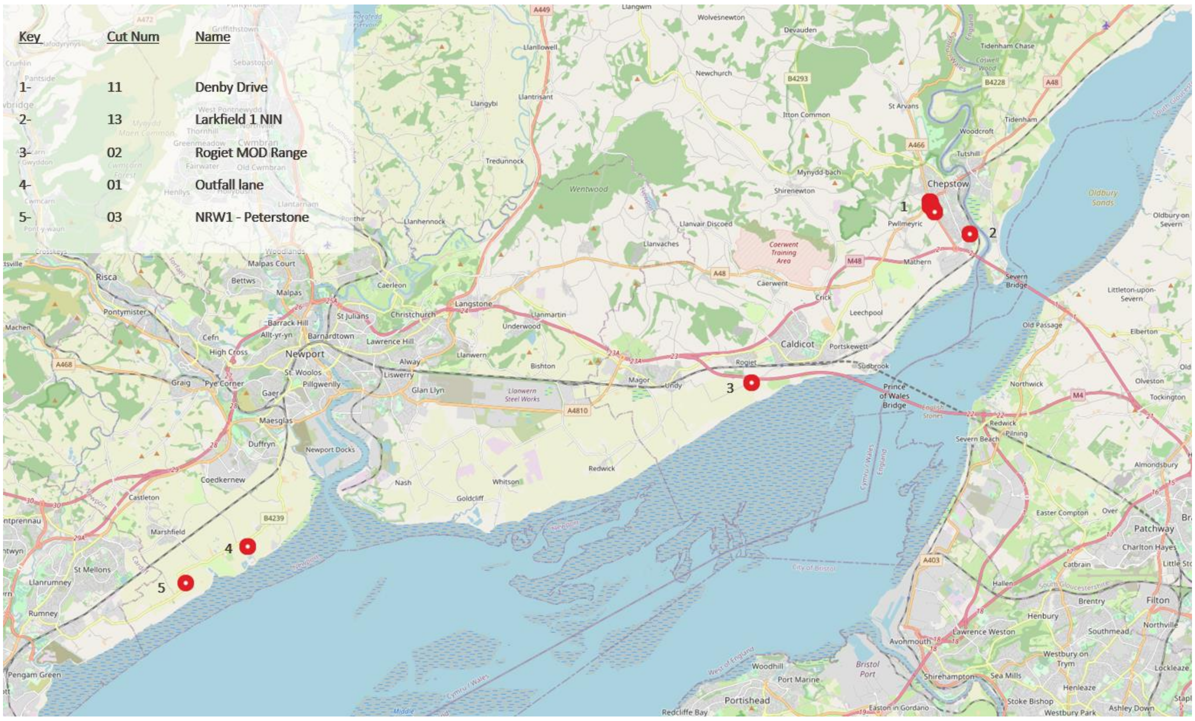


Figure 6.3 Sample locations for analysis of biomass

Figure 6.4 Maps showing sites in Chepstow for Cut and Collect samples

6.3 Samples collected for analysis

Figure 6.5 Ensiled samples and packaged up samples to be sent off the laboratory

Once collected the samples were ensiled as can be seen in Figure 6.5 and all stored until Jan 2023 when they were packaged, collected and sent to the laboratory for analysis.

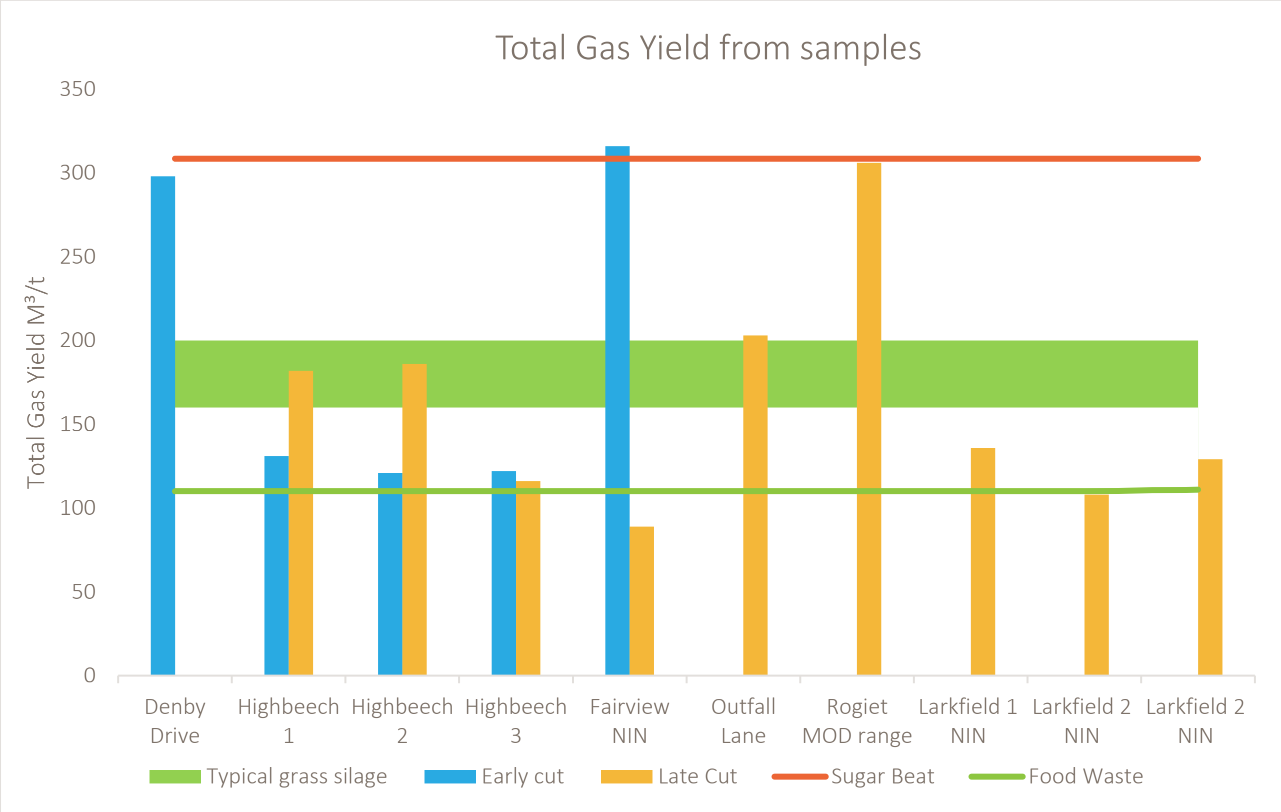


Figure 6.6 Graph showing the total gas yield calculated for each sample collected

6.4 Trial Conclusions

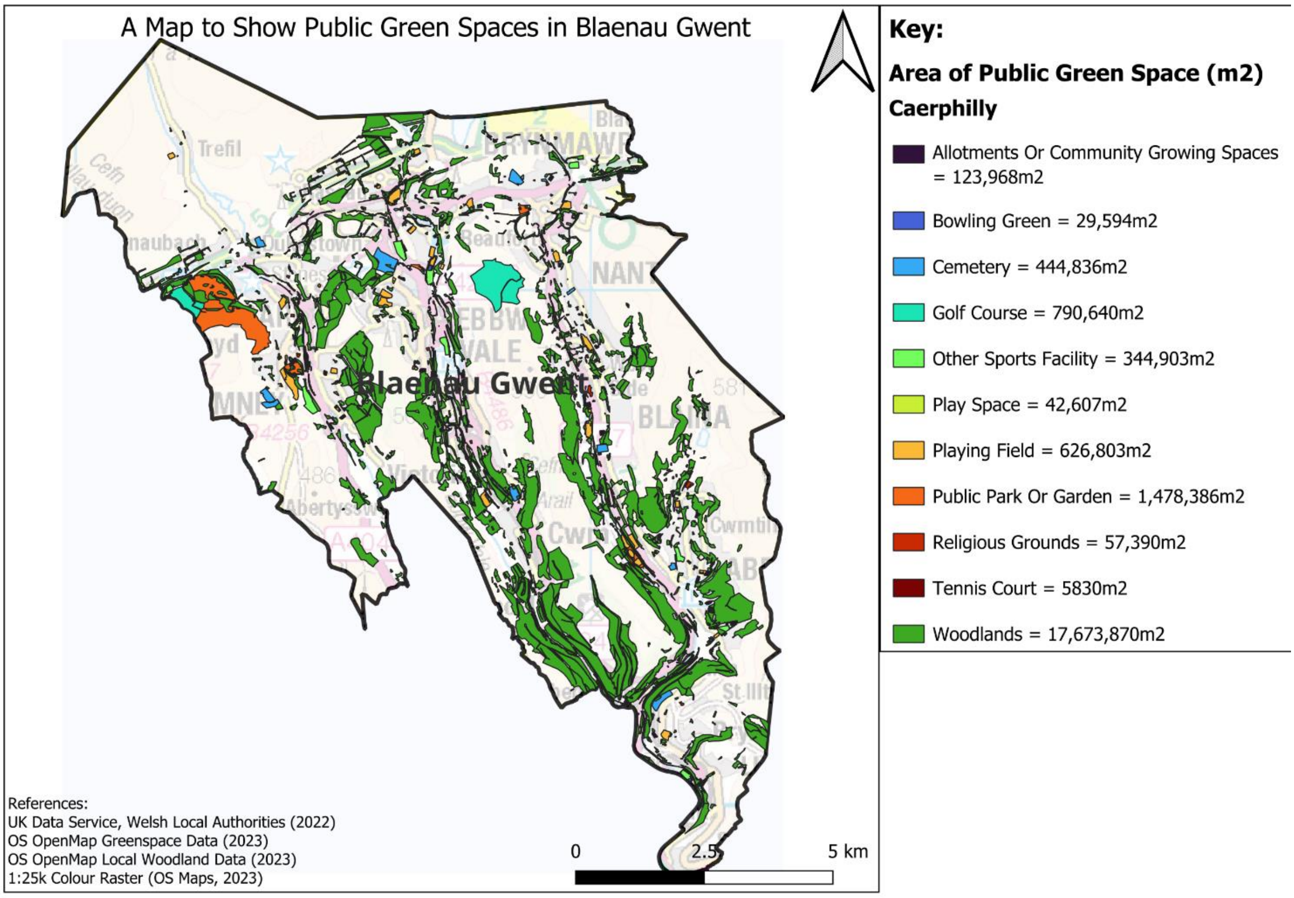
The samples collected from all sites produced encouraging gas yield results with the average yield being just below that of the identified typical grass silage yield at circa 149 M^3/t. It is also of note that only one sample, the late cut taken from Fairview NIN showed a worse gas yield potential than the average yield provided by food waste.

7 Mapping & Biomass Availability

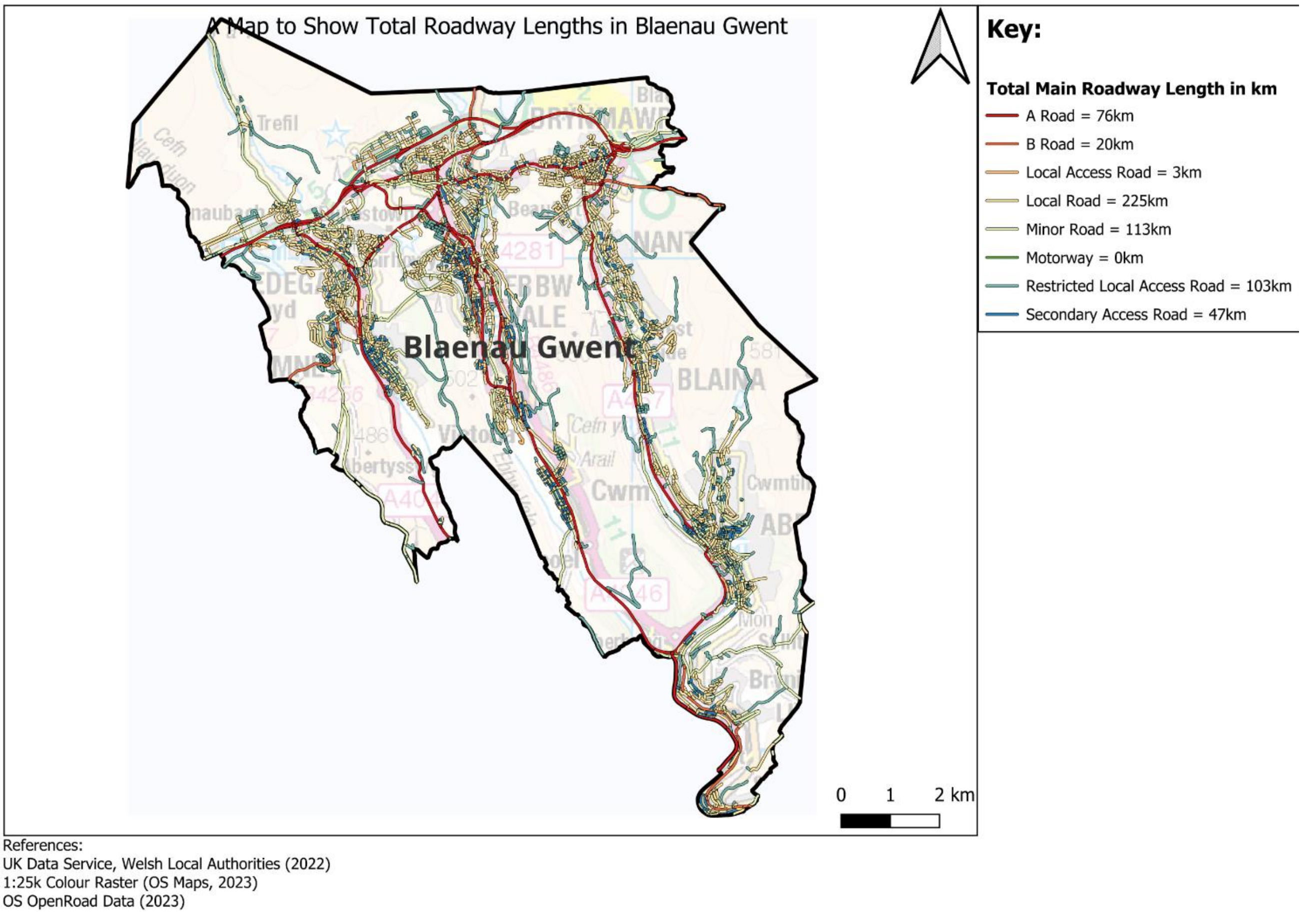
In order to assess the availability of grass biomasses we conducted an open-source research and mapping exercise and have obtained data on green spaces and roadside verge availability for each local authority as set out below. the trial conducted highlighted the challenges of collecting the cuttings from highly managed grass areas such as sports pitches & bowling greens is difficult due to the required management to keep swath length short over the growing season. Therefore, we have focused on the availability of grass and other biomass from allotments or community growing spaces, cemeteries, public park and gardens and religious grounds as highlighted in the first map for each region. In addition, we have made identified the available roadside verges for harvesting using a desktop study as shown in the second map for each region.

Based on results of previous trials highlighted earlier in the report on biomass yields from such sites, we have calculated average potential yields for each region of 2.5-3.3 tonnes dry mass/ha/yr. All roadside verge data is based on an assumption of a 1.2m cut width along both sides of the identified roads.

7.1 Blaenau Gwent

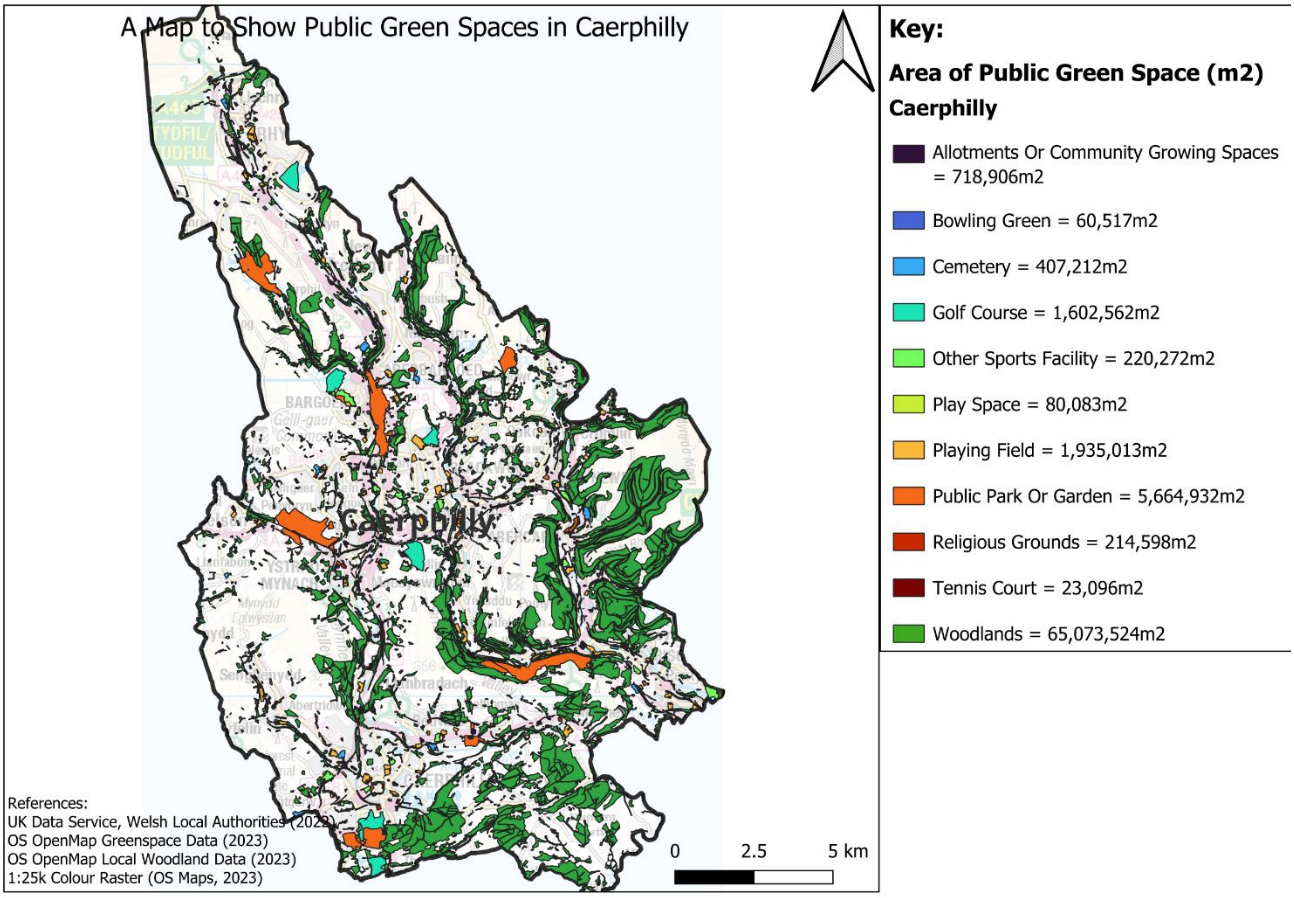


In total there is 2,104580m2 or just over 210 hectares of manageable biomass that can be managed for collection, offering in the region of 525 and 700 tonnes of dry mass per annum.

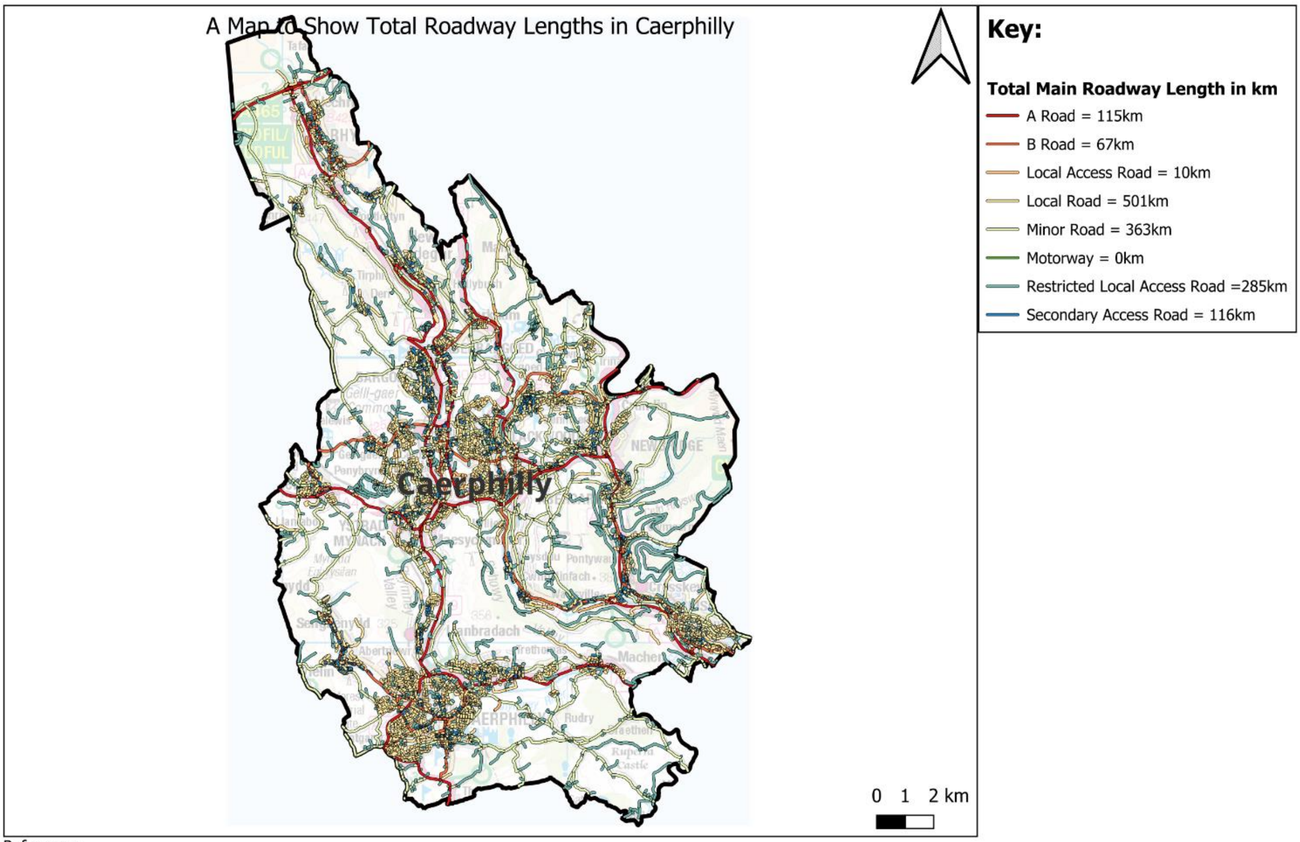


With 76km of A-roads in the county this is a potential harvestable verge area of 182 hectares with a biomass yield potential of 455 to 606 tonnes dry mass per annum.

7.2 Caerphilly



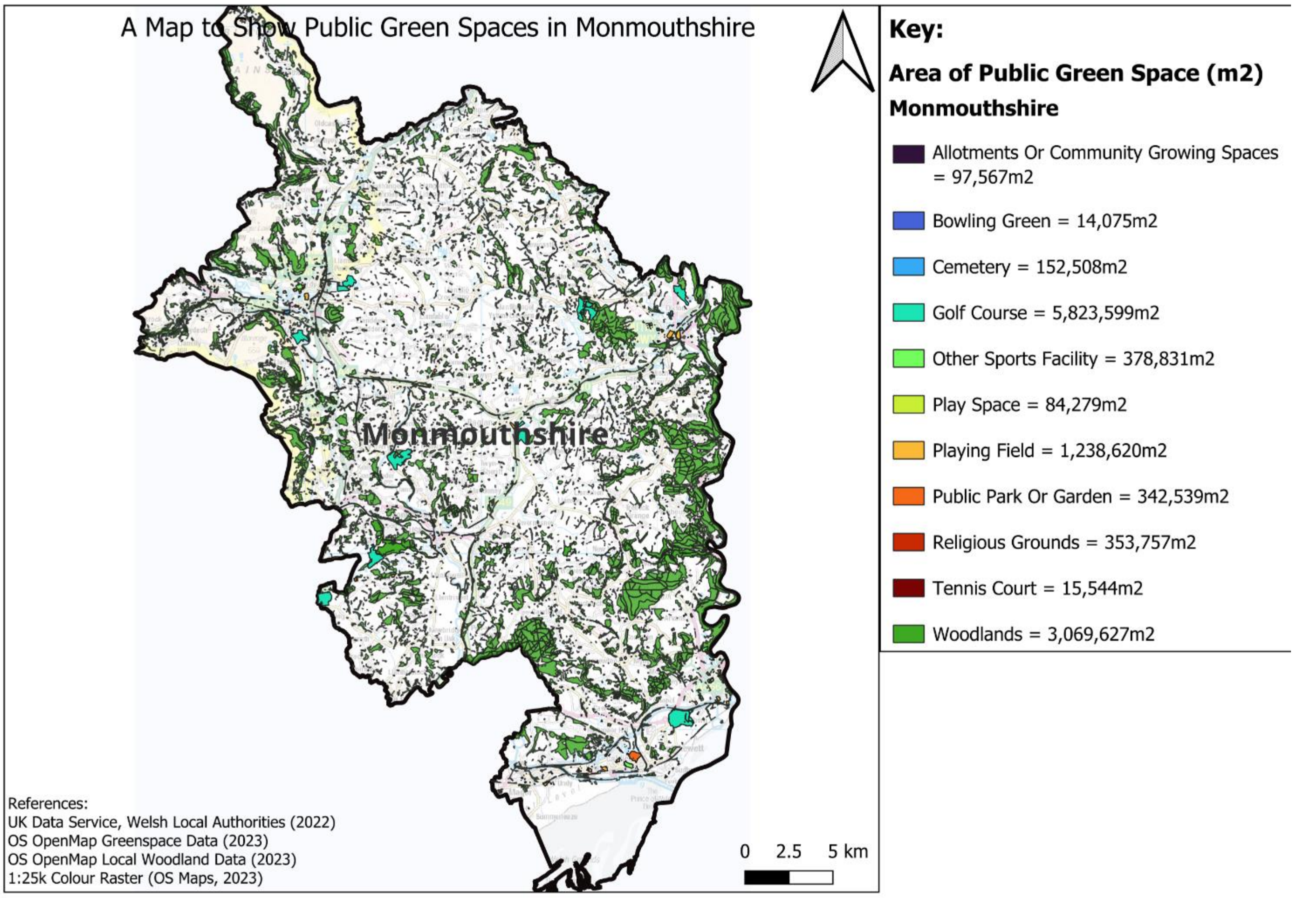
In total there is 7,005,648m2 or just over 700 hectares of manageable biomass that can be managed for collection, offering in the region of 1750 and 2310 tonnes of dry mass per annum.



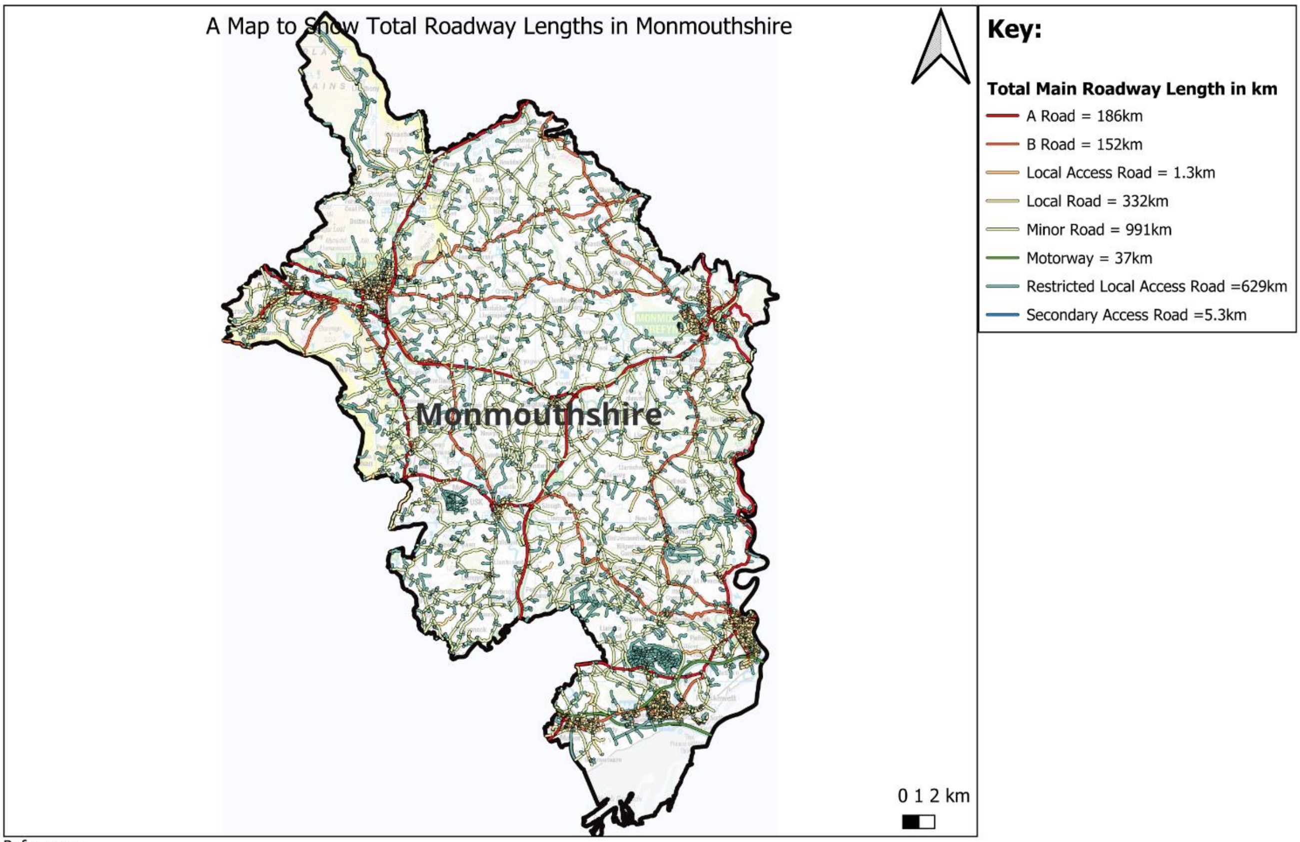
References:
UK Data Service, Welsh Local Authorities (2022)
1:25k Colour Raster (OS Maps, 2023)
OS OpenRoad Data (2023)

With 115km of A-roads in the county this is a potential harvestable verge area of 276 hectares with a biomass yield potential of 690 to 910 tonnes dry mass per annum.

7.3 Monmouthshire



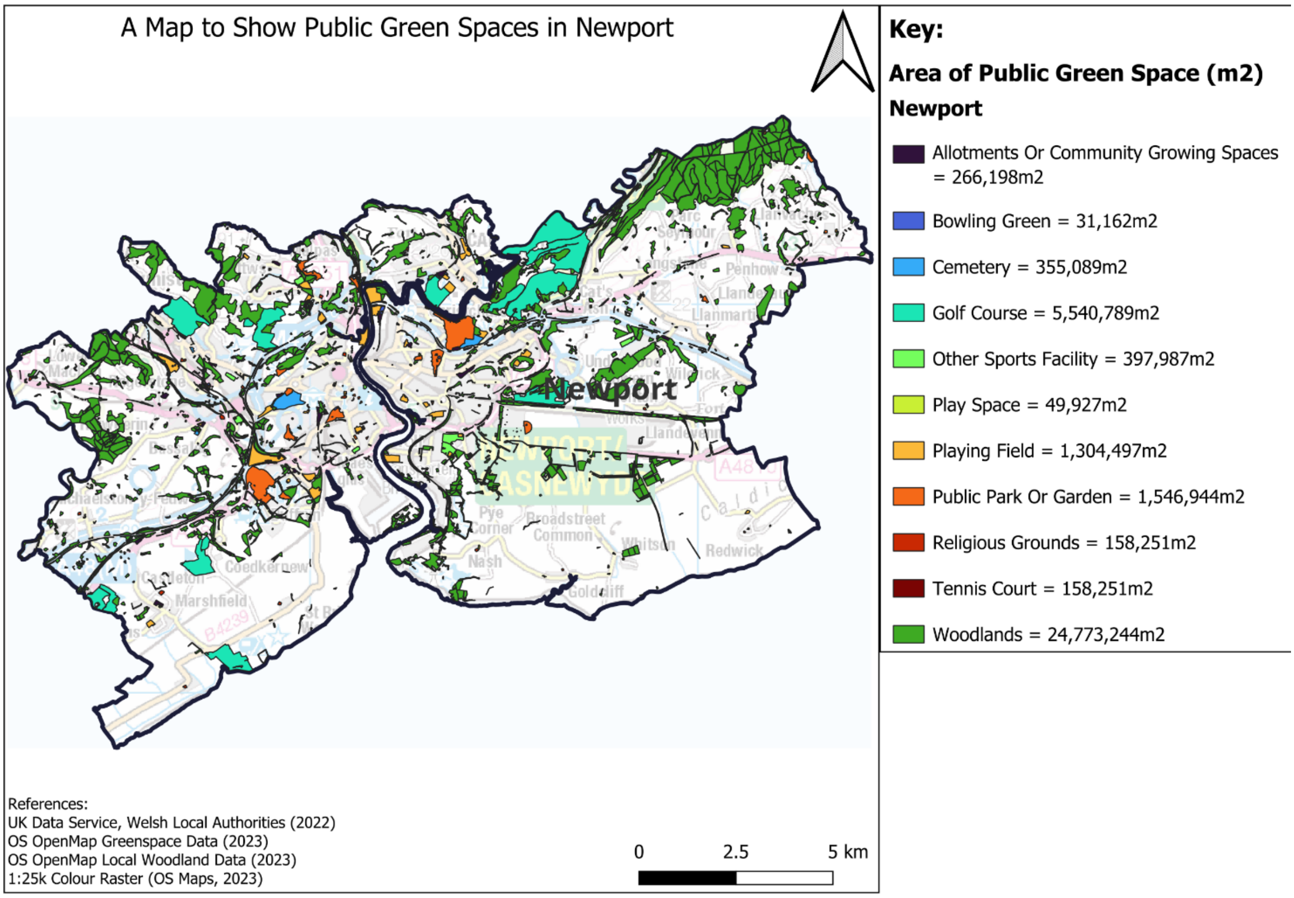
In total there is 946,371 m2 or just over 94 hectares of manageable biomass that can be managed for collection, offering in the region of 235 and 310 tonnes of dry mass per annum.



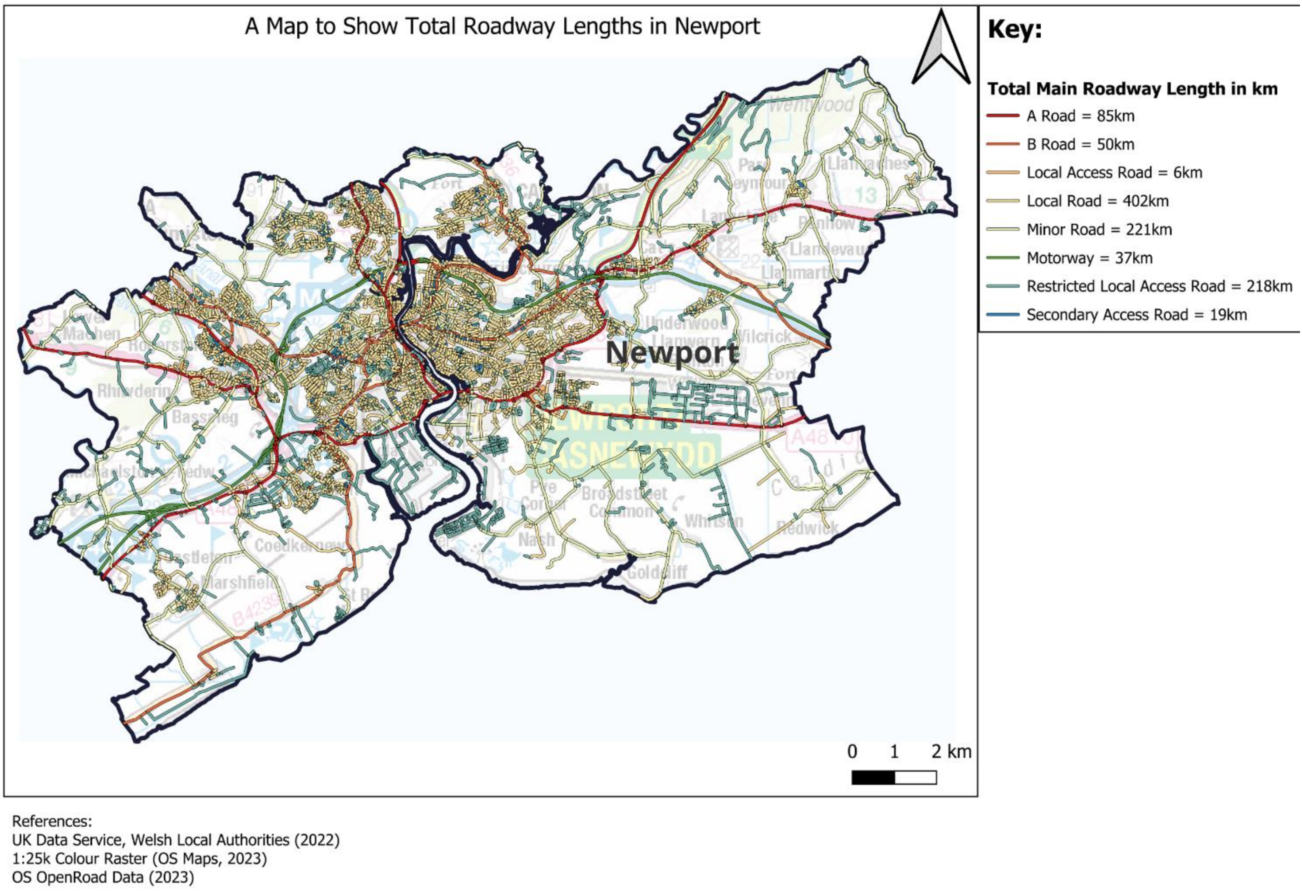
References:
UK Data Service, Welsh Local Authorities (2022)
1:25k Colour Raster (OS Maps, 2023)
OS OpenRoad Data (2023)

With 186km of A-roads in the county this is a potential harvestable verge area of 446 hectares with a biomass yield potential of 1115 to 1471 tonnes dry mass per annum.

7.4 Newport

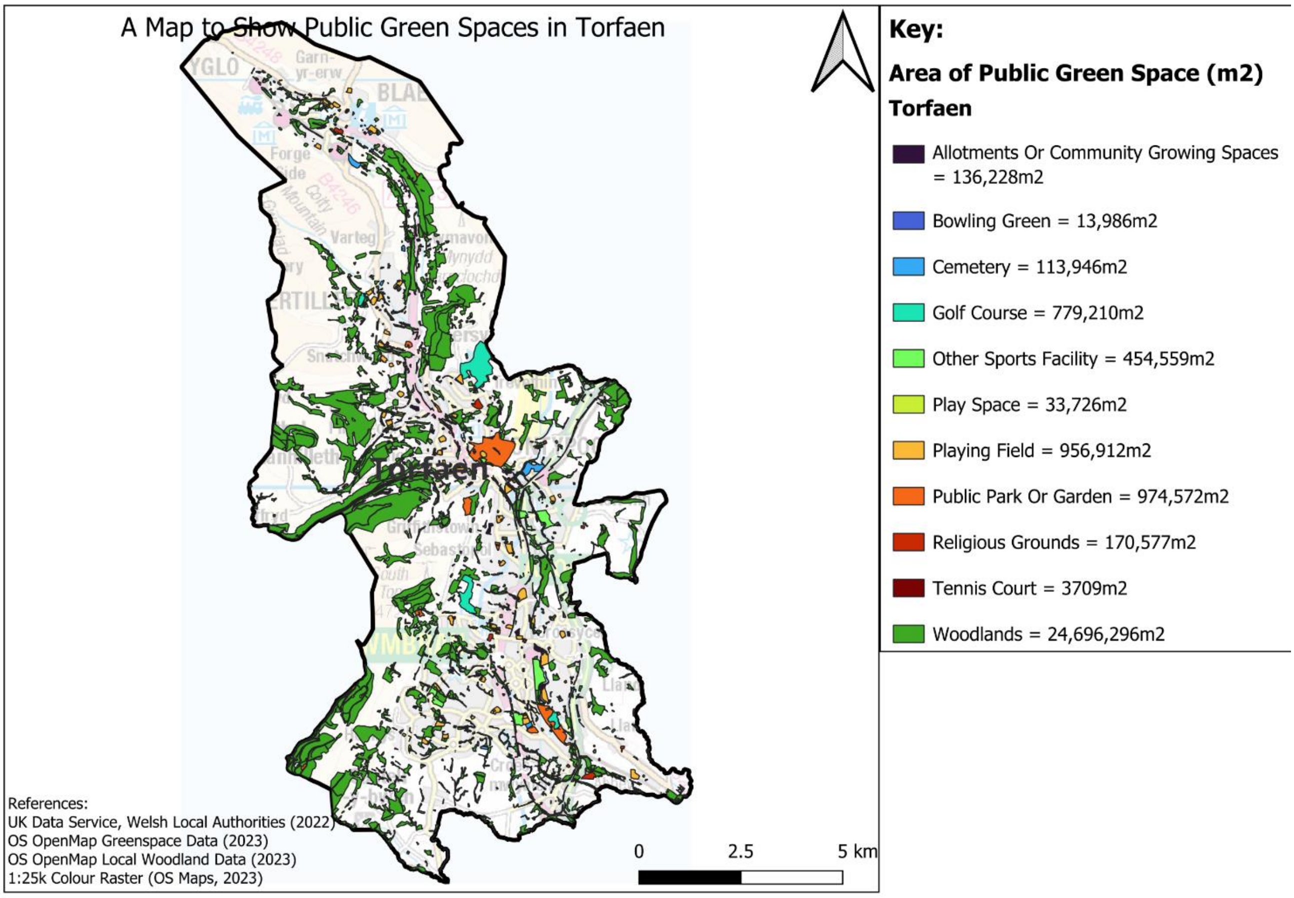


In total there is 2,326,482m2 or just over 232 hectares of manageable biomass that can be managed for collection, offering in the region of 580 and 765 tonnes of dry mass per annum.

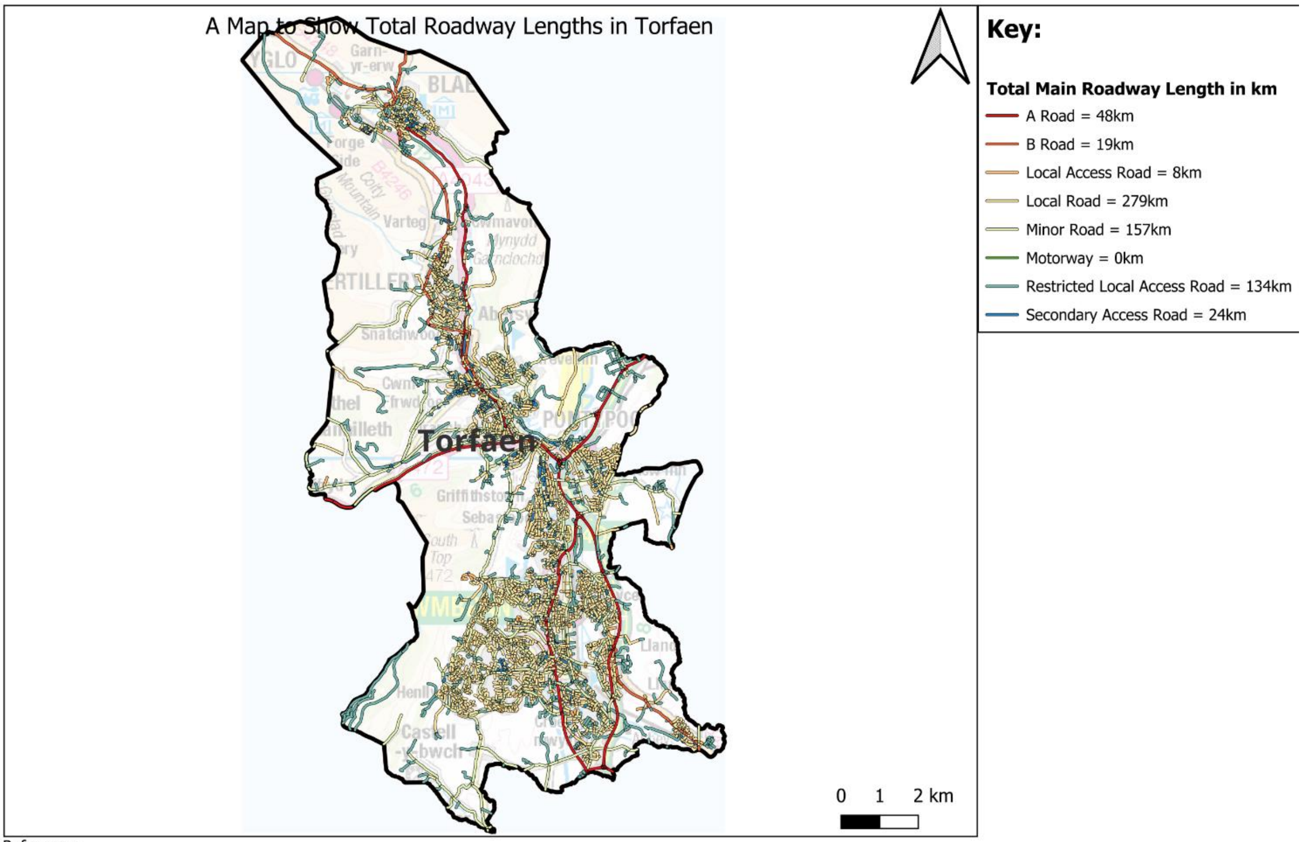


With 85km of A-roads in the county this is a potential harvestable verge area of 204 hectares with a biomass yield potential of 510 to 673 tonnes dry mass per annum.

7.5 Torfaen



In total there is 1,395,323 m2 or just over 139 hectares of manageable biomass that can be managed for collection, offering in the region of 347 and 458 tonnes of dry mass per annum.



References:
UK Data Service, Welsh Local Authorities (2022)
1:25k Colour Raster (OS Maps, 2023)
OS OpenRoad Data (2023)

With 48km of A-roads in the county this is a potential harvestable verge area of 115 hectares with a biomass yield potential of 287 to 379 tonnes dry mass per annum.

8 Life Cycle Analysis

The life cycle analysis is a method of determining the impact of products on the environment throughout the entire life cycle of the product, beginning with the extraction of raw materials, their conversion, manufacture, transportation and use of the products, ending with their disposal and waste management upon the end of their useful life. In terms of its definition, LCA is limited to consideration of environmental factors. Besides these aspects, there are also other factors that must be taken into account when making a decision, such as social, economic, political, and technical aspects. Therefore, life cycle assessment should be viewed in a broader context, as a tool that helps decision makers to understand the product's environmental impacts (Berg, 2018; Miettinen & *Hämäläinen*, 1997).

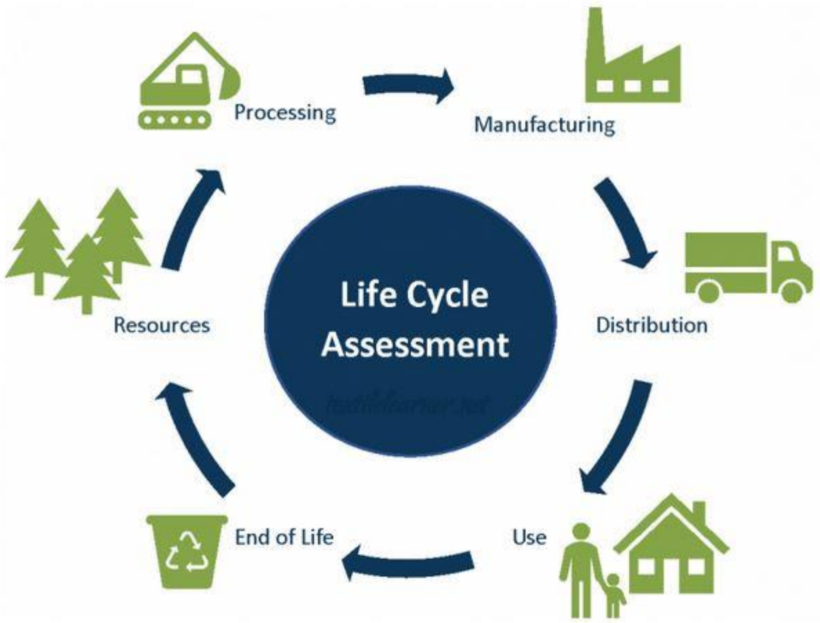


Figure 1: Life cycle assesment phases (Kiron, 2022).

Among the main applications of LCA are analyses of origins of problems related to a particular product, comparative analysis of improvement variants, the design of new products, and the selection of appropriate products among a number of comparable ones. In relation to products, LCA can be an important tool in environmental management both publically and privately, as it involves both an environment comparison of existing products and the development of new products (Singh *et al.*, 2013).

8.1 LCA software tools in the markets

There are a number of software tools that can be used to conduct LCAs, including Simapro, Gabi, Sphera, Ecochain Mobius, OneClick LCA, OpenLCA, iPoint Umberto, and others. Using all of these tools, it is possible to perform a Life Cycle Assessment in accordance with scientific standards. Simapro and Sphera are great tools for facilitating expert use. However, Ecochain enables users without a LCA background to conduct an environmental assessment (https://lca-software.org/, 2023). Due to differences in characterization factors between LCA software tools, the results obtained differ. figure1 shows A brief overview of commonly used LCA softwares, a total of 22 papers (38%) did not specify the software used or used less common software such as EASETECH, TOTAL, Wastewater Energy Sustainability Tool (WWEST), and TEAM (Razman, Hanafiah and Mohamad, 2022).

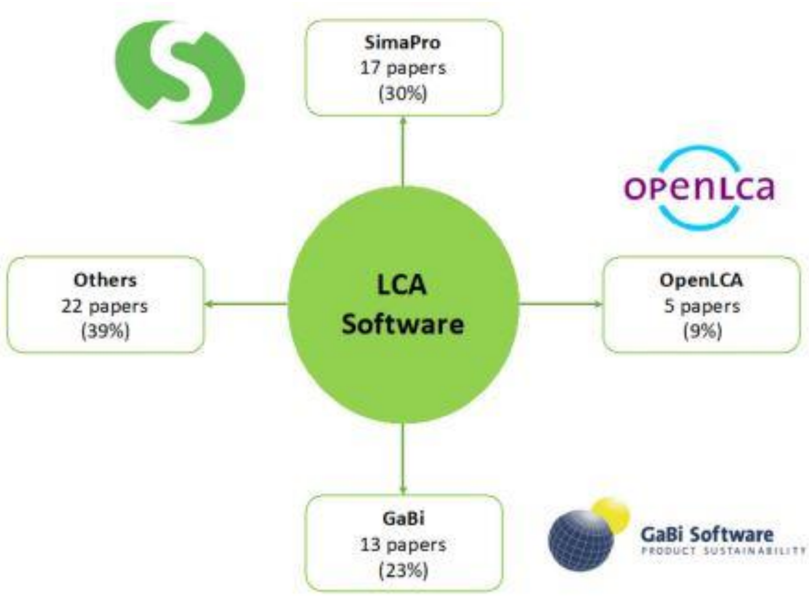


Figure2: LCA software is frequently used in reviewed studies (Razman, Hanafiah and Mohamad, 2022).

One Click LCA: Leading businesses use the software in more than 130 countries. The system integrates all leading standards, databases, and design software tools available worldwide. There are several applications for the software, including buildings, infrastructure, renovations, construction products and materials, and portfolio management.
Sphera's LCA: With Sphera's LCA for Experts, Life Cycle Assessment (LCA) models and reports from reliable sources can now be combined with environmental data. Sphera provides companies with access to more than 20 industry-specific databases, enabling them to understand environmental impacts throughout product life cycles and make informed decisions.
Ecochain Mobius: Ecochain Mobius is a popular Life Cycle Assessment software program that is widely used by businesses and organizations. It is known for its user-friendly interface and advanced features, which facilitate the collection and analysis of product data across a product's lifetime.

SimaPro: SimaPro is the preferred LCA software among research institutes and consultants. In terms of features, SimaPro offers what LCA specialists would expect from a professional package of LCA software.	
The Umberto LCA: The Umberto LCA software solution is one of the most widely used solutions in the world. Experts in LCA from industry, consulting, research and education have used it for more than 25 years. Using the latest version Umberto LCA+, users will be able to access the ecoinvent database directly within the software through the standard database integration.	
openLCA: In the world, openLCA is the only free, open-source life cycle assessment software that can be used for the analysis of ecology, social welfare, and economic aspects of life cycles. In addition to life cycle assessments, openLCA can also be used to calculate carbon and water footprints, eco-design, environmental product declarations, life cycle costing, and social life cycle assessment, among other applications.	

8.2 The Life cycle analaysis roles in the sustainability industry

In recent years, LCA has been the method of choice for a variety of new technologies related to bioenergy production and carbon sequestration. Defining sustainable biofuel production is relatively easy. Nevertheless, determining an appropriate framework to characterize economic, environmental, and social impacts is quite challenging. Sustainable development is defined as meeting the needs of the present without compromising the needs of future generations. A product's or technology's sustainability is normally assessed based on three dimensions: social, economic, and environmental (Singh et al., 2013) as shown in the figure 3.

Figure 3: Economic, social, and environmental aspects

of sustainable renewable energy sources (Grade 4: Rocks, Minerals and Erosion, no date).

All aspects of the energy production chain have an environmental impact: transformations, the production and application of chemicals, cultivation of energy crops, biofuel production, transport, and use. Pollutants are generated at many points during the production process. A renewable energy production process's sustainability depends on how much energy is gained as a net result of its input, which is affected by inputs like harvesting, transportation, and processing facility emissions all of which can be analyzed using life cycle analysis software (Singh *et al.,* 2013).Therefore, LCAs are commonly used to monitor reductions in GHG emissions and to estimate fossil fuel substitution efficiency.

8.3 The life cycle analysis beneficial for determining the environmental impact of using grass as a biomass source to produce biogas and biochar

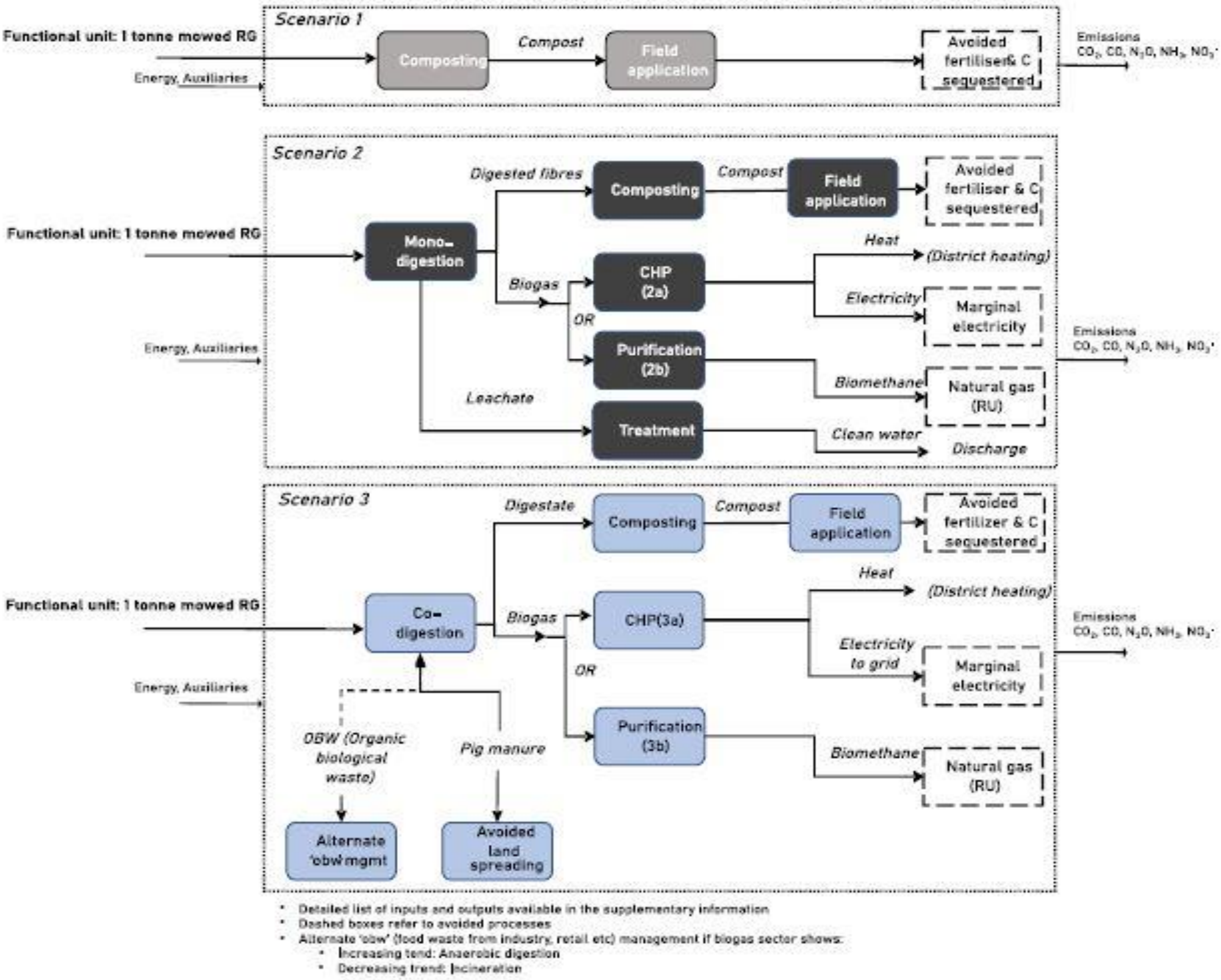
Scenario 1: Environmental impact of the production of biogas from grass biomass

It is often emphasized that biogas technology is an environmentally friendly alternative to fossil fuels, as a valid and sustainable alternative. It is also possible to enhance energy security by reducing greenhouse gas emissions through biogas production (Paolini *et al.*, 2018).

- In comparison with combustion-based methods for these biomasses, recycling an agricultural and zootechnical byproduct or municipal waste allows exploitation of these byproducts with minimal impact on air quality.
- Digestate, a by-product of anaerobic digestion, appears to be a suitable material for agricultural purposes.
- This technology is highly scalable, allowing it to be utilized to maximize the energy potential of biomass sources that are distributed.
- A biogas fuel can be converted to biomethane, used as a vehicle fuel, or injected into the national natural gas grid.

Case study 1: Using Simpapro software LCA, a recent study by Ravi et al. (2023) examined the environmental impacts of utilizing roadside grass clippings as an alternative feedstock for producing biogas for use as fuel in these northern European regions. The study focused on three scenarios to compare mono- and co-digesting of RG with other feedstocks, as illustrated in the figure3.

Figure 4: A system boundary for managing one tonne of roadside grass clippings. The dashed boxes indicate



those processes that were avoided. The sub-scenarios labelled 'a' and 'b' represent variations of the valorisation of biogas. In scenario 3, the co-digestion process is expanded in order to isolate the environmental impacts associated with RG. When RG is co-digested with pig manure, food waste is displaced, which can be managed alternatively. In the absence of co-digestion, pig manure would be applied to the fields (Ravi et al., 2023).

Based on LCA results, co-digestion of roadside grass (RG) and manure is a more environmentally friendly alternative to composting. It is estimated that composting RG alone creates significant amounts of biogenic carbon dioxide; however, RG monodigestion creates environmental challenges due to the emission of fugitive gases and the treatment of leachate.

The following are some examples of the results of the LCA. As compared to mono-digestion, i.e. scenario 2, (2a: 1.17E-02; 2b: 1.05E-02) and codigestion, scenario 3, (3a: 4.13E-02; 3b: 3.83E-02), scenario 1 appears to have the highest net impact (3.16E-03). As a result of the treatment of leachate, a byproduct of mono-digestion, 4.8 eq of CO2 were released into the atmosphere.

As a result of biogenic emissions during composting (CO2 and CH4) as well as field application (CO2 and N2O), Scenario 1 carries a high burden. When compared with Scenario 1 (RG composting), the impacts of climate change potential were approximately three times lower with mono-digestion as shown in the figures 4, 5 and 6.

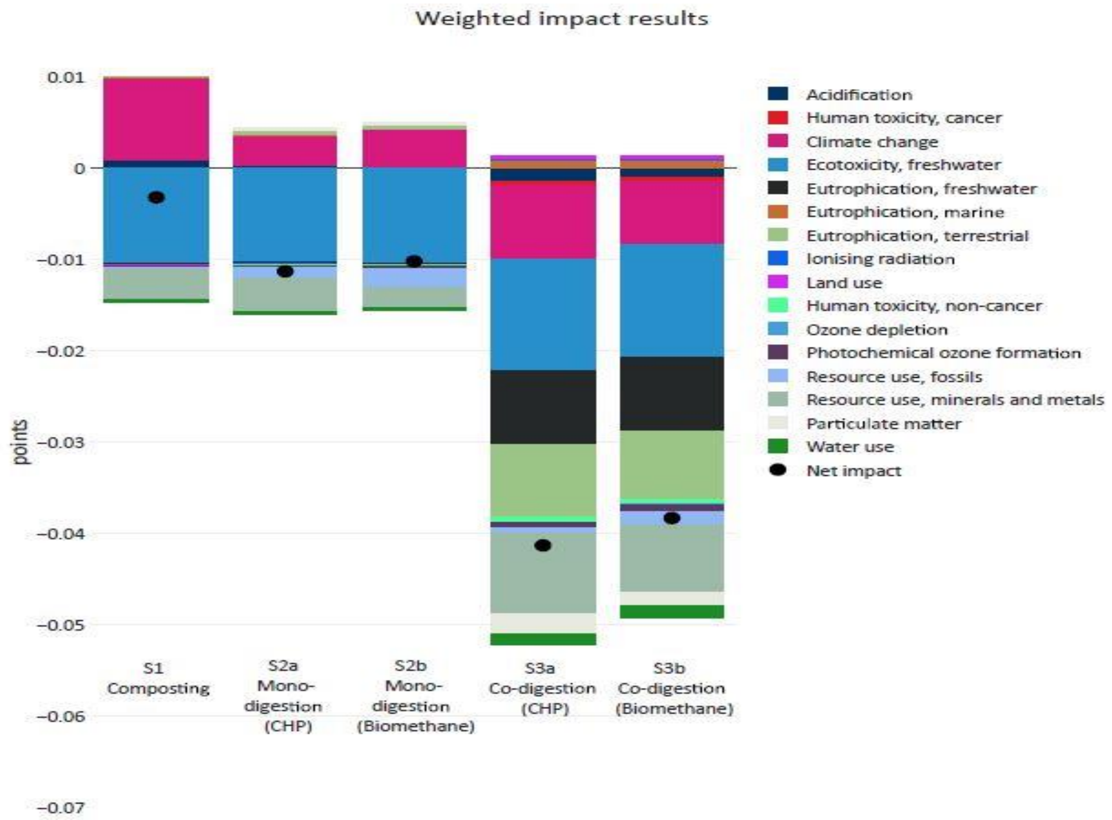


Figure 5: The overall impact score after normalization and weighting by function, i.e. processing mowed roadside grass (Ravi et al., 2023).

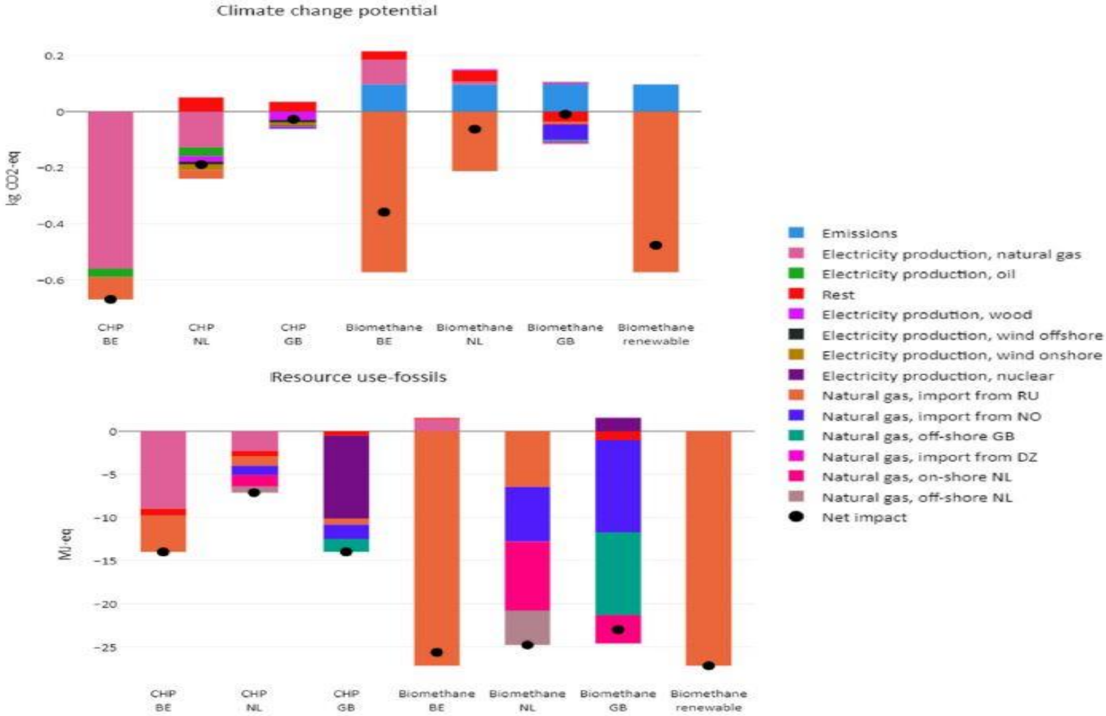


Figure 6: Comparing the environmental impact and fossil resource use of biomethane versus CHP for valorising 1 m3 of biogas (Ravi et al., 2023).

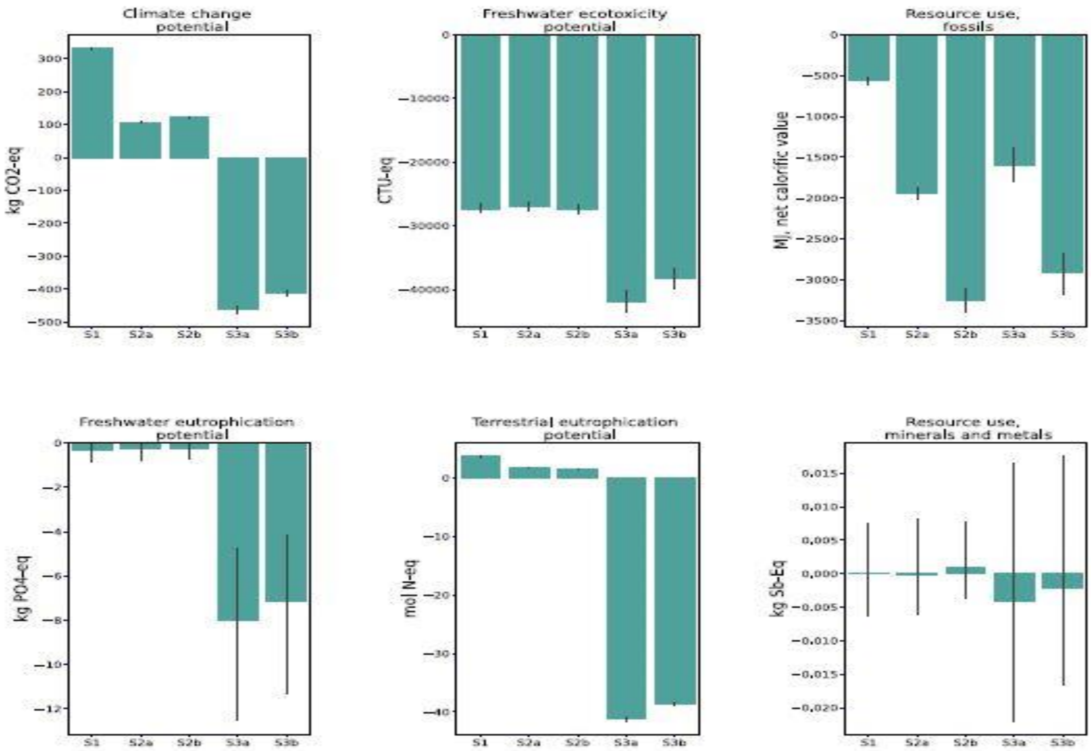


Figure 7: A summary of the effects for the most relevant impact categories per functional unit, e.g. processing of roadside grass after 1000 Monte Carlo simulations (Ravi et al., 2023).

Case study 2: Bedoić *et al.* (2019) studied the application of abundant quantities of residue as a source of heat and electricity, as well as creating a fertiliser from digested substrates. These waste products were used to identify the environmental impacts as it can be seen in table 1.

Table 1:Samples (Bedoić et al., 2019).

Reaction mixture	Inoculum	Residue grass	Maize silage	Cattle slurry
MMS	4.500	/	4.500	/
MRG1	4.500	4.500	/	/
MRG2	4.500	4.500	/	/
MRG3	4.500	4.500	/	/
C1	4.500	2.250	/	2.250
C2	4.500	1.687	0.563	2.250
C3	4.500	1.125	1.125	2.250
C4	4.500	0.563	1.687	2.250
C5	4.500	/	2.250	2.250
IN	4.500	/	/	/

Considering only the results from co-digestion processes (C1eC5), we can see that process C1, carried out with grass residue and cattle slurry, has 3.6 times better ecosystem quality than process C5, carried out with maize silage and cow slurry as Figures 7 and 8 show greenhouse gas (GHG) emissions. A large proportion of these emissions are due to greenhouse gas emissions from fossil fuels used for agricultural machinery, grass collection and maize silage transportation. In comparison with maize silage, all grass types studied yield lower biogas, increasing transportation emissions, since more grass needs to be transported to the AD plant to produce the same amount of energy. Due to this, process C1 generated 32% more greenhouse gases than process C5.

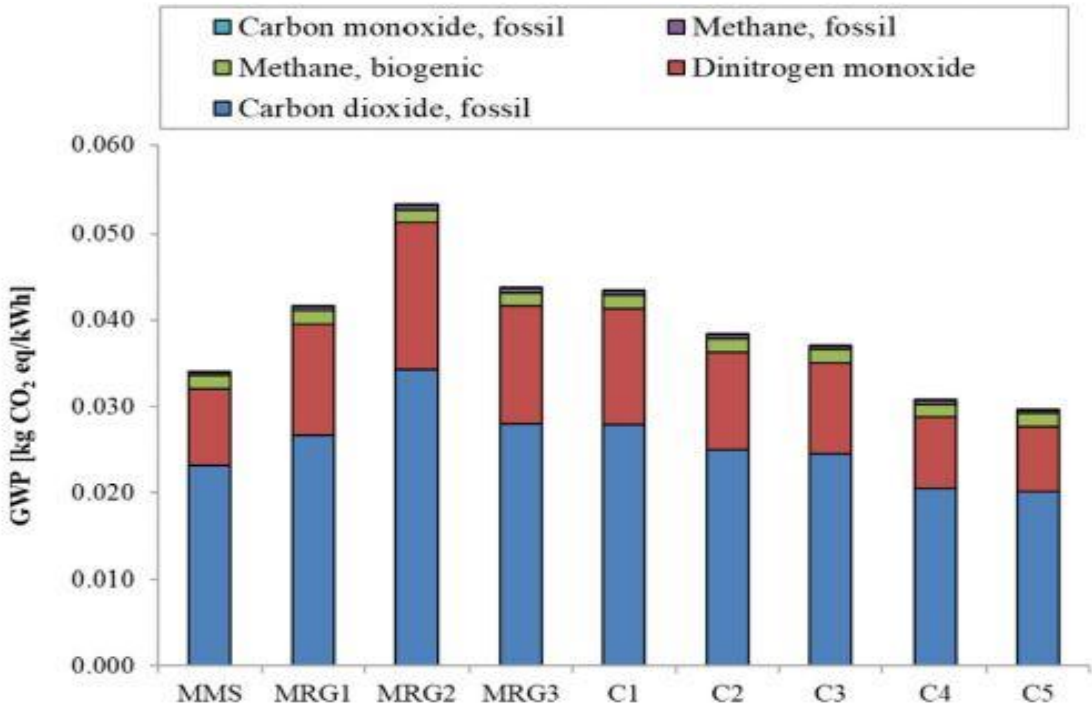


Figure 8:The Global warming potential (GWP) results (Bedoić et al., 2019).

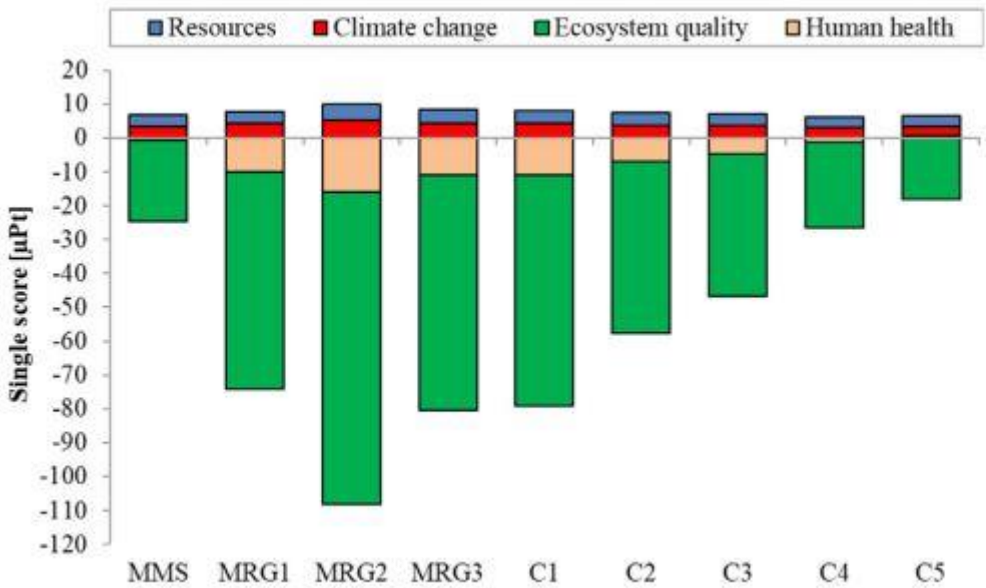
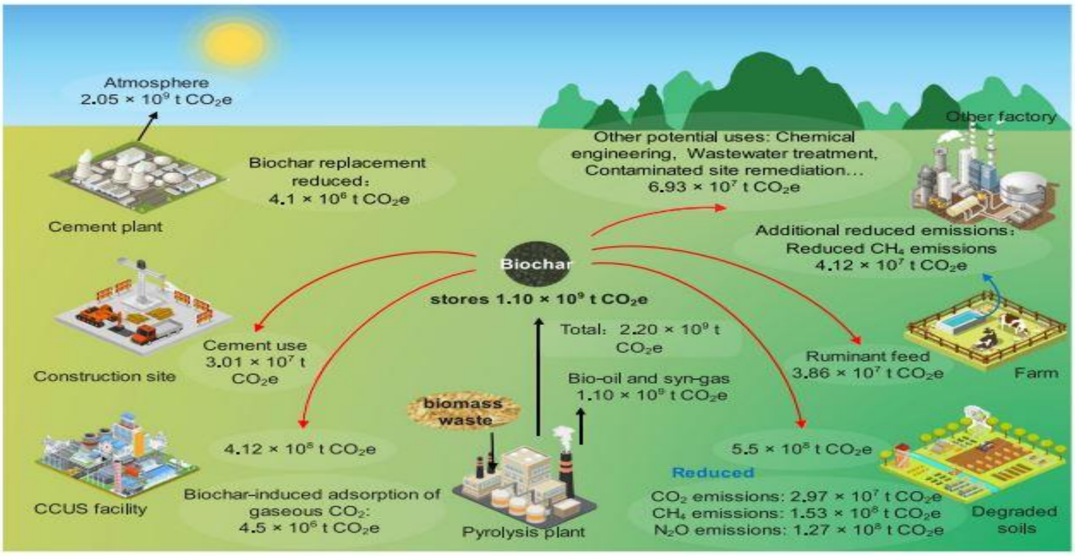


Figure 9: The single score results of the life cycle impact assessment (Bedoić et al., 2019).

Scenario 2: Environmental impact of the production of biochar from grass biomass

In this context, biochar has gained a new level of importance as a soil amendment traditionally used to improve fertility and remediate contaminants. Biochar application can be a powerful tool to mitigate a significant amount of greenhouse gas (GHG) emissions, accounting for 5.0% of global emissions. By suppressing CH_4 and N_2O emissions as well as improving soil health, biochar can significantly improve soil health as a result of the application. Carbon neutrality can also be achieved in non-soil applications with biochar. Additionally, biochar added to Portland cement and low impact development (LID) infrastructure can reduce carbon footprints and increase resilience. Biochar can also serve as a supercapacitor and novel battery. Carbon capture, utilization, and storage (CCUS) with biochar has a high CO_2 adsorption capacity. Technologies such as biochar have a huge potential to mitigate as much as 2.56 109 t CO_2 per year as shown in the figures 10 and 11 (Wang *et al.,* 2023).



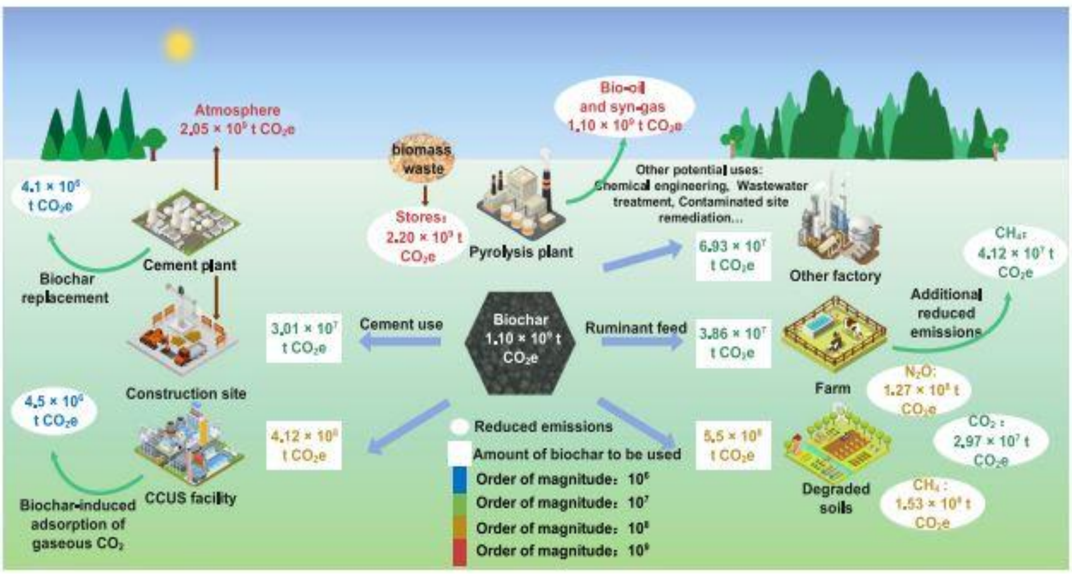


Figure 10: Various applications of biochar toward carbon neutrality (Wang *et al.*, 2023).

Case study 1: For climate change mitigation and fossil fuel reduction, biomass can be pyrolyzed and returned to the soil with biochar. By applying biochar to soils, pyrolysis provides four coproducts: long-term carbon (C) sequestration, renewable energy, soil amendments, and biomass waste management. Roberts *et al.* (2010) study, Agricultural residues (corn stover), yard waste, and switchgrass energy crops were analyzed as shown in the Figure 9.

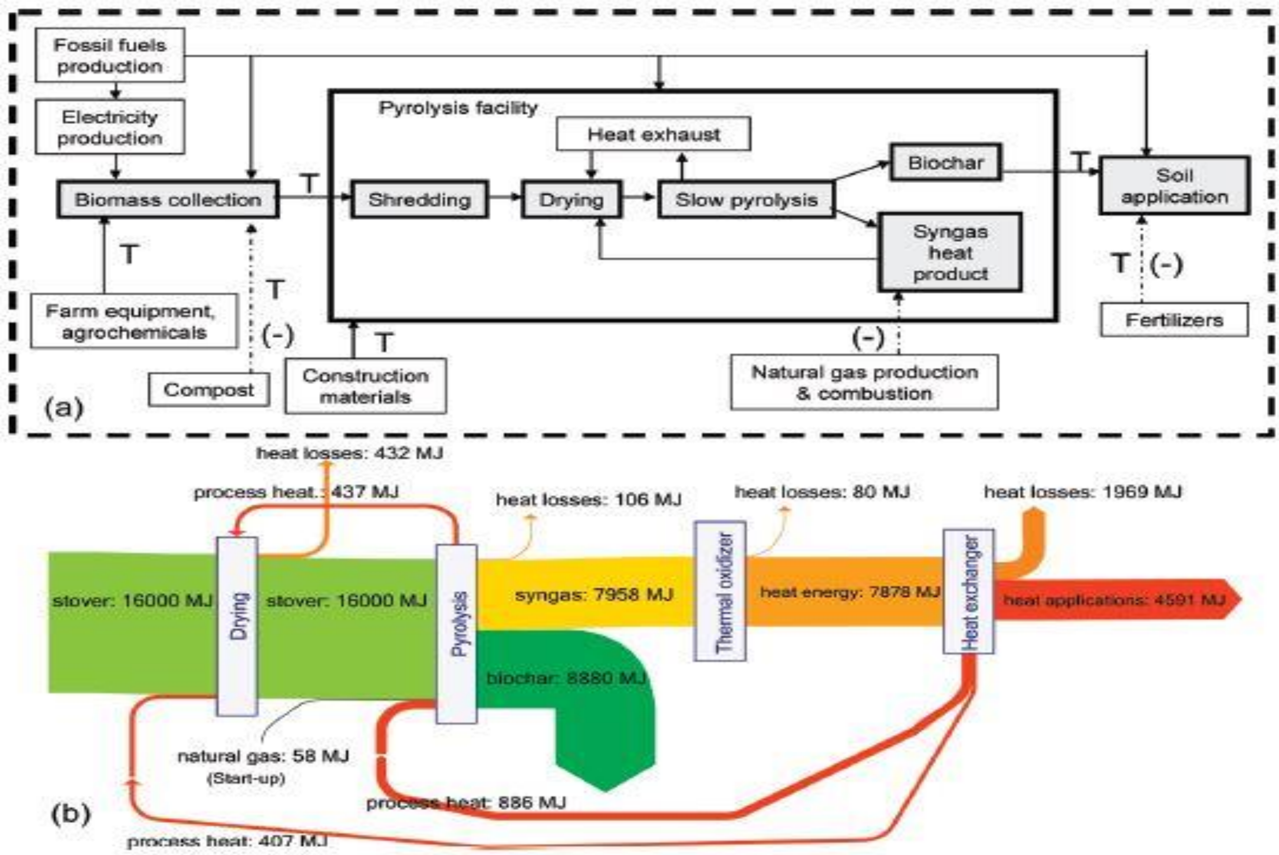


Figure 11: (a) System boundaries for the LCA of a biochar system with bioenergy production are denoted by a dashed box. Dashed arrows with (-) indicate avoided processes. The "T" represents transportation. The avoided compost process applies only to yard waste. (b) Energy flows (MJ t-1 dry feedstock) of a pyrolysis system for biochar with bioenergy production using late stover as a functional unit (Roberts et al., 2010).

Switchgrass (4899 MJ t-1 dry feedstock) offers the highest net energy. Both stover and yard waste result in net greenhouse gas (GHG) reductions of -864 and -885 kg CO2e per tonne, respectively. C sequestration in biochar accounts for 62-66% of these reductions. The switchgrass biochar-pyrolysis system can be a major GHG emitter (+36 kg CO2e t-1 dry feedstock), depending on the accounting method for indirect land-use change impacts. According to the analysis of feedstocks assessed, each system generates more energy than it consumes, which is referred to as a positive net energy as shown in the life cycle assesment result of the figure 10.

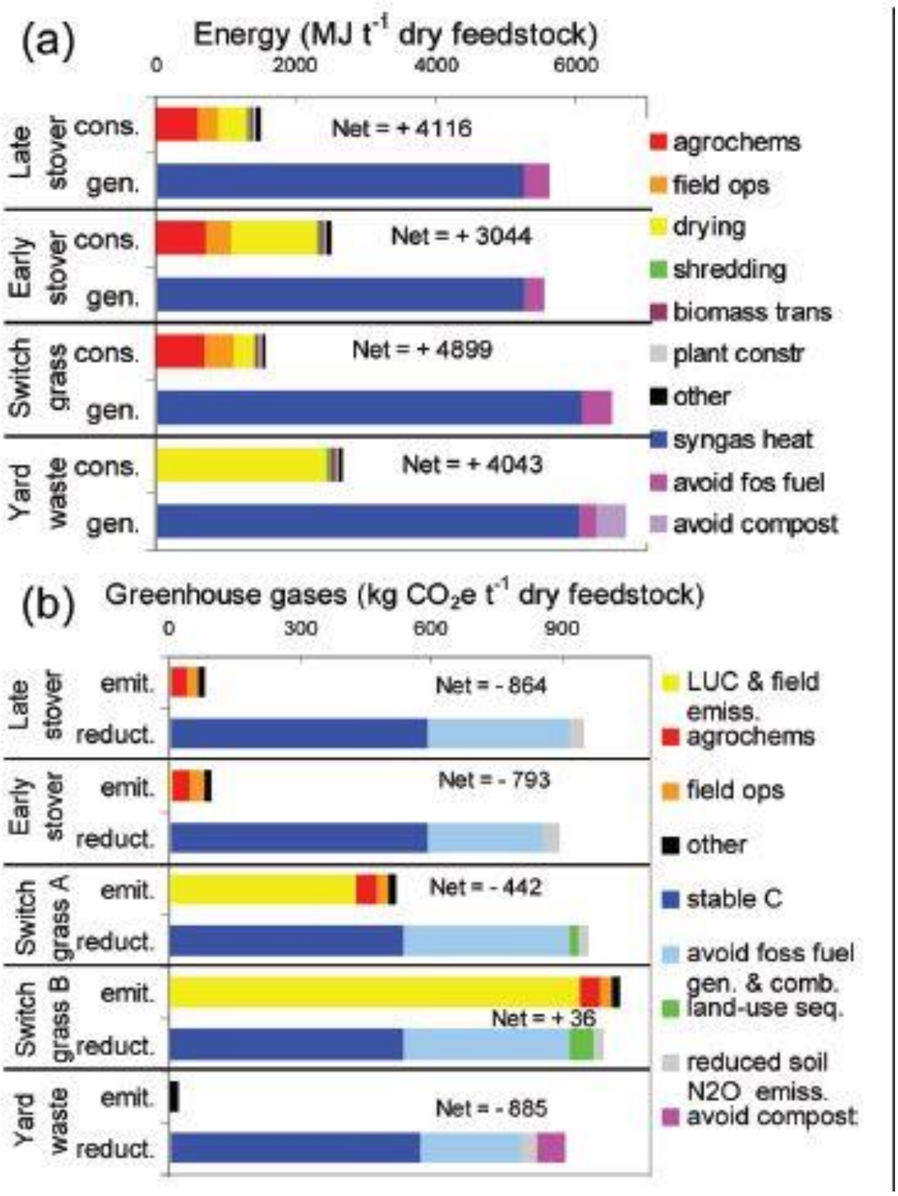


*Figure 12: (a) Contribution analysis for the net energy per dry tonne of late stover, early stover, switchgrass, and yard waste in biochar systems with bioenergy production. Each pair of bars is associated with a feedstock. The top bar represents energy consumption, the bottom bar is energy generated, and the difference represents the net energy of the system. Switchgrass A and B have the same energy contribution profile, and only scenario A is shown. (b) Contribution analysis for the net climate change impact per dry tonne of late stover, early stover, switchgrass, and yard waste in biochar systems with bioenergy production. Each pair of bars is associated with a feedstock. The top bar represents GHG emissions, the bottom bar is GHG emission reduction, and the difference represents the net GHG emission balance of the system. (LUC) land-use change (*Roberts et al., 2010*).*

Case study 2: An overview of the potential factors that may affect pyrolysis use in Germany was conducted by Heinrich *et al.* (2023) using the feedstock, grass from periodically flooded polder areas in the LOV National Park, as a case study. Based on the table below, three different pyrolisis techniques have been employed.

Table 2: The inputs of grass feedstock and the outputs of biochar produced are included on a dry basis (DB) in the presented experiments. This code includes: 1) farm-scale (F); 2) autothermal pyrolysis in an inert environment (A); 3) batch or continuous process (B); and 4) pyrolysis from stalks, briquettes, or pellets of grass (Heinrich et al., 2023).

Reactor	Mode of operation	Code	Replication	Total input (kg_{db})	Biochar output (kg_{db})
Carbontwister	Autothermal, batch	FA-BS	4	584.4	75.4
VarioL	Allothermal, batch	FI-BB	1	172.1	62.5
C63-F	Allothermal, continuous	FI-CP	1	2458.6	505.0

As a result of the simultaneous production of biochar and heat using underutilized grass as a feedstock, multiple benefits have been identified, including the production of independent and local negative emissions heat, as well as the development of biochar, a high value soil amendment. Based on the European Biochar Certificate and the guidelines of Carbonfuture, Germany, a potential broker for certificates in Germany, the potential C-sink of the produced biochar was calculated.

$$\text{C–Sink} = C_{Biochar}\frac{A_r^{\circ}(C)}{A_r^{\circ}(CO_2)} - CO_{2eqDiesel} - CO_{2eqDecay} - CO_{2eqElectricity}\left[t_{CO_2eq} * t_{Biochar}^{-1}\right]$$

In units FA-BS, FI-BB and FI-CP, a carbon neutral biochar can provide a C-sink of approximately 1.68, 1.92 and 1.50 t of CO2eq per t and it also describes the enrgy input and output of each unit as shown in the figures 11 and 12.

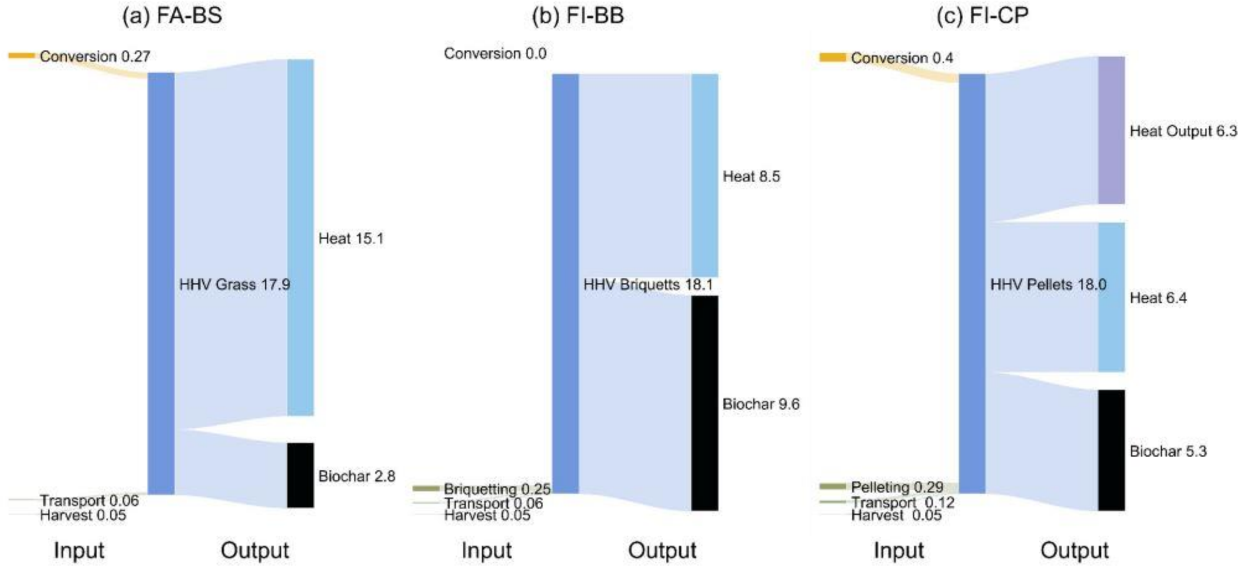


Figure 12: Energy flow in biochar production via three conversion technologies (Heinrich et al., 2023).

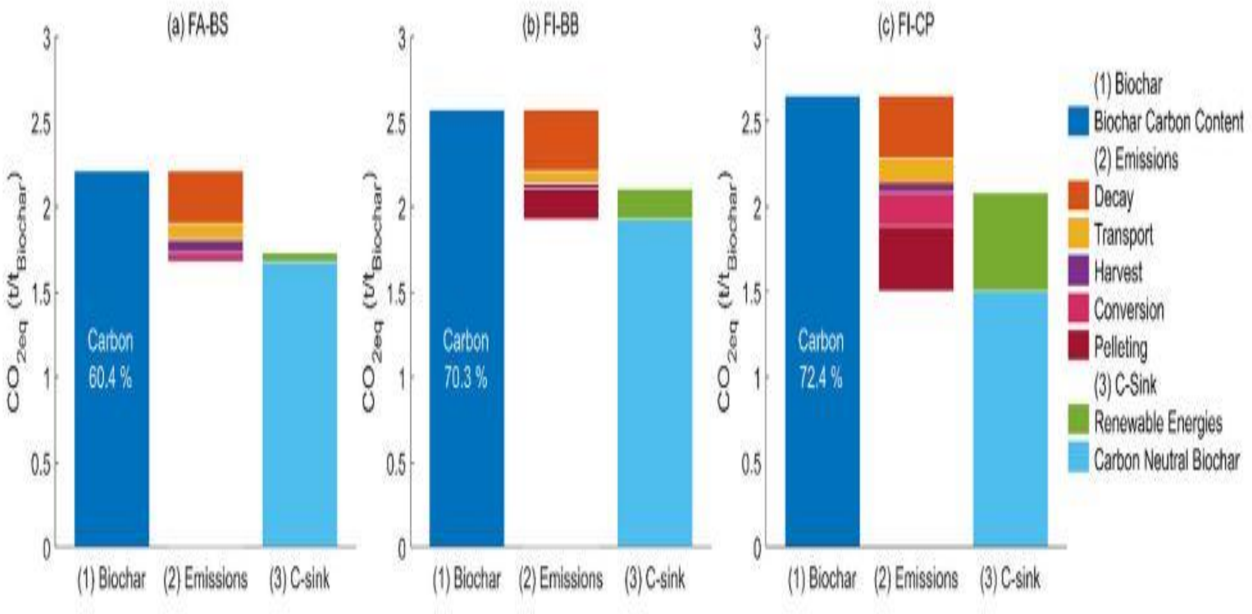


Figure 13: These bars show (1) the carbon content of the biochars, (2) the associated carbon emissions associated with their production and use, and (3) the carbon sink potential of the biochars produced from three different conversion units (a) FA-BS, (b) FI-BB, and (c) FI-CP (Heinrich et al., 2023).

Scenario 3: Environmental impact of the production of biochar and biogass from grass biomass, integrating AD and pyrolisis together

Case study 1: In anaerobic digestion (AD), lignocellulosic biomass cannot be valorized due to its reluctant structure, resulting in significant amounts of energy remaining in the solid digestate. In recent years, AD and pyrolysis have been integrating together to mitigate this effect. Yang *et al* (2023) stated that a comprehensive evaluation of this integration has been undertaken, using varying periods of AD, to produce biogas, bio-oil, and biochar, in addition to improving energy recovery as shown in the figure 13.

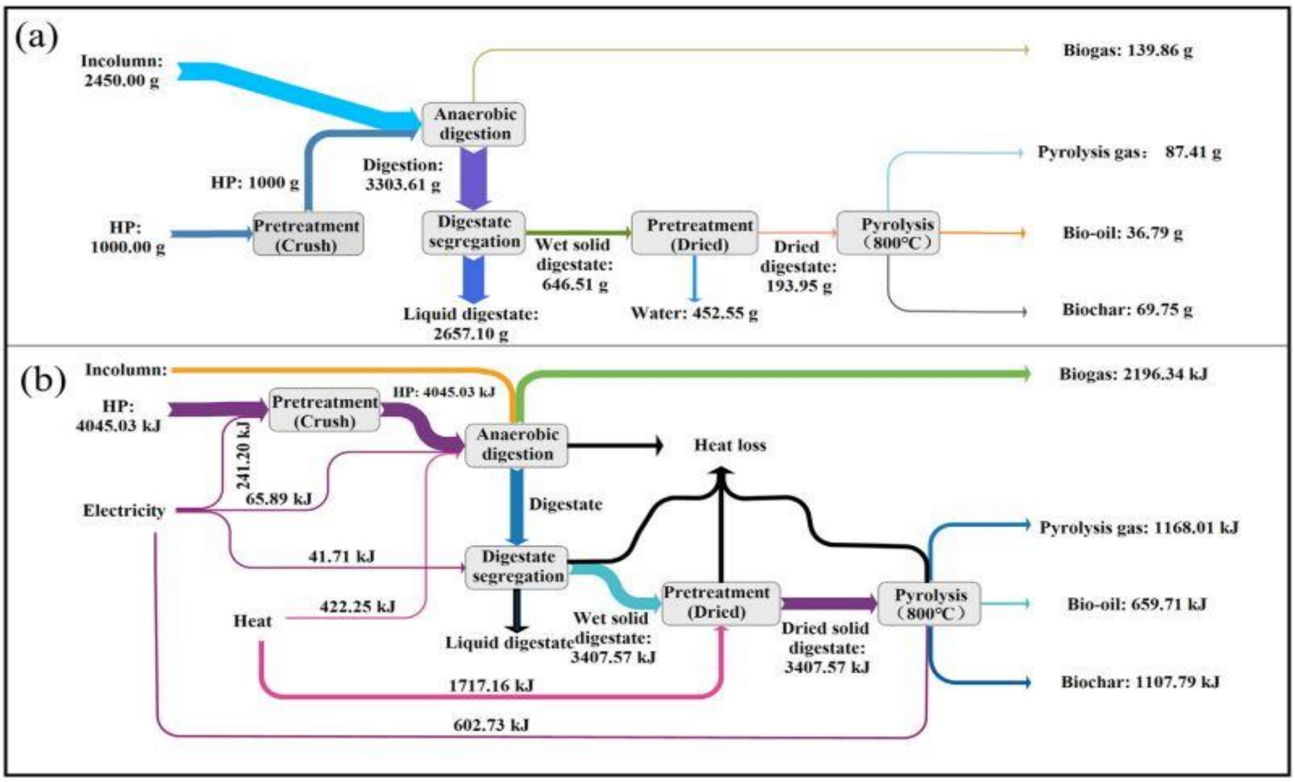
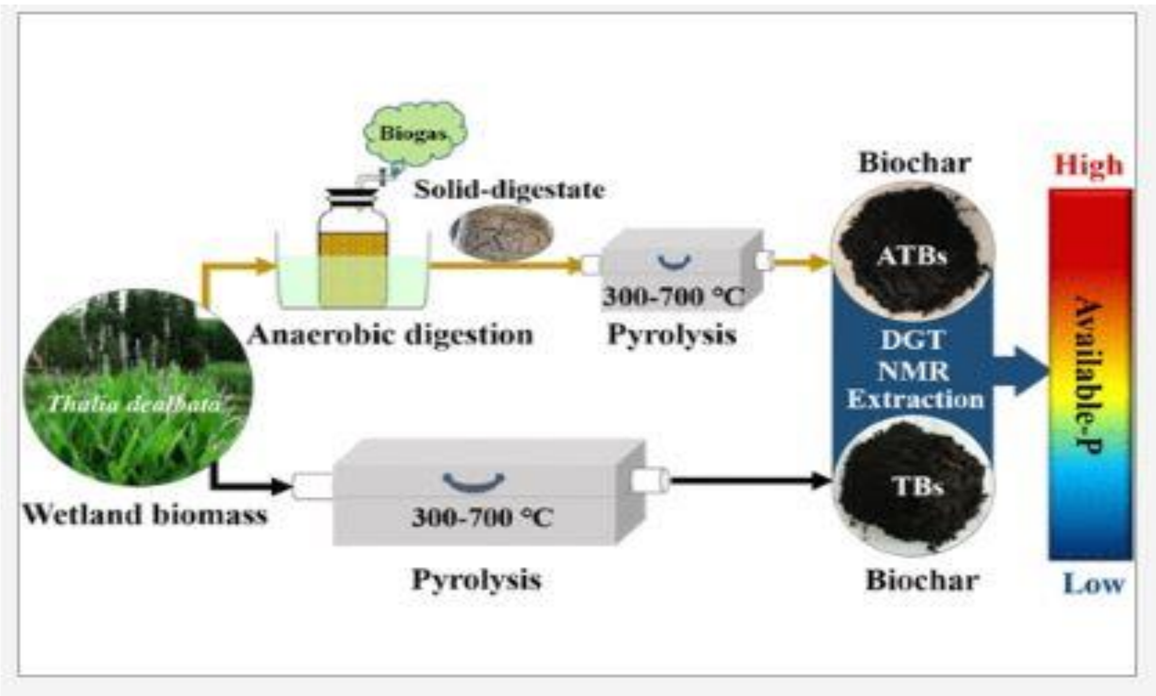


Figure 14:The mass (a) and energy (b) flows of valorizing grass biomass by integrated AD and Py via the Day-12 scenario (Yang et al., 2023).

As AD time increased from 3 to 15 days, the cumulative CH4 yield increased from 33.23 to 249.20 mL/g VS. Based on the pyrolysis of the solid digestate, biochar was produced in a percentage of 28.81 to 35.96 percent, while bio-oil and pyrolysis gas were also decreased. In accordance with the energy flow analysis, the coupled system optimization at an AD time of 12 days resulted in the highest energy efficiency of 71.9 % with a net energy gain of 2.0 MJ/kg wet biomass. The results of this study provide new insight into how biomass waste can be converted into energy products, as well as a new method for recycling biomass wastes (Yang *et al.*, 2023).

Case study 2: As an alternative to anaerobic digestion for treating organic solid wastes, anaerobic digestion with pyrolysis (AD–pyrolysis) is increasingly being considered. As part of the evaluation of AD–pyrolysis' potential to reclaim phosphorus from wetland plants, wetland plants were disposed of at a range of temperatures (300, 500, and 700 °C) by pyrolysis and AD–pyrolysis. Upon pyrolysis, biochars produced showed high pH and abundant functional groups. The AD-pyrolysis biochars, on the other hand, had a high phosphorus and ash contents (19.52–27.53 mg g–1), which reduced phosphorus leaching loss by transforming phosphorus into a stable pool. AD–pyrolysis improved plant-available phosphorus formation by 21.50-71.69% in biochars. Based on diffusive gradients in thin films (DGT), AD–pyrolysis-derived biochars significantly increased P availability in soils, and DGT-P had a positive correlation with sodium hydroxide and sodium hydrogen carbonate contents. Biochar from wetland plants can be improved with AD–pyrolysis for increased P recovery (Yu *et al.,* 2022).

Figure 15: Differentiation between the use of pyrolysis and the usage of both pyrolysis and aerobic digestion for production of biochar from biomass (Yu et al., 2022).



Case study 3: An assessment of the life cycle and spatial distribution of biomethane yield was conducted in northwestern Ireland. Three different scenarios had been used as shown in the figure 15 (Mehta *et al.,* 2022).

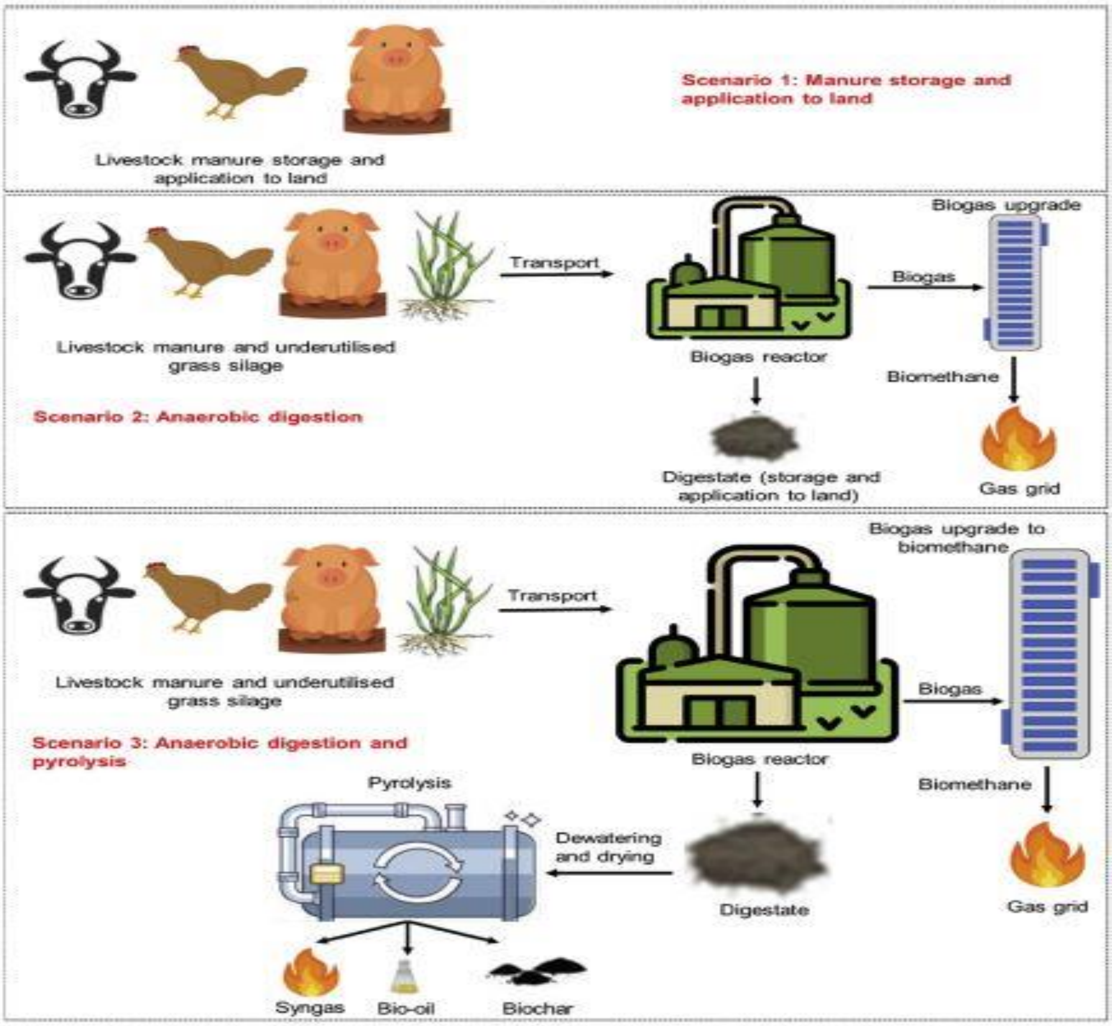


Figure 16:An overview of the three scenarios and associated processes considered in the life cycle assessment (Mehta et al., 2022).

Manure management, namely storing and applying it to grasslands, results in greenhouse gas emissions of 344 kg per person and ammonia emissions of 9.7 kg per person. A second scenario involves anaerobic digestion of collected manure and underutilised grass silage, producing 6124 GWh, equivalent to 464 kg of CO2. Combined anaerobic digestion with pyrolysis produces 6124 GWh and 200 tonnes of biochar, retaining 64% of manure phosphorus, and 563 kg CO2. Biomethane based decarbonisation requires a comprehensive approach which balances energy potentials and nutrient management, which is analyzed in this research as shown in the figures 16 and 17.

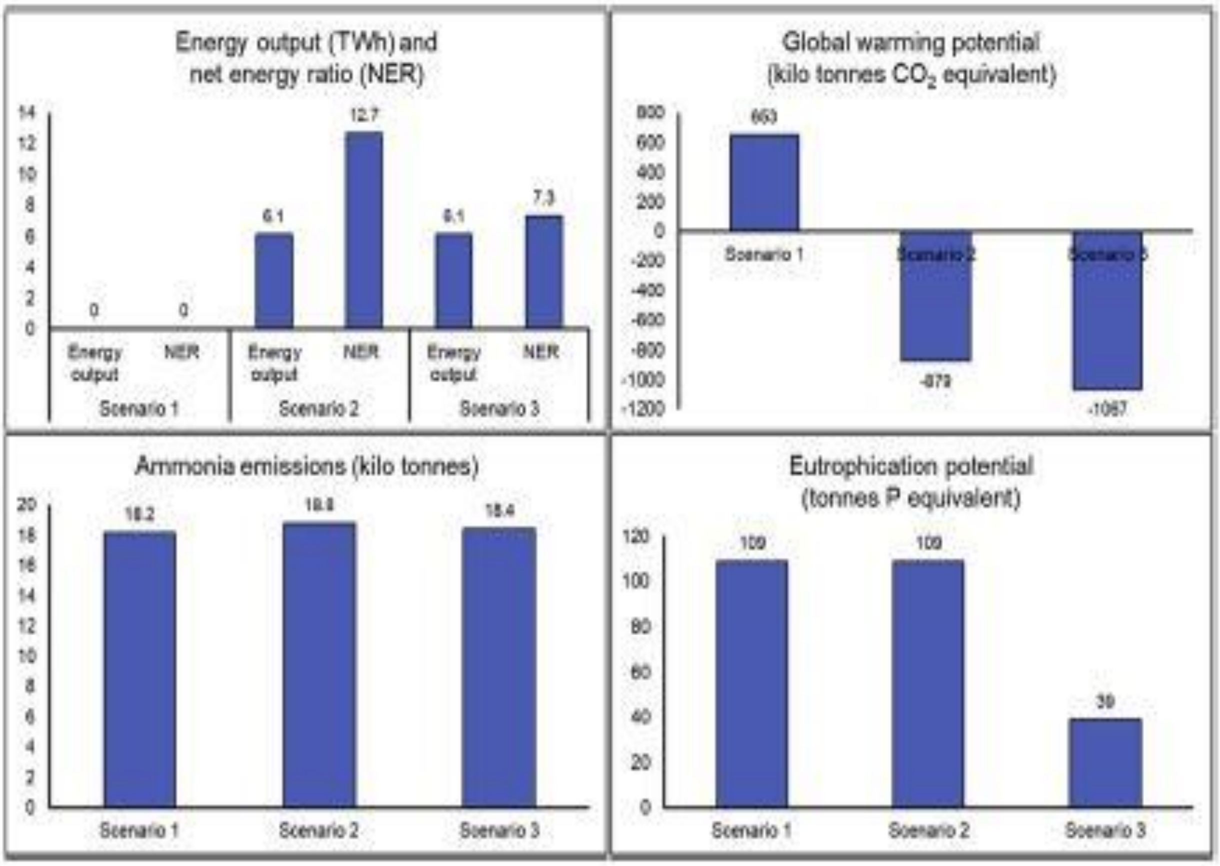


Figure 17: The following is a summary of the environmental impacts incurred based on three scenarios for the year 2020: Scenario 1 (no manure treatment), Scenario 2 (anaerobic digestion of livestock manure and underutilised grass silage), and Scenario 3 (anaerobic digestion and pyrolysis) (Mehta et al., 2022).

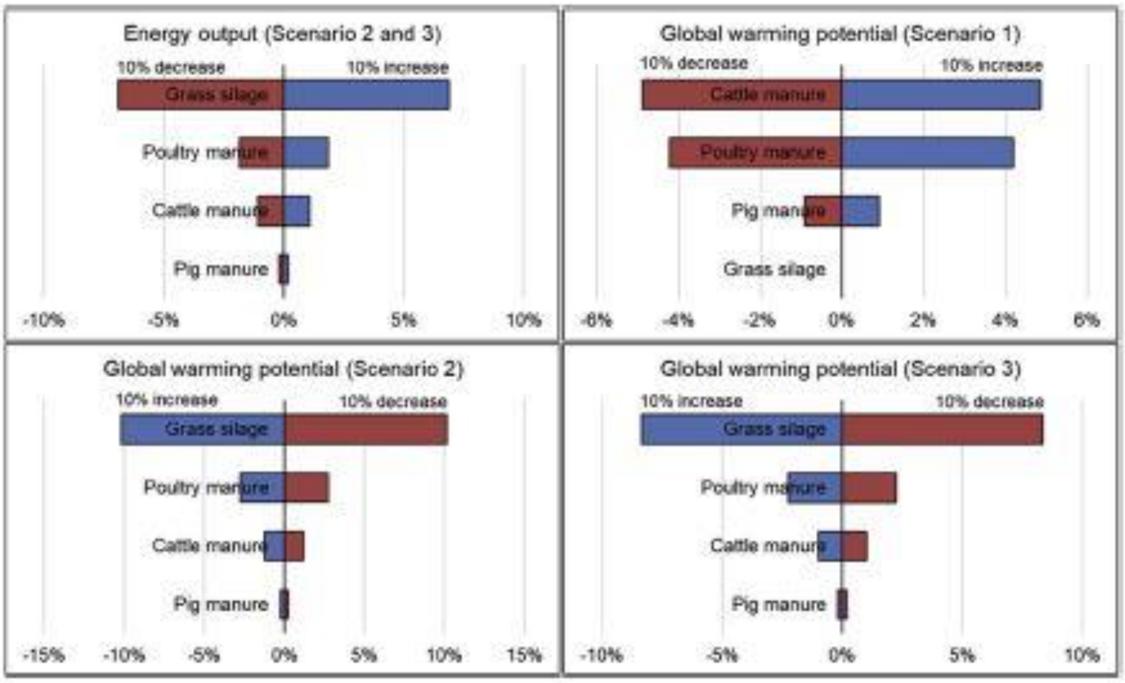


Figure 18: The tornado plot shows the extent to which an increase of 10% in feedstock quantities will affect energy produced (as output) and global warming potential for biomethane production chains in Scenario 1, Scenario 2, and Scenario 3 (Mehta et al., 2022).

9 Case Study & Financial Modelling

Introduction

In this section we will cover the economics of biomass management by pyrolysis in conjunction with AD with a view to providing an overview of the key questions of the feasibility study; namely the cost of carbon removal in order for the concept to be economically viable and investible.

The cost of removal is derived through discounted cash flow financial modelling over the period of a representative project's life. Modelling combines the capital costs, operational costs and finance costs with the projected revenues that the concept will produce over an operational lifetime to derive a cash flow to service an investment. This cash flow needs to achieve an Internal Rate of Return (IRR %) that surpasses what is thought to be a reasonable investment hurdle rate when considering the risk of the project, we discuss hurdle rates later on.

The financial model will be performed on a representative future project at years 2025 and 2030, we test on different dates at the costs and market prices are projected to differ over time. All other things being equal, the cost of removal is derived by altering the carbon price until the project IRR passes the hurdle rate. So we define the Removal Cost as the carbon price required within financial modelling to achieve the target hurdle rate.

This section is structured as follows:

• COSTS: In the first section we cover the indictive costs of concepts, the capital and the operational costs

• REVENUES: In the second section we cover potential revenues and the market prices that drive these and our assumptions around how these evolve over time towards 2030

• FINANCIAL MODEL & RESULTS: Finally, we cover the financial model and the modelling results.

We have discussed a range of technology and site opportunities previously in the report. For modelling we use a standard representative site and concept that we believe will be typical and most feasible, that is a single module pyrolysis site, energy recovery and heat export to a local heat network. The heat network is owned by 3rd party is represented as a customer and end user of the heat.

9.1 COSTS

CAPEX

The project will comprise three main capital elements: 1) the core pyrolysis technology, the 2) primary energy conversion equipment and 3) the balance of plant and energy centre and then soft costs.

Pyrolysis Technology

A range of pyrolysis systems are available and in this model, we have assumed an indicative technology provided by Pyrocore, specifically a 500kg/hr module system capable of processing in the region of 4000 tonnes of feedstock per annum. The cost of this system is £1.575m as outlined below.

Description	Price
Pyrolysis Kiln	Inc.
Char Cyclone	Inc.
Char Cooling Screw	Inc.
Char Recovery	Inc.
Thermal Oxidiser	Inc.
Heat Recovery	Inc.
Control System PLC	Inc.
Documentation	Inc.
Mechanical & Electrical Assembly & Commissioning	Inc.
Total price FCA (PyroCore workshops)	£1,575,000

Like all pyrolysis providers on this emerging marketplace the Pyrocore technology is at around TRL 9 with only a few operational plants at be this scale. This is indicative of the wider market place with the majority of manufacturers being in this position. Therefore, costs of such units are expected to reduce over the coming years as manufacturers upscale production and scale.

There is a limit to this as pyrolysis units are modular and although 1000kg/hr plants are in development the sector does not anticipate single module above this scale being developed, with a multi module solution preferred for sites with larger throughout demands.

For the purposes of financial model projections, we have used the following unit costs:

	Current model	2025	2030
£/Unit	£1,575,000	£1,450,000	£1,350,000

Energy Technology: CAES System

There are several options for maximising the heat output of a pyrolysis unit for electrical energy generation in addition to heat offtake options. This is due to the high temperature output of pyrolysis (up to 900 degrees C) compared to the low temperature requirements of a heat offtaker (often 60-80 degress C). Options such as Organic Rankin Cycle (Orc) technology are well established and can feed base load power back to the grid at efficiencies in the region of 15%. However, in this model we have assessed the opportunities of an emerging technology to exploit the congested grid challenges faced across the UK and provide a solution applicable across a range of sites, therefore reducing risk in against connection challenges. Compressed Air Energy Storage (CAES) technology such as that engineered by Cheesecake Energy is highly replicable and scalable. The majority of the components are re-purposed mass-produced elements including the thermal stores (shipping containers), compressed air stores (gas cylinders) and energy converters (re-purposed diesel engines).

CAES technology is currently at TRL 6/7 and with demonstration units projected at £690k when the technology is deployed alongside a pyrolysis unit.

The major cost elements would be the engine manifolds, valve actuators and heat exchangers. These are currently individually machined and hand produced elements, therefore, as production increases these elements will be engineered for mass production using new techniques such as casting. The cost per unit is forecast to reduce significantly towards 2030 falling by around 80% to under £150,000 per unit. This is then comparable with ORC costs.

We have used the 2025 and 2030 cost projections in the financial model.

Balance of Plant and Energy Centre

The remainder of the concept CAPEX is captured in the balance of plant and energy centre cost elements. This comprises all the mechanical and electrical completion equipment, the building requirements and building utilities, the feedstock storage and reclaim system and any other ancillary systems. This element would also include the heat network interface elements, but not the neat network itself as the heat is being supplied over the fence with a heat network having its own financial and operational model.

The costs for an energy centre have been estimated based on an indicative site such as this by Vital Energi, an example contractor with a history of delivery for biomass sites and heat networks. It is estimated at around

£890,000**.** For the purpose of modelling in 2025 and 2030 we have assumed there is no change in cost over time (ignoring inflation) as these are simple mechanical and civil costs that will not generally benefit from scale savings.

These costs can vary based on specific sites and are only an estimation.

Development and Soft Costs

Development and other soft costs factor in the technical and legal development costs required to bring forward a project. These include legal, planning, permitting and associated 3rd party costs.

Solar Costs

The operational demand of an energy centre is relatively low and always have a large amount of available roof space therefore we have included for a small amount of solar installation in this concept of 300 kWe in order to reduce imports of power. This has the effect of reducing the carbon in power impact on LCA and reduces the need to import to cover parasitic load.

Heat Network Costs

The heat network capex costs are not included in the capex costs. This model expects the plants to be selling heat over the fence to an existing or co-developed heat network offtaker/operator.

9.2 REVENUES

In order to achieve the lowest possible cost of carbon removal the concept looks to maximise the value of saleable products, and minimise the cost of operation, relative to both biochar generation and capital cost (plant sizing). Revenues include:

- sale of char,
- sale of heat,
- sale of electrical power,
- arbitrage of power,
- sale of power related services (ancillary services) and
- sale of CO2 derived products.

The value of product export will be dictated by volumes exported and prices. Volumes will be a function of production output which will vary depending on plant operating regime and ambient factors. Volumes could also depend on demand as in the case of heat export. Prices could be stable and fixed in the case of long-term export contracts (eg for heat or PPAs) or volatile as in the case of merchant power sales.

In this section we will discuss these operational trade-offs and build a series of process operating points across which we will model the economic case for the different concept configurations. Generally, for each configuration we will consider operation seasonally and diurnally, laying out assumptions for how demand and process will change over time.

Revenue Sources and Market Prices

This concept relies on several sources of revenue alongside carbon removal sales. These revenue sources supplement project income and act to reduce the removal cost. Revenue amount is a function of volume and market price. All things equal, ignoring the potential for efficiency improvements the volume should remain the same for different builds/sites started in different periods. However, the market prices that they capture will change as markets and the wider economy evolve. This is important to recognise when we are assessing a concept to manage biomass in the 2030s and onwards.

Here we cover the main revenue sources and the assumptions we make around evolution of prices over time, we then present the revenue assumptions for the periods of interest; 2025 and 2030.

Char Revenue

The biochar will have two values, the sequestration value and the physical char value. Sequestration value is the Removal Price that is being paid to sequester carbon. The physical char value is the price that someone is willing to pay for the physical properties and benefits of the char itself, other than the carbon sequestration potential. The sequestration value is discussed later in this section and is dependent on the requirements of the concept operator. In the case of a public body, it is likely that selling or trading carbon credits will not be a desirable option, instead wanting to claim the carbon savings from their own operations in support of their net zero ambitions.

The use cases for char are discussed in more detail earlier in the report but generally comprise applications to soils, use in horticulture, use in animal feed and use in construction. At present the biochar market is not well developed and the use cases are relatively niche, generally this is horticultural and as such the realised prices are quite high. As the market develops, as supply increases these niche markets will become saturated, and prices will fall bringing other potential use cases into the market.

It is therefore quite challenging to forecast the value of char over the 25-year concept lifetime. We have taken a starting value at 2025 of £300/tonne falling to £200/tonne by 2030. Char revenue forms in the region of 12%-13% of total revenue.

Heat Revenue

The concept assumes sales for the heat that it exports to local offtakers. There are many conceivable arrangements. Sales directly into a heat network operating company, co-developing a site-specific heat network to own and operate, or selling directly into a single offtaker consumer. Its offtaker could be domestic, commercial or industrial.

Revenues will be based on p/kWh energy sold. This could be based on amount used or around a minimum annual offtake. It is important to note there may be penalties associated with nonavailability.

Heat sales are a major, stable and secure revenue source for the concept and the financial performance of it is highly sensitive to this. A heat sale load factor of around 57% of heat generated is sold per year has been assumed. The reason for divergence is that heat sales would typically not precisely align with any given site, and heat sales vary over the seasons. Nevertheless, this is quite a conservative number and in reality, you would expect to target sites that can offtake more than this, but we feel that this gives a robust foundation.

PYROLYSIS HEAT

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Days in Month		31	28	31	30	31	30	31	31	30	31	30	31	
Operating Days		30.69	27.72	30.69	28.5	23.25	22.5	23.25	23.25	28.5	29.45	29.7	30.69	
Hours		736.56	665.28	736.56	684	558	540	558	558	684	706.8	712.8	736.56	
Avg Duty		0.99	0.99	0.99	0.95	0.75	0.75	0.75	0.75	0.95	0.95	0.99	0.99	
Available Heat	kW	1,454	1,454	1,454	1,396	1,102	1,102	1,102	1,102	1,396	1,396	1,454	1,454	
Daily Capacity	kWhth	34,903	34,903	34,903	33,493	26,442	26,442	26,442	26,442	33,493	33,493	34,903	34,903	
Capacity	kWhth	1,082,007	977,296	1,082,007	1,004,796	819,702	793,260	819,702	819,702	1,004,796	1,038,289	1,047,103	1,082,007	11,570,667
Heat Seasonality Facto Factor		0.95	0.95	0.80	0.35	0.20	0.20	0.20	0.20	0.35	0.65	0.90	0.95	
Heat Sold	kWhth	1,017,627	919,147	856,949	334,095	122,955	118,989	122,955	122,955	334,095	641,144	932,969	1,017,627	6,541,508
													Factor	56.5%

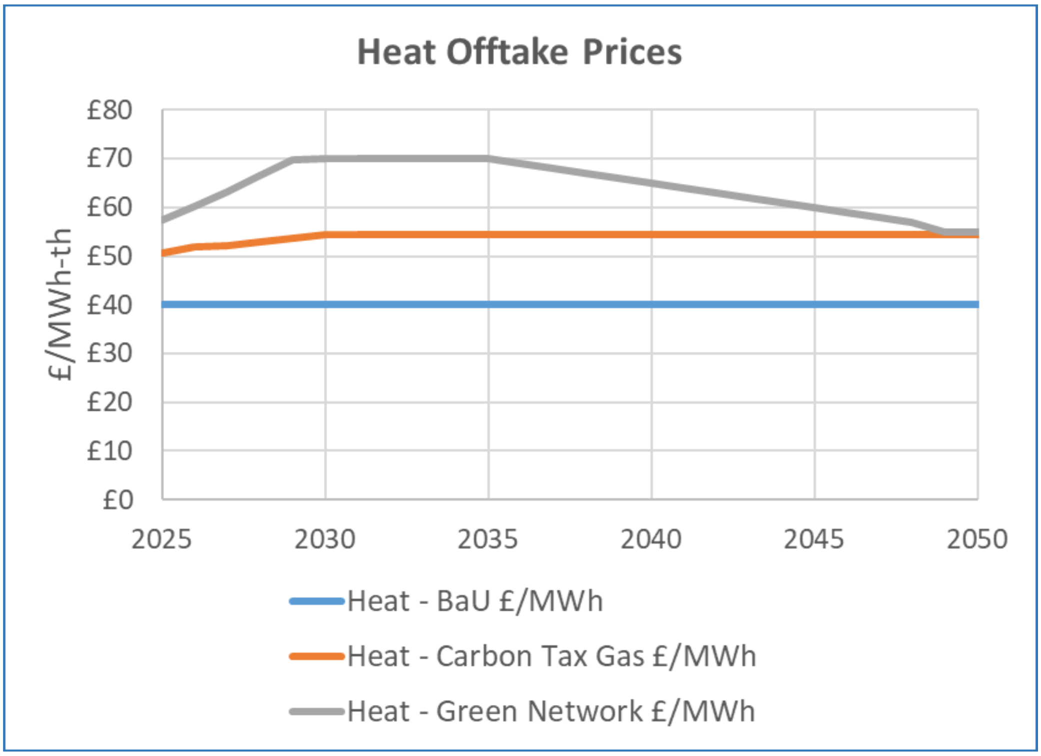
Heat revenues are the largest revenue source at 40%-45% of total concept revenue. If heat sales were increased to 70% then the costs of removal would reduce significantly and IRR increase.

Heat Energy Prices

Forecasting heat energy prices to 2030 is very challenging. The concept would sell zero carbon or carbon neutral heat and there are few counterfactuals for this nor a liquid market to compare it to.

The basic price of heat can be referenced from the price of gas plus some efficiency cost (say 85% efficiency) and some maintenance cost. However, process have gone through a hugely unstable period ranging from around £3/MWhth in 2020 to around £50/MWhth. We consider £40/MWhth a conservative starting point. But this is not carbon neutral, a proxy for which is to apply a carbon tax rate. If we assume the phasing in of a carbon tax to £70/tonne towards 2030 then the heat price becomes £54/MWhth.

This is not a true carbon neutral proxy, however. A preferred option is to determine what the cost might be from an alternative network infrastructure able to deliver carbon neutral heat, the options for which are likely to be either heat pump powered or biomass powered sources. Heat from these sources would be costlier than gas over the short to medium term, but reducing back towards comparable levels as the wholesale cost of electricity driving heat pump operational costs falls back. This is the price system that we will use for the financial modelling.



Electrical Power Export Revenue

This is electricity generated on site and exported to grid (or consumed on site to off-set import from the grid).

Electrical energy volumes are generally sold through either bi-lateral long-term contract (Power Purchase Agreements) which can be up to 15 years and can be fixed or floating price. Or through active trading in the day ahead markets of balancing mechanism, which carries a lot more risk, but potentially a much greater reward. A facility that is able to generate zero-carbon flexible dispatchable power would arguably be better trading in shorter term markets in the future.

Figure 1 - ESC from Cornwall insight source

Figure 14: Modelled capture prices for wind and solar power (2018 money)

Source: Cornwall Insight

Electrical power revenues are relatively small forming just around 1-2% of total revenues.

Electrical Power Arbitrage Revenue

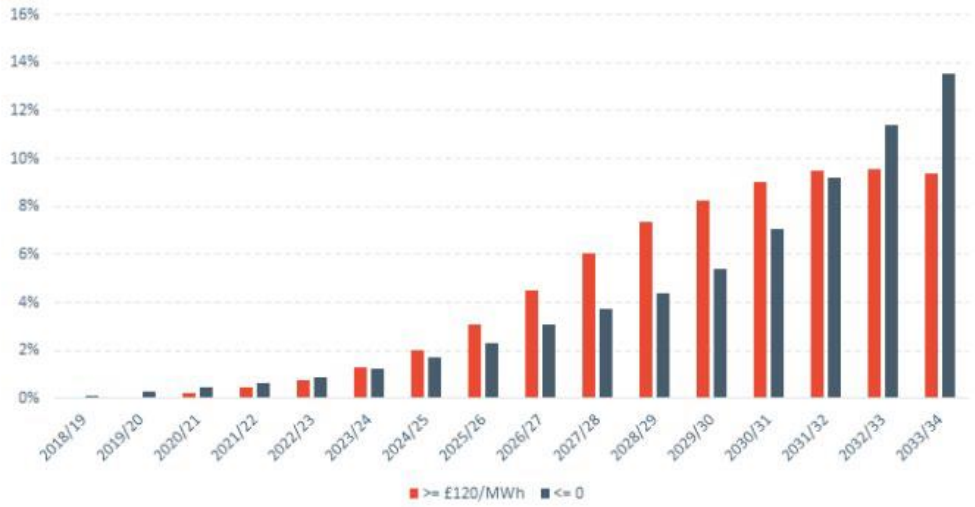
Power arbitrage is different to power export in that it involves the import and export of power that is not generated on site. The rationale is that power is imported during low price periods and exported during high price periods. This activity can be highly lucrative when high price differentials can be exploited.

Arbitrage could be a major revenue factor for the concept using the Compressed Air Energy Storage (CAES) system to import, store and export power at near to 100% efficiency, performing better than electrical battery at a much lower cost. This is an early-stage development concept and is an example of the opportunities that are developing in the market at this present time.

The system would trade in the Balancing Mechanisms or intra-day trading markets. The market durations over which the system would operate arbitrage would likely be 6-48 hours. The factor that is driving the opportunity for arbitrage is the forecast increase in volatility of power prices over the next 10-15 years. Typical wholesale power baseload prices are around £30-£40/MWh. However as seen below, the frequency of both very high (>£120/MWh) and very low (<£0/MWh) power prices is due to increase rapidly. This is being driven by the increased penetration of intermittent renewables onto the energy system, a positive move that brings with it system instability.

Figure 12: Annual frequency of <=£0/MWh & >=£120/MWh price periods 2018 through 2034

Source: Cornwall Insight

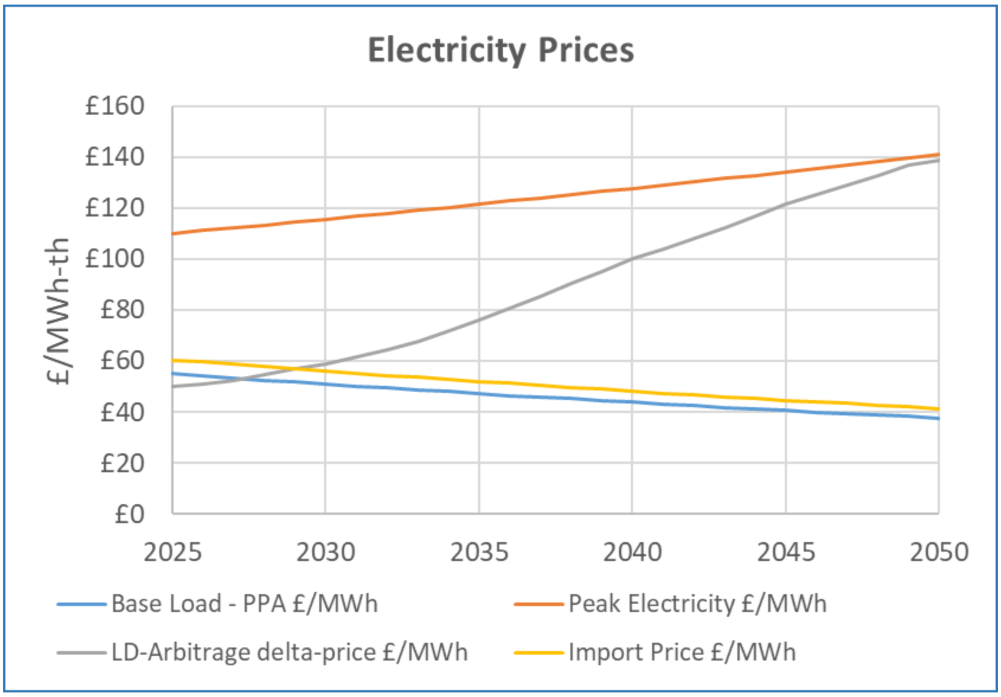


The model assumes that an arbitrage price differential can be exploited once every 2 days. This is difficult to forecast, at present differentials are diurnal, low prices at night and high during the 4pm-7pm evening peak, but this might not hold in the future and so our approach is more conservative. The differential amount per MWh we have assumed starts on average around £50/MWh today and increases to £110/MWh past 2035.

Electrical arbitrage revenue is forecast to be at around 33% of the concepts revenue stack.

Summary: Power Revenue Price

The following graph summaries the prices used in power related revenues within the financial model.



Other Revenues (not modelled)

There are several promising revenue sources that could be available to such developments in the near future that we have not included in the financial modelling but summaries below.

Ancillary Services (Fast Response & Dynamic Containment) – The system operator procures a number of electrical power related services which are more about energy 'quality' than volume in that they concern the way in which power is delivered. These services are required in order to support the safe, stable and reliable operation of the electrical system within certain parameters, in particular voltage and frequency regulation.

Fast response and DC are generally reserved for processes with very short response times like batteries and might not be applicable.

Ancillary Services (Fast Reserve & STOR) – At some times of the day National Grid needs access to sources of extra power, in the form of either generation or demand reduction, to be able to deal with actual demand being greater than forecast demand and/or unforeseen generation unavailability. These are reserve volumes that are kept in the case that post gate closure the system is still not in balance. This revenue stream will be more applicable to configurations that can comfortably operate in part load.

Ancillary Services (Inertia) – from an electrical engineering perspective, inertia is the measure of the ability of a synchronous AC system to oppose changes in frequency after a sudden loss of generation of load. Inertia is a new service that National Grid are starting to procure from eligible suppliers. The requirement for inertia in the electrical system has always existed, inertia is the 'force' that keeps electrical frequency within the marginal bounds of acceptance following an event (loss of load or generator) that would cause a

deviation. It reduces the Rate Of Change Of Frequency (ROCOF) and is created by inertial masses synchronised onto the electrical system. Historically this was inherent given power was generated by gas or steam turbines.

As these disappear off the grid and are replaced by solar and wind, which provide zero inertia, then a replacement needs to be sought. NG have just started to contract with suppliers that include either electrical solutions or specific inertia projects. Both come at a high cost, and power projects that can integrate inertia at low cost will be highly beneficial to the system. In any configuration where we consider rotating machinery therefore, we can specify flywheel inertia additions for very low marginal cost, and this can be contracted under long term contracts to NG. There may also be a benefit or premium to being able to cost effectively offer local inertia capacity as grids become more loosely coupled and increasingly sensitive. System level inertia can be sufficient but local systems could still be exposed to high ROCOF.

Carbon Removal Revenues

The final revenue is the target variable for the modelling, the Removal Cost. The revenue is determined by multiplying a carbon price (the Removal Cost) by the quantity of carbon forecast to be sequestered by such a biomass concept on an annual basis.

Removal Cost (£/tonne) x Carbon Sequestered (t/yr) = Annual Removal Revenue (£/yr)

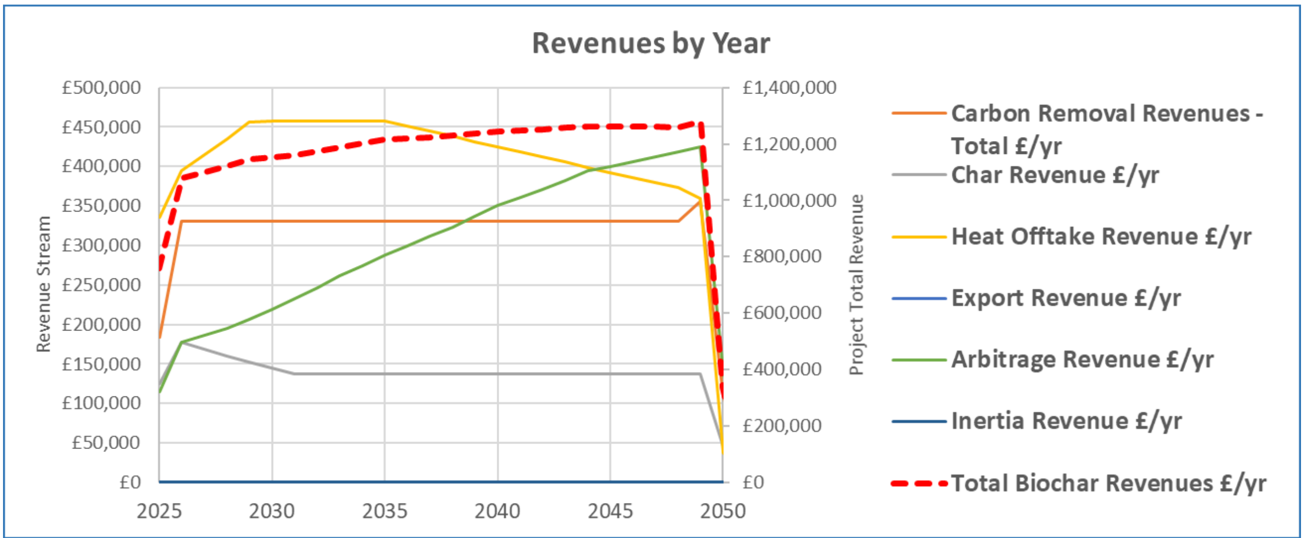
The amount of carbon sequestered per year is a function of the char production and the LCA for carbon in char which for our model we take as 2.8 tonnes CO_2 per tonne of char as a conservative estimate.

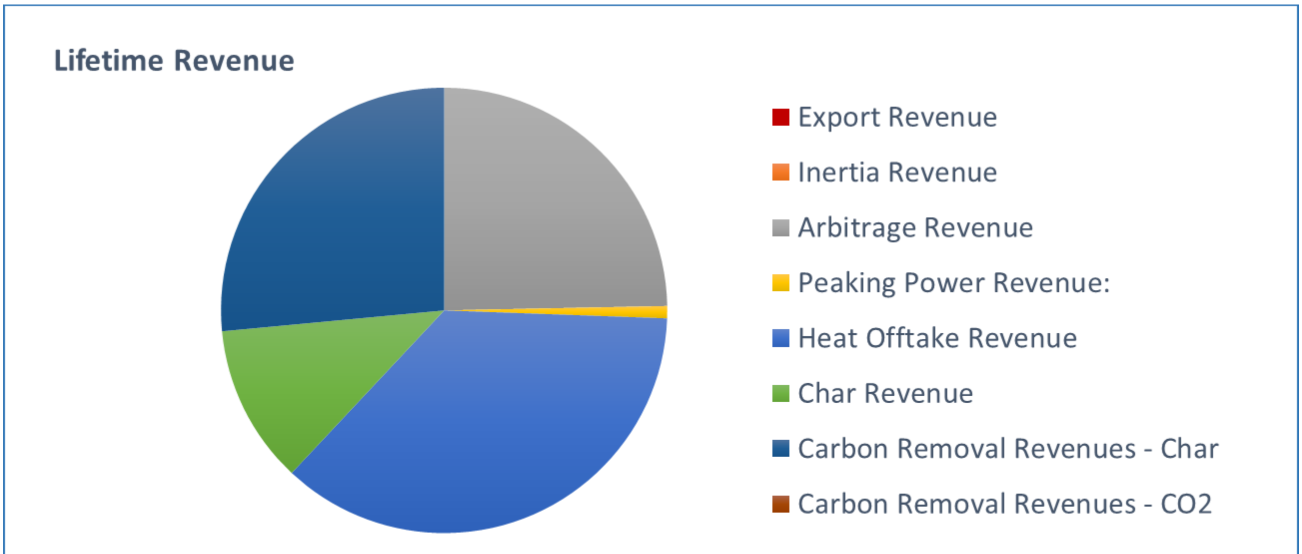
Char Output (t/yr) x LCA Carbon in Char (t per t) = Carbon Sequestered (t/yr)

Resultant carbon Removal prices are discussed further below in results, but the Carbon Removal Revenues represent around 11% of the revenue stack.

Revenue Overview

The resultant revenue stack over the concept lifetime is given in the graph below for a build starting in 2025 (concepts are forecast to operate over a 25-year lifespan). And the pie chart below shows the revenue mix for the fully operational concept.





9.3 Other Modelling Input Assumptions

Operational Hours

We have assumed an annual operational duty of 90% for the concept, with operation around 99% in the winter months and dropping to 75% in the summer months. This factors in operational downtime due to annual maintenance and other related factors. In total we have assumer 7870 operational hours per year.

FINANCIAL MODEL

Financing Costs / Hurdle Rates

Hurdle rates are defined as the minimum financial return that a developer would require over a development lifetime on a pre-tax real basis. The Hurdle Rate is key in our calculations as, all other things being equal (costs and revenues) the Hurdle rate must be met and this will be done through varying the Removal Cost.

The financing of a project is comprised of both debt and equity, both effectively financing costs and so the Hurdle Rate is also arrived at through assuming a cost of debt, an equity rate of return and an acceptable gearing ratio. The equity rate of return is driven in large part by risk premium perceived by investors specific to the project and its technology.

We have used the BEIS (now DESNZ) 2020 ELECTRICITY GENERATION COSTS 20201 paper that relied on inputs from Europe Economics2. The table below is the starting point from that paper.

	BEIS Figures					
	Real Cost of Debt	Real Cost of Equity	Effective Tax	Gearing	2018 Hurdle	2015 Hurdle
CCGT	1.70%	8.40%	17.00%	35.00%	7.50%	7.80%
CCGT CHP						
Biomass 5-100MW	2.45%	10.00%	17.00%	45.00%	7.90%	9.00%
Biomass CHP	2.45%	13.00%	17.00%	45.00%	9.90%	12.20%
CCS Biomass	2.45%	17.40%	17.00%	65.00%	9.10%	11.40%
ACT Standard	2.45%	11.70%	10.20%	56.00%	7.20%	9.20%
ACT CHP	2.45%	15.20%	10.20%	56.00%	8.90%	11.20%
EfW	3.05%	9.90%	10.20%	57.50%	6.50%	7.40%
EfW CHP	3.05%	12.20%	10.20%	57.50%	7.60%	9.40%

There is no precise technological equivalent for the concept we are proposing in the BEIS analysis and the technologies above, but the concept shares a number of features with several of these. In arriving at a hurdle rate we consider the following:

Heat Offtake Risk - There is generally a 2-3% difference between a thermal technology. and its CHP equivalent. This is driven by a dependency risk on a major offtaker (the heat consumer). And this must be considered.

Feedstock Risk - Biomass is relatively higher risk due to feedstock procurement risks. This can be underwritten through long term procurement and contracting with local resource, and in this case by utilising existing biomass resources.

Technological Familiarity – we assume that over the period 2025 to 2030 as the technology and approach become more familiar to investors, so the equity risk premium will reduce slightly.

Community Investment Factor – we will use a hurdle rate specific to our target investor market, the social impact/community investor. Generally, community concepts are able to raise equity at rates slightly below market rates as they speak to other non-financialobjectives of investors.

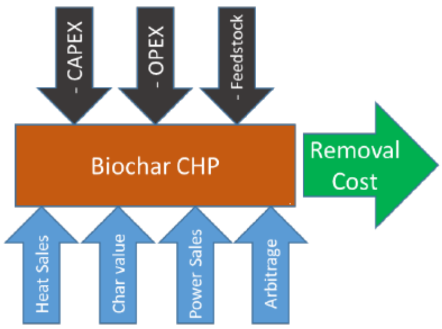
We will therefore adopt a Hurdle Rate of around **9-10%**.

Costs of Removal

The concept modelled is a power, heat and system flexibility solution with carbon removal as a by-product. This allows for cost effective removal with the stacking of multiple revenues into any development. The table below shows a revenue stack example for a small site.

Revenues evolve over time as markets change. In particular base power markets become less valuable and peaking and arbitrage markets much more valuable and zero carbon heat is also much more valuable (see Annex E). Conversely, we are conservative in forecasting char intrinsic market value. We exclude inertia revenue for now, this should be very cheap to include.

		2025	2030
Carbon Removal Price:	£/tonne	£140	£60
Total Revenue	£	£29,782,034	£25,925,674
Carbon Removal Revenue:	£	£8,146,170	£3,491,216
Heat Revenue	£	£10,500,525	£10,214,696
Power Export Revenue:	£	£0	£0
Peaking Power Revenue:	£	£272,568	£286,472
Char Revenue:	£	£3,545,396	£3,404,414
Arbitrage Revenue:	£	£7,589,943	£8,815,349
Inertia Revenue:	£	£0	£0
Total Revenue Annual avg	£/yr	£1,191,281	£1,037,027
Net Income after Costs	£/yr	£598,563	£478,934
Pre-Tax IRR:	%	11.26%	11.81%
Post-Tax IRR:	%	9.06%	9.34%



For smaller delivery sites with char carbon removal only the model estimates the cost of removal at between £<140/tonne in the 2020s and around £50/tonne in the 2030s. A plant built today would struggle to finance at £90/tonne but economics should quickly improve. The fall in removal costs is related to the improved income from other revenues in particular heat sales and power arbitrage as these markets become more valuable.

It should be noted that the results are highly sensitive to some of the more significant assumptions such as the quantity of heat sales on individual sites, the agreed offtake price of heat and future power market price volatility delivering the predicted benefit of power arbitrage.

10 Conclusions & recommendations

In summary the study has identified that across the 5 regions there is the potential to collect up to 8,582 tonnes of grass biomass per annum. Used effectively this has the potential to provide significant energy generation in the form of heat (up to 12GWhth) and electricity, produce upto 1500 tonnes of biochar per annum whilst sequestering 4200 tonnes of CO2 from the atmosphere, making a significant contribution towards the regions net zero carbon ambitions.

It is noteworthy that based on current carbon offset credit market prices of £200 the value of this sequestration is £840,000.

Analysis of collected grasses during the pilot operation and comparisons with existing accepted research shows that contamination risks are low and manageable with sensible staff collection and resourcing to monitor for large waste. Whilst contaminants such as heavy metals are not of significant levels that would prevent use of the grasses in either AD or Pyrolysis.

The analysis also demonstrated the calorific value of the grasses collected were favourable for use in AD. However, the quantities, susceptibility to weather variability and diminishing yield over time mean that feeding an AD system on these feedstocks alone would be unsuitable.

Market research with AD providers has shown that there is a market for providing these feedstocks to existing AD facilities with costs ranging from zero gate fee to £20 per tonne income for selling them to an existing operation. The quantity of feedstock existing plants would be willing to accept range from 10 – 25% of operational capacity depending on their existing arrangements.

Whilst being the simplest outlet and alternative use for the available biomass this option does not support further use of the biomass post AD and is the least beneficial from a carbon savings perspective. This can be weighed up in the future against accurate development costs for the alternative pyrolysis options.

An alternative concept is a pyrolysis facility which would utilise the heat output of its own operation to dry the incoming feedstock, produce biochar, heat and electricity for sale whilst sequestering carbon. Space and capital investment requirements are not as significant as for an AD facility and co-locating a plant at an existing waste facility or another feedstock provider location could improve the financial model further.

Finally, a hybrid solution is one option whereby the grass feedstocks are processed at a centralised facility through an integrated process to separate the solid and liquid fractions of the biomass. The resultant liquid faction can then be sent to existing AD facilities as a feedstock whilst the solid faction can be retained for additional processing through a pyrolysis plant. This option incurs additional capital and operational investment costs but maximises the beneficial use of the feedstock.

In addition to the models as set out in the report is it noteworthy that there may be opportunities to structure the business in such a way that allows an element of grant funding and to develop associated activities such as a heat network to reduce the capital investment requirements and to provide long term stable income.

Lastly the planning environment for such developments would be supportive and there are a number of potential established and experienced technology providers that could support further development and delivery.

10.1 Recommendations

The study has identified several key recommendations to take forward:

- Continue with the regions transition to cut and collect procedures.
- Identify sites of interest to the authorities for both co-location with existing or new standalone facilities
- Complete a detailed and site-specific feasibility study considering the preferred concept and site-specific realities such as planning, energy offtake and locality to feedstocks.
- Scope and identify potential grant opportunities to aid site development whilst also identifying potential internal investment which could be made.

12 References

[1] M. Obersteiner, C. A. Azar, P. Kauppi and K. Möllersten, "Managing climate risk," *Science,* vol. 294, no. 5543, pp. 786-787, 2001.

[2] NASA, "Global Temperature," 2022. [Online]. Available: https://climate.nasa.gov/vital-signs/global-temperature/.

[3] NASA, "Effects of climate change," 17 03 2023. [Online]. Available: https://climate.nasa.gov/effects/.

[4] IPCC, "GLobal Warming of 1.5ºC," IPCC, 2018.

[5] Department for Transport, " Road length (kilometres) by road type, region and country in Great Britain," 05 03 2022. [Online]. Available: https://www.gov.uk/government/statistical-data-sets/road-length-statistics-rdl.

[6] Department for Infrastructure, "Northern Ireland Transport Statistics 2017-2018," 27 09 2018. [Online]. Available: https://www.infrastructure-ni.gov.uk/publications/northern-ireland-transport-statistics-2017-2018.

[7] J. Way, "Road Verges on Rural Roads," Monks Wood Experimental Station, The Nature Conservancy, Huntington, 1972.

[8] A. Crofts and R. G. Jefferson, The Lowland Grassland Management Handbook 2nd Edition, English Nature/The Wildlife Trusts, 1999.

[9] T. T. Parr and J. M. Way, "Management of Roadside Vegetation: The Long-Term Effects of Cutting," *Journal of Applied Ecology,* vol. 25, no. 3, pp. 1073-1087, 1988.

[10] A. Helden and S. Leather, "Biodiversity on urban roundabouts—Hemiptera, management and the species–area relationship," *Basic and Applied Ecology,* vol. 5, no. 4, pp. 367-377, 2004.

[11] J. Noordijk, K. Delille, A. Schaffers and K. Sykora, "Optimizing grassland management for flower-visiting insects in roadside verges," *Biological Conservation,* vol. 142, no. 10, pp. 2097-2103, 2009.

[12] "Management mitigates the impact of urbanization on meadow vegetation," *Urban Ecosystems,* vol. 13,

pp. 461-481, 2010.

[13] S. E. al, "Anaerobic digestion of verge cuttings for transport fuel," *Waste and Resource Management,* vol. 160, no. 3, pp. 105-112, 2007.

[14] C. Smith, J. Elston and B. A, "THE EFFECTS OF CUTTING AND FERTILIZER TREATMENTS ON THE YIELD AND BOTANICAL COMPOSITION OF CHALK TURF," *Grass and Forage Science,* vol. 26, no. 4, pp. 213-220, 1971.

[15] T. W. Parr and W. J. M, "Management of Roadside Vegetation: The Long-Term Effects of Cutting," *Journal of Applied Ecology,* vol. 25, no. 3, pp. 1073-1087, 1988.

[16] T. C. E. Wells, "Management options for lowland grassland. Amenity Grassland: An Ecological Perspective," Wiley, Chichester, 1980.

[17] P. J. Grubb, "The maintenance of species-richness in plant communities: the importance of the regeneration niche," *Biological Review,* vol. 52, pp. 107-145, 1977.

[18] A. P. Schaffers, M. Vesseur and K. V. Sýkora, "Effects of delayed hay removal on the nutrient balance of roadside plant communities," *Joural of Applied Ecology,* vol. 35, no. 3, pp. 349-364, 1998.

[19] Department for Transport, *RDL0201: Road length (kilometres) by road type, region and country in Great Britain,* Department for Transport, 2018.

[20] N. Cheffins, "Verges Biomass: A Feasibility Study into the utilization of Anearobic Digestion to sustain the harvesting of Low Input Diversity road verge biomass," Peakhill Associates, 2015.

[21] M. Piepenschneider, "Urban Grass and Grass-Leaf Litter Mixtures as Source for Bioenergy Recovery," 2016.

[22] COMBINE, "Converting Organic Matters from European urban and natural areas into storable bio-Energy," [Online]. Available: http://www.combine-nwe.eu/index.php?id=34. [Accessed 2022].

[23] R. C. Brown and T. R. Brown, Biorenewable Resources: Engineering New Products from Agriculture, 2nd Edition, Wiley-Blackwell, 2014.

[24] R. T. Franco, P. Buffière and R. Bayard, "Ensiling for biogas production: Critical parameters. A review," *Biomass and Bioenergy,* vol. 94, pp. 94-104, 2016.

[25] J. McEniry, E. Allen, J. D. Murphy and P. O'Kiely, "Grass for biogas production: The impact of silage fermentation characteristics on methane yield in two contrasting biomethane potential test systems," *Renewable Energy,* vol. 63, pp. 524-530, 2014.

[26] IEA, "Biogas from Energy Crop Digestion by the IEA)," 2023. [Online]. Available: https://www.biogas-info.co.uk/about/feedstocks/.

[27] NNFCC, "AD COST CALCULATOR," NNFCC, 15 09 2016. [Online]. Available: https://www.nnfcc.co.uk/publications/tool-ad-cost-calculator.

[28] C. Rodriguez, A. Alaswad, K. Benyounis and A. Olabi, "Pretreatment techniques used in biogas production from grass," *Renewable and Sustainable Energy Reviews,* vol. 68, no. 2, pp. 1193-1204, 2017.

[29] R. Franco, P. Buffiere and R. Bayard, "Ensiling for Biogas production: critical parameters," *A ReviewBiomass Bioenergy,* vol. 94, pp. 94-104, 2016.

[30] J. McEniry, E. Allen, J. Murphy and P. O'Kiely, "Grass for biogas production: The impact of silage fermentation characteristics on methane yield in two contrasting biomethane potential test systems," *Renewable Energy,* vol. 63, pp. 524-530, 2014.

[31] P. Stegmann, M. Londo and M. Junginger, "The circular bioeconomy: Its elements and role in European bioeconomy clusters," *Resources, Conservation & Recycling: X,* p. , 2020.

[32] M. Ferdes, M. N. Dinca, G. Moiceanu, B. S. Zabava and G. Paraschiv, "Microorganisms and Enzymes Used in the Biological Pretreatment of the Substrate to Enhance Biogas Production: A Review," *Sustainable Environment and Renewable Energy Studies,* vol. 12, 2020.

[33] A. Gerlach and H.-P. Schmidt, "The use of biochar in cattle farming," The Biochar Journal, Arbaz, Switzerland., 2014 08 01. [Online]. Available: https://www.biochar-journal.org/en/ct/9. [Accessed 23 03 2023].

[34] Grand View Research, "Biochar Market Size, Share & Trends Analysis Report By Technology (Gasification, Pyrolysis), By Application (Agriculture (Farming, Livestock)), By Region, And Segment Forecasts, 2019 - 2025," Grand View Research, 2019.

[35] C. Kammann, J. Ippolito, N. Hagemann, N. Borchard, M. L. Cayuela and J. M. Estavillo, "Biochar as a tool to reduce the agricultural greenhouse-gas burden – knowns, unknowns and future research needs," *Journal of Environmental Engineering and Landscape Management,* vol. 25, no. 2, pp. 114-139, 2017.

[36] P. Covell, G. Gammie, S. Hunt, L. Brunjes, F. Ng and D. Nees, "Advancing Biochar in the Chesapeake: A Strategy to Reduce Pollution from Poultry Litter," Forest Trends, 2011.

[37] H. E. al, "Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options," *Journal of Animal Science,* vol. 91, no. 11, pp. 5095-5113, 2013.

[38] I. Tapio, T. J. Snelling, F. Strozzi and R. J. Wallace, "The ruminal microbiome associated with methane emissions from ruminant livestock," *Journal of Animal Science and Biotechnology,* vol. 8, no. 7, 2017.

[39] R. M. Murray, A. M. Bryant and R. A. Leng, "Rates of production of methane in the rumen and large intestine of sheep," *British Journal of Nutrition,* vol. 36, no. 1, 2007.

[40] Y. e. al, "Impacts of 1.5 °C and 2.0 °C global warming above pre-industrial on potential winter wheat production of China," *European Journal of Agronomy,* vol. 120, 2020.

[41] N. Panwar, A. Pawar and B. Salvi, "Comprehensive review on production and utilization of biochar," *SN Applied Sciences,* 2019.

[42] J. R. Kana, A. Teguia, B. M. Mungfu and J. Tchoumboue, "Growth performance and carcass characteristics of broiler chickens fed diets supplemented with graded levels of charcoal from maize cob or seed of Canarium schweinfurthii Engl," *Tropical Animal Health and Production,* vol. 43, pp. 51-56, 2010.

[43] J. Kana, A. Teguia and A. Fomekong, " Effect of substituting soybean meal with cowpea (Vigna unguiculata WAL) supplemented with natural plant charcoals in broiler diet on growth performances and carcass characteristics," *Iranian Journal of Applied Animal Science,* vol. 2, p. 377–381, 2012.

[44] K. Yamauchi, J. Ruttanavut and S. Takenoyama, "Effects of dietary bamboo charcoal powder including vinegar liquid on chicken performance and histological alterations of intestine.," *Journal of Animal and Feed Sciences,* vol. 19, pp. 257-268, 2010.

[45] K. Yamauchi, Y. Matsumoto and K. Yamauchi, "Egg collagen content is increased by a diet supplemented with wood charcoal powder containing wood vinegar liquid," *British Poultry Science ,* pp. 601-611, 2016.

[46] H. M. Resh, Hydroponic Food Production, Boca Raton: CRC Press, 2012.

[47] D. Schwarz and W. Gross, "Algae affecting lettuce growth in hydroponic systems," *The Journal of Horticultural Science and Biotechnology,* pp. 554-559, 2004.

[48] S. Corbel, C. Mougin and N. Bouaïcha, "Cyanobacterial toxins: Modes of actions, fate in aquatic and soil ecosystems, phytotoxicity and bioaccumulation in agricultural crops," *Chemosphere,* 2014.

[49] Department for Transport, RDL0201: Road Length (Kilometres) by Road Type, Region and Country in Great Britain, 2018.

[50] Department for Infrastructure, Northern Ireland Transport Statistics 2017-2018, 2018.

[51] J.M. Way, Road Verges on Rural Roads, NERC, 1972.

[52] A. Crofts, R.G. Jefferson (Eds.), Natural England, Lowland Grassland Management Handbook, second ed.GRASSLAND, 2007.

[53] J.S. Rodwell, British Plant Communities Volume 3 – Grasslands and Montane Communities, Cambridge University Press, 1992.

[54] British Standard Institution, BS 4428:1989 Code of Practice for General Landscape Operations (Excluding Hard Surfaces), 1989.

[55] Phoenix Amenity, D.O.T. Verge grass seed mix, 2017 15/04/2019]; Available from, https://www.phoenixamenity.co.uk/store/products/d-o-t-verge-grass-seed-mix/.

[56] Pitch Care, DOT grass seed, 2019 15/04/2019]; Available from: https://www.pitchcare.com/shop/banks-and-verges-landscaping-grass-seed/limagrain-dot-g rass-seed-20kg.html.

[57] T.W. Parr, J.M. Way, Management of roadside vegetation: the long-term effects of cutting management on roadside vegetation and soil nutrient levels at Ickleton and Keyston, Cambridgeshire, England, J. Appl. Ecol. 25 (1988) 1073–1087

[58] A. Salter, et al., Anaerobic digestion of verge cuttings for transport fuel, in: Proceedings of the Institution of Civil Engineers Waste and Resource Management, 2007, pp. 105–112.

[59] R.C. Brown, T.R. Brown, Biorenewable Resources: Engineering New Products from Agriculture, second ed., Wiley Blackwell, 2014.

[60] R.T. Franco, P. Buffiere, R. Bayard, Ensiling for biogas production: critical parameters. a Review, Biomass Bioenergy 94 (2016) 94–104.

[61] J. McEniry, et al., Grass for biogas production: the impact of silage fermentation characteristics on methane yield in two contrasting biomethane potential test systems, Renew. Energy 63 (2014) 524–530

[62] N. Cheffins, Verge Biomass: A Feasibility Study into the Utilisation of Anaerobic Digestion to Sustain the Harvesting of Low Input High Diversity Road Verge Biomass, 2015

[63] Bedoić, R. *et al.* (2019) 'Green biomass to biogas – A study on anaerobic digestion of residue grass', *Journal of Cleaner Production,* 213, pp. 700-709. Available at: https://doi.org/10.1016/j.jclepro.2018.12.224.

[64] Berg, S. (1997) *Some aspects of LCA in the analysis of forestry operations.* Elsevier BV.

[65] Heinrich, T. *et al.* (2023) 'Biochar production from late-harvest grass – Challenges and potential for farm-scale implementation', *Sustainable Production and Consumption,* 37, pp. 256-267. Available at: https://doi.org/10.1016/j.spc.2023.02.019.

[66] Kiron, M.I. (2022) 'Life Cycle Assessment (LCA): The Cradle to Grave of Your Clothes', Available at: https://textilelearner.net/life-cycle-assessment-of-your-clothes/ .

[67] *LCA SOFTWARE OVERVIEW 2023 Find the right software to make a Life Cycle Assessment Get started* (2023). Available at: https://lca-software.org/ .

Lesson: Sustainability -Decision Making Learning Outcomes and Indicators SCIENCE Grade 4 Rocks, Minerals and Erosion.

[68] Mehta, N. *et al.* (2022) 'Evaluating the opportunity for utilising anaerobic digestion and pyrolysis of livestock manure and grass silage to decarbonise gas infrastructure: A Northern Ireland case study', *Renewable Energy,* 196, pp. 343-357. Available at: https://doi.org/10.1016/j.renene.2022.06.115.

[69] Miettinen, P. and Hämäläinen, R.P. (1997) 'Adaptive policies, policy analysis, and policymaking', *European Journal of Operational Research,* 102(2), pp. 279. Available at: https://doi.org/10.1016/S0377-2217.

[70] Paolini, V. *et al.* (2018) 'Environmental impact of biogas: A short review of current knowledge', *Journal of Environmental Science and Health, Part A,* 53(10), pp. 899-906. Available at: https://doi.org/10.1080/10934529.2018.1459076.

[71] Ravi, R. *et al.* (2023) 'Exploring the environmental consequences of roadside grass as a biogas feedstock in Northwest Europe', *Journal of Environmental Management,* 344, pp. 118538. Available at: https://doi.org/10.1016/j.jenvman.2023.118538.

[72] Razman, K.K., Hanafiah, M.M. and Mohammad, A.W. (2022) 'An overview of LCA applied to various membrane technologies: Progress, challenges, and harmonization', *Environmental Technology & Innovation,* 27, pp. 102803. Available at: https://doi.org/10.1016/j.eti.2022.102803.

[73] Roberts, K.G. *et al.* (2010) 'Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential', *Environmental Science & Technology,* 44(2), pp. 827-833. Available at: https://doi.org/10.1021/es902266r.

[74] Singh, A., Pant, D. and Olsen, S. (2013) *Importance of Life Cycle Assessment of Renewable Energy Sources.* United Kingdom: Springer London, Limited.

[75] Wang, L. *et al.* (2023) 'Role of biochar toward carbon neutrality', *Carbon Research,* 2(1) Available at: https://doi.org/10.1007/s44246-023-00035-7.

[76] Yang, J. *et al.* (2023) 'Optimization of integrated anaerobic digestion and pyrolysis for biogas, biochar and bio-oil production from the perspective of energy flow', *The Science of the Total Environment,* 872, pp. 162154. Available at: https://doi.org/10.1016/j.scitotenv.2023.162154.

[77] Yu, F. *et al.* (2022) 'Coupling Anaerobic Digestion with Pyrolysis for Phosphorus-Enriched Biochar Production from Constructed Wetland Biomass', *ACS Sustainable Chemistry & Engineering,* 10(12), pp. 3972-3980. Available at: https://doi.org/10.1021/acssuschemeng.1c08537.

GRID GWYRDD GWENT
GWENT GREEN GRID

13 Appendix-A Survey Responses

13.1 Monmouth Response

Resilient Grasslands- Cut and Collect data collection survey

Areas of collection

1. Which of these green spaces do you currently manage? (Please tick)

	Do you currently manage?	Department responsible	External contractors
Community gardens (Allotments)	No	Allotments are under States Dept. Managed by Allotments groups	
Parks	Yes	Grounds and Cleansing Dept	
Common land	No	I don't think we have any but if we did, likely to be Countryside Team in MonLife	
Roadside verges	Yes	Mix of Grounds and Highways Depts but work carried out by Grounds	Most rural road verges out to contract
Cemeteries	Yes	Estates -work carried out by Grounds dept	
Social housing	Some under contract to housing assocaiton. Mostly MHA	Grounds	
Schools	Some. Where contracted to do so	Individual schools are responsible	Some where contracted to do so
Playing fields	Yes	Grounds Dept	
Sports clubs pitches (Rugby, cricket,	Some where MCC has	Grounds dept	Some contracted out

pitches, etc)	not leased them to sports associations		by sport associations
Woods	Some woodland	Countryside team in MonLife manage some urban and notified sites. Farm woods owned by Estates dept that have not been included in farm tenancies are not managed. Small areas of urba woods under grounds dept – safety management ownly.	
Other	NHS land under contract	Grounds	

2. Are these areas cut and collect or cut and leave? (Please tick a box)

Areas	Cut and collect (%)	Cut and leave (%)
Community gardens (Allotments)		
Parks		
Common land		
Roadside verges		
Cemeteries		

Social housing		
Schools		
Playing fields		
Sports clubs pitches (Rugby, cricket, pitches, etc)		
Woods		
Other		

3. Are there any additional green spaces in your local authority area that you are intending to manage or collect from in the future (e.g., Schools, sport clubs, allotments, NHS grounds etc.)?
   We have introduced a significant amount of cut and collect over the last couple of years and unlikely to add any more MMC land to this regime as we are probably at the limit of what is acceptable to our residents.
   There may be more areas of grassland that could be managed by cut and collect owned by housing associations and NHS. We have started conversations with these bodies to see what the scope is

4. Do you have any mapping/GIS of these areas, if not do you have the resource capacity to map them in the future?

We have mapped all areas of grassland that we mow. Some sites we will be mapping areas for cut and collect. Other sites, it is more a judgement call for operatives on the ground as to how much is managed this way. We could look at some averages across sites to get an indicative area.

Current practices

5. Please give an overview of your current practices for the following types of spaces (e.g. cut and leave twice a year on a ride on mower, cut and collect twice a year for the roadside verges)?

   a. Community gardens

   b. Parks

   c. Common land

   d. Roadside verges

6. Are there any changes you have already made for the benefit of wildlife for example "No Mow May"?

We have a project running called Nature isn't Neat that focuses on managing amenity grassland with more consideration for biodiversity and ecosystem services. We promoted No Mow May in 2021 but will not be doing so again as it conflated issues with Nature isn't Neat

7. Are there any that are planned in the future?

Nature Isnt Neat is a long running programme that will continue for the foreseeable future

8. Would you be able to estimate volumes of grassland currently managed? Hectares or tonnes.

Would like to and will be looking to do so in the coming months

9. Which of the sites that you manage, would you consider to be your key or flagship sites (e.g., Caldicot Country Park or Allt-yr-Yn nature reserve)? Specify the size of the area

10. If all the grassland management is not conducted by yourselves, could you estimate what percentage is put out to tender for contractors?

11. What are the limitations restricting you from conducting all grassland management yourselves?

Logistics – removal of grass cuttings from sites (particularly in very urban areas) and disposal of cuttings.

Equipment and logistics

12. What current equipment do you use for grassland management (Trailers, vehicles, machinery) and how are they powered (Electric, petrol etc) and what is the capacity (Load limit) to collect grass?

Type of equipment Trailers, vehicles, machinery)	How are they powered	Load limit

13. How much of your current equipment is cut and collect style equipment and is there any reason you do not use the equipment to full capacity?

14. Do you have a budget for the purchase or rental of new equipment in the near future?

15. What is the location of your grass cutting depot/depots? And what is the furthest distance travelled to conduct work in this local authority from depot

16. What is the quantity of grass cuttings that you are currently collecting? *If this is not a value that you are able to provide, please try to quantify the area of green waste collection (e.g. acres of parks, field or forest, miles of roadside greenery and number of households collected from).*

17. Which of these waste disposal methods do you use?

    a. Landfill

    b. Anaerobic digestion

    c. Energy from Waste/Combustion

    d. Commercial composting

    e. Community composting

    f. Composted on sites

18. How often do you come across grassland that is heavily contaminated with litter?

    Never Rarely Sometimes Often Always

19. How often do you come across grassland that is heavily contaminated with dog faeces?

    Never Rarely Sometimes Often Always

20. What procedures/interventions are in place to deal with litter and faeces?

21. If you are willing to share the information what is the value of these contracts (this could include any gate fees)?

22. Any other comments?

Thank you for your response. We really appreciate your time.

Please return via email to dafyddt@severnwye.org.uk

13.2 Torfaen Response

Resilient Grasslands- Cut and Collect data collection survey

Areas of collection

23. Which of these green spaces do you currently manage? (Please tick)

	Do you currently manage?	Department responsible	External contractors
Community gardens (Allotments)	NO		Note: Allotments run by allotment societies.
Parks	YES	Neighbourhood Services – Streetscene and Environment	
Common land	Yes (some)	Neighbourhood Services – Streetscene	Note: some common land owned by TCBC,

		and Environment	otherwise we work in partnership with commoners
Roadside verges	YES	Neighbourhood Services – Streetscene and Environment	
Cemeteries	YES	Neighbourhood Services – Streetscene and Environment	
Social housing	YES	Neighbourhood Services – Streetscene and Environment	
Schools	YES	Neighbourhood Services – Streetscene and Environment – Contracted to maintain 1 School at present.	External Contractors maintain 99 % of our Schools
Playing fields	YES	Neighbourhood Services – Streetscene and Environment	
Sports clubs pitches (Rugby, cricket, pitches, etc)	YES – FOOTBALL PITCHES	Neighbourhood Services – Streetscene and Environment	
Woods	NO	Neighbourhood Services – Streetscene and Environment	
Other			

24. Are these areas cut and collect or cut and leave? (Please tick a box)

Areas	Cut and collect (%)	Cut and leave (%)
Community gardens (Allotments)	None known	None known
Parks	100%	
Common land	Small percentage of heather is cut.	
Roadside verges	0%	
Cemeteries		40%
Social housing	80%	20%

Schools	0%	
Playing fields	70%	30%
Sports clubs pitches (Rugby, cricket, pitches, etc)	0%	
Woods	A number of urban woodlands are managed accordingly	
Other		

25. Are there any additional green spaces in your local authority area that you are intending to manage or collect from in the future (e.g., Schools, sport clubs, allotments, NHS grounds etc.)?

    Yes we have increased our cut an collect sites by 25% for this season, they will be in Housing Estates, along main roads and Parks

26. Do you have any mapping/GIS of these areas, if not do you have the resource capacity to map them in the future?
    This is currently being looked into.

Current practices

27. Please give an overview of your current practices for the following types of spaces (e.g. cut and leave twice a year on a ride on mower, cut and collect twice a year for the roadside verges)?

    e. Community gardens – very little

    f. Parks - Once per year cut and collect.

    g. Common land – TCBC heather management undertaken in accordance with a management. 5 year rota?

    h. Roadside verges – Once per year cut and collect.

28. Are there any changes you have already made for the benefit of wildlife for example "No Mow May"?
    We did this last year on some of main routes.

29. Are there any that are planned in the future?
    The same as last year.

30. Would you be able to estimate volumes of grassland currently managed? Hectares or tonnes.
    Unknown

31. Which of the sites that you manage, would you consider to be your key or flagship sites (e.g., Caldicot Country Park or Allt-yr-Yn nature reserve)? Specify the size of the area
    Seven Local Nature Reserves (LNR) and a number of urban parks including Cwmbran Park, Blaenavon Flower Park, Cwmbran Boating Lake, Pontypool Park

32. If all the grassland management is not conducted by yourselves, could you estimate what percentage is put out to tender for contractors?
    We do have a local farmer that does cut and bale 4 or 5 of our fields.

33. What are the limitations restricting you from conducting all grassland management yourselves?
    None really as we always look at alternative ways of managing the grassland working with our Operational Teams and the Ecology Team.

Equipment and logistics

34. What current equipment do you use for grassland management (Trailers, vehicles, machinery) and how are they powered (Electric, petrol etc) and what is the capacity (Load limit) to collect grass?

Type of equipment Trailers, vehicles, machinery)	How are they powered	Load limit
John Deere Box Collector Mower	Diesel	600 Litres
Amazone Profi Hooper	Diesel	1200 Litres

Transit Crew Cab Tippers	Diesel	
Ifor Williams Trailers		

35. How much of your current equipment is cut and collect style equipment and is there any reason you do not use the equipment to full capacity?
    We only have 2 machines that are cut and collect, but we are looking to purchase further cut and collect machines for the purposes of grassland management.

36. Do you have a budget for the purchase or rental of new equipment in the near future?
    Funding for new equipment has been supported by external grant aid.

37. What is the location of your grass cutting depot/depots? And what is the furthest distance travelled to conduct work in this local authority from depot – We are located centrally within our County Borough and further travel is between 7 and miles.

Disposal

38. What is the quantity of grass cuttings that you are currently collecting? *If this is not a value that you are able to provide, please try to quantify the area of green waste collection (e.g. acres of parks, field or forest, miles of roadside greenery and number of households collected from).*

39. Which of these waste disposal methods do you use?

    g. Landfill

    h. Anaerobic digestion

    i. Energy from Waste/Combustion

j. Commercial composting

k. Community composting

l. Composted on sites (some sites)

40. How often do you come across grassland that is heavily contaminated with litter?

Never Rarely Sometimes Often Always

41. How often do you come across grassland that is heavily contaminated with dog faeces?

Never Rarely Sometimes Often Always

42. What procedures/interventions are in place to deal with litter and faeces?
    We also litter pick the area first as best as we can before cutting and then carry out a secondary litter pick if required. With dog fouling it is difficult as you can't always see it in long grass but we do have signage in place on some of our sites.

43. If you are willing to share the information what is the value of these contracts (this could include any gate fees)?

44. Any other comments?

Thank you for your response. We really appreciate your time.
Please return via email to dafyddt@severnwye.org.uk

13.3 Newport Response

Resilient Grasslands- Cut and Collect data collection survey

Areas of collection

45. Which of these green spaces do you currently manage? (Please tick)

	Do you currently manage?	Department responsible	External contractors
Community gardens (Allotments)	x		
Parks	x		
Common land			
Roadside verges	x		
Cemeteries	x		
Social housing		Newport City Homes	
Schools	x		
Playing fields	x		
Sports clubs pitches (Rugby, cricket, pitches, etc)	x		
Woods	x		
Other - Local Nature Reserves and set aside open green spaces	x		

46. Are these areas cut and collect or cut and leave? (Please tick a box)

Areas	Cut and collect (%)	Cut and leave (%)
Community gardens (Allotments)		5%
Parks	2%	98%
Common land		
Roadside verges		100%
Cemeteries	2%	98%
Social housing		
Schools	5%	95%
Playing fields		100%
Sports clubs pitches (Rugby, cricket, pitches, etc)		100%
Woods		
Other – Local Nature Reserves Set aside Open Green Spaces	100%	 100%

47. Are there any additional green spaces in your local authority area that you are intending to manage or collect from in the future (e.g., Schools, sport clubs, allotments, NHS grounds etc.)?

Set aside open spaces we are aiming to collect 100% going forward (2022/2023)

48. Do you have any mapping/GIS of these areas, if not do you have the resource capacity to map them in the future?
Yes

Current practices

49. Please give an overview of your current practices for the following types of spaces (e.g. cut and leave twice a year on a ride on mower, cut and collect twice a year for the roadside verges)?

    i. Community gardens – Cut and leave with a ride on mower 6 times a year

    j. Parks – Cut and leave with ride on tractor mounted equipment - 6 -14 times a year

    k. Common land

    l. Roadside verges – Cut and leave between 2-6 times per year

50. Are there any changes you have already made for the benefit of wildlife for example "No Mow May"?
    Yes, we are managing in total about 25-30 hectares differently to benefit nature. Taking part in No Mow May, and leaving allocated set aside open spaces until August/Sept

51. Are there any that are planned in the future?
    Plans for the future are to collect and collect on the set aside open spaces that we currently cut and drop on.

52. Would you be able to estimate volumes of grassland currently managed? Hectares or tonnes.

up to 30 hectares

53. Which of the sites that you manage, would you consider to be your key or flagship sites (e.g., Caldicot Country Park or Allt-yr-Yn nature reserve)? Specify the size of the area
    Allt-Yr-Yn 2 hectare, Percoed Reen 3 hectare , High Cross Open Space 7 Hectares, St Julians LNR , Parklands Open Space 2 Hectares, Ty Coed 3 Hectares, Ringland Circle 1 Hectare, 19 Hills 3 hectares,

54. If all the grassland management is not conducted by yourselves, could you estimate what percentage is put out to tender for contractors? 25%

55. What are the limitations restricting you from conducting all grassland management yourselves?
Plant and equipment

Equipment and logistics

56. What current equipment do you use for grassland management (Trailers, vehicles, machinery) and how are they powered (Electric, petrol etc) and what is the capacity (Load limit) to collect grass?

Type of equipment Trailers, vehicles, machinery)	How are they powered	Load limit
Agricultural tractors 100HP	Diesel	
Grass Cutting implements (Various)	PTO	N/a
Trailers x 2		7-10 tonne
Tractor mounted cut and collect X 2	PTO	
Profihopper	Self propelled diesel engine	2m cut

57. How much of your current equipment is cut and collect style equipment and is there any reason you do not use the equipment to full capacity?
As Above

58. Do you have a budget for the purchase or rental of new equipment in the near future? Yes (grant funded)

59. What is the location of your grass cutting depot/depots? And what is the furthest distance travelled to conduct work in this local authority from depot – Corporation Road Newport, furthest distance from yard 8-9 miles

Disposal

60. What is the quantity of grass cuttings that you are currently collecting? *If this is not a value that you are able to provide, please try to quantify the area of green waste collection (e.g. acres of parks, field or forest, miles of roadside greenery and number of households collected from).*
Most left on site, previous year 20- 30 bales.

61. Which of these waste disposal methods do you use?

m. Landfill

n. Anaerobic digestion

o. Energy from Waste/Combustion

p. Commercial composting - x

q. Community composting

r. Composted on sites - x

62. How often do you come across grassland that is heavily contaminated with litter?

Never Rarely Sometimes ***Often*** Always

63. How often do you come across grassland that is heavily contaminated with dog faeces?

Never Rarely ***Sometimes*** Often Always

64. What procedures/interventions are in place to deal with litter and faeces? Council Waste Enforcement Team

65. If you are willing to share the information what is the value of these contracts (this could include any gate fees)?

66. Any other comments?

Thank you for your response. We appreciate your time.
Please return via email to dafyddt@severnwye.org.uk

13.4 Blaenau Gwent Response

Resilient Grasslands- Cut and Collect data collection survey

Areas of collection

67. Which of these green spaces do you currently manage? (Please tick)

	Do you currently manage?	Department responsible	External contractors
Community gardens (Allotments)	No		
Parks	√	Grounds Maintenance	
Common land	No		
Roadside verges	√ 1m verge only on behalf of Highways Dept who are the responsible department for the management.		
Cemeteries	√		
Social housing			

Schools	√	We act as contractors to schools who buy an SLA service from us.	
Playing fields	√		
Sports clubs pitches (Rugby, cricket, pitches, etc)	√		
Woods	No		
Other			

68. Are these areas cut and collect or cut and leave? (Please tick a box)

Areas	Cut and collect (%)	Cut and leave (%)
Community gardens (Allotments)		NA
Parks		√
Common land		NA
Roadside verges	Some small trial areas	√ (some identified as cut and collect as part of trial project)
Cemeteries	Old cemetery areas where headstones removed are cut and collect by local farmer.	√
Social housing		NA
Schools		√
Playing fields		√

Sports clubs pitches (Rugby, cricket, pitches, etc)		√
Woods		NA
Other		

69. Are there any additional green spaces in your local authority area that you are intending to manage or collect from in the future (e.g., Schools, sport clubs, allotments, NHS grounds etc.)?

70. Do you have any mapping/GIS of these areas, if not do you have the resource capacity to map them in the future? Yes currently use GGP GIS. Unfortunately, no in-house capacity or funding to update/renew open spaces grass-cutting GIS overlay to identify areas no longer cut following being identified to be cut once per year instead of x6. This is done manually on the map print outs

Current practices

71. Please give an overview of your current practices for the following types of spaces (e.g. cut and leave twice a year on a ride on mower, cut and collect twice a year for the roadside verges)?

    m. Community gardens – NA

    n. Parks - Cut and left as amenity areas on regular schedule

    o. Common land – NA

    p. Roadside verges – only 1m verges cut throughout growing season to prevent encroachment. Areas identified as a trial project in 2020 with Veronika Brannovic, Local Nature Partnership Coordinator, Blaenau Gwent and Torfaen to cut and collect annually.

72. Are there any changes you have already made for the benefit of wildlife for example "No Mow May"?
    Trail areas as identified above and working closely with Biodiversity Officer colleagues to identify areas to change management of grassland

73. Are there any that are planned in the future?
    As above

74. Would you be able to estimate volumes of grassland currently managed? Hectares or tonnes.
    No sorry.

75. Which of the sites that you manage, would you consider to be your key or flagship sites (e.g., Caldicot Country Park or Allt-yr-Yn nature reserve)? Specify the size of the area

76. If all the grassland management is not conducted by yourselves, could you estimate what percentage is put out to tender for contractors?
    Unable to provide % specific details but we have recently outsourced our open spaces and cemeteries contract but in a hybrid format utilising our own tractor drivers to cut larger areas with contractor manually cutting areas not accessible to tractors (compact) such as bankings, obstacles (trees, barriers etc) and fence-lines.
    In relation to the cemeteries, of our 7 cemeteries, 3 remained in-house using FTE staff and seasonal staff allowing flexibility to be able to respond to other grounds related issues.

77. What are the limitations restricting you from conducting all grassland management yourselves?
    Difficulty in recruiting the required qualified and skilled seasonal staff.

Equipment and logistics

78. What current equipment do you use for grassland management (Trailers, vehicles, machinery) and how are they powered (Electric, petrol etc) and what is the capacity (Load limit) to collect grass?

Type of equipment Trailers, vehicles, machinery)	How are they powered	Load limit
Large 90hp tractors for large sportsground and school site	Diesel	

Compact Tractors	Diesel	
Small manual equipment: Mowers, blowers, hedgcutters, chainsaws etc	Petrol but transitioning to battery operated with blowers, hedgecutters and some chains all now battery. Brushcutters efficiency and effectiveness still be investigated	
Crew Cab Tipper Vans	Diesel – Council in process of a fleet management review to transition to electric. Long process with at present 4 Highway electrical vehicles in use.	

79. How much of your current equipment is cut and collect style equipment and is there any reason you do not use the equipment to full capacity?
    q. No specialist machinery within fleet at present.
    r. Topography of much of Blaenau Gwent means that large areas have to be cut manually and if collected would also have to undertaken manually.
    s. Ground conditions are often poor weight factor of machinery plus load would cause issues.
    t. As mentioned earlier investigations have been made into identifying a suitable machine that could be of benefit and operational within the constraints as mentioned in b & c but as yet this has proved difficult.

80. Do you have a budget for the purchase or rental of new equipment in the near future?
    u. All our fleet is leased via our Transport dept over a given period and within an allocated budget. When the lease term of each machine/equipment/vehicle is due to end we review all options available within the budget.

81. What is the location of your grass cutting depot/depots? And what is the furthest distance travelled to conduct work in this local authority from depot
    - The location of our Central Operational Depot is Brynamwr, NP23 4YF
    - Approx furthest distance is 7-8 miles

Disposal

82. What is the quantity of grass cuttings that you are currently collecting? *If this is not a value that you are able to provide, please try to quantify the area of green waste collection (e.g. acres of parks, field or forest, miles of roadside greenery and number of households collected from).*

Only small trial areas with a cut/collect process. Not able to provide areas

83. Which of these waste disposal methods do you use? The arising from the areas we have cut over the last 2 years is taken to our designated "green waste" area with our colleagues at the site arranging its disposal. I am unable to identify which of the below options is applicable.

    s. Landfill

    t. Anaerobic digestion

    u. Energy from Waste/Combustion

    v. Commercial composting

    w. Community composting

    x. Composted on sites

84. How often do you come across grassland that is heavily contaminated with litter?

Never Rarely Sometimes Often Always

85. How often do you come across grassland that is heavily contaminated with dog faeces?

Never Rarely Sometimes Often Always

86. What procedures/interventions are in place to deal with litter and faeces?

Grass cutting contract states that the site is to inspected for litter before cutting and collected.

No procedure for faeces unless excessive where by our teams would liaise with our Cleansing Section to attend and support

87. If you are willing to share the information what is the value of these contracts (this could include any gate fees)?

88. Any other comments?

Thank you for your response. We appreciate your time.

Please return via email to dafyddt@severnwye.org.uk

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development: Europe Investing in Rural Areas
Llywodraeth Cymru
Welsh Government

14 Appendix-B

14.1 Appendix of trial methodology

Gwent Green Grid, Pollinator Friendly Grassland - Workstream 5.

Cut and collect trial to assess volumes and values of collected grass.

Introduction

This project is a collaboration between the five partner councils, Monmouthshire, Blaenau Gwent, Caerphilly, Newport, and Torfaen, and Severn Wye Energy Agency. There are five dedicated workstreams for this project of which this project sits within Workstream 5 - Pollinator Friendly Gwent comprising two elements: Nature isn't neat and Resilient Grasslands (Cut and Collect). The cut and collect project has been designed to consider the barriers to cut and collect management, specifically the logistics around disposal of collected grass arising from this management, and identifying potential treatments to utilise grass cuttings. Information required achieve this includes understanding fuel consumption, quantities, and location of grass biomass available for cut and collection.

Severn Wye Energy Agency is leading this project in partnership with each LA collating information on key locations/strategic sites/areas to improve grasslands for pollinators and in the design and support for the delivery of the trial.

This document presents the outline and method statement of the trial to ensure a standard and replicable approach to ensure high quality consistent data is collected for evaluation and interpretation. This includes specifications in terms of the biomass sample selection, the transporting issues, the fuel consumption the analysis and the technical procedure from biomass sampling. It includes the required analytical methods, the investigation parameters as well as the supply of samples for the laboratory analysis.

Planned trial

The proposed approach aims to be the least demanding or logistically challenging method to avoid impacting on cutting schedules and manpower. Over the course of the cutting season, partners will be asked to collect samples of grass cuttings on four separate occasions, throughout the cutting season, measure fuel consumption, weight of grass and measure moisture content.   A further control cutting round should be completed where no grass is collected to assist with modelling fuel consumption against standard amenity grass cutting.

The data will be used to produce a Life Cycle Analysis (LCA) of the current practices to produce a detailed report for this project.

Work and sample flow of small-scale sampling

1. Identification of Biomass samples

2. Harvest or Collection of the samples

3. Specification of Biomass samples

4. Storing (ensiling) the Samples

5. Transporting the Samples

Identification of Biomass Samples

Partner local authorities investigate the available cut and collect grass in their region. To be considered for tests within the GGG Project the residual biomass should fulfil the following requirements:

- It should be available free of costs or at low costs
- There is currently no energetic or material use for it except composting or combustion in a waste treatment plant
- It must be available in large quantities
- Collected grass in the trial must be storable and transportable

Following the completion of Severn Wye Survey and a follow up interview, each partner has identified the site suitable for cut and collect management suitable for the trial.

For the purposed of the trial, partners can identify a key site with specific environmental conditions or concerns, that could potentially be a focus as a sampling site.

Harvest or collection of biomass samples

We have identified from the surveys and interviews conducted that the key grassland types that will be investigated are large parkland area and roadside verges. Regarding scientific soundness of the results, it is necessary to provide four repetitions of each investigated biomass. This gives the opportunity for the project consortium to investigate four samples from five locations providing a total of 20 samples

The partner will be responsible to organise the collection of samples of collected grass with an interval period of 4 to 5 weeks starting in May.

Specification of biomass samples

Samples should comprise approximately 30kg at 20-30% dry matter content (typical average). Note, weather conditions prior to the sampling day will affect moisture content and samples volume will need to reflect this. Sample with a higher moisture content will need to be heavier, depending on the dry matter of the samples. Dryer samples will weigh less, wetter samples will weigh more.

Storing (ensiling) the Samples

The biomass must be cut and subsequently to be filled into polyethylene barrels during heavy compaction for ensiling. Somebody must step into the blue barrel every now and then to trample down the biomass, compacting it with a lot of weight. Simple filling of the barrel and closing it will not lead to silage but to rotting biomass!!!

The closing of the barrels must be gas-proof.

30L- Barrels are available from- https://oipps.co.uk/30-l-plastic-blue-un-approved-open-top-drum

The samples must be assigned with a clear label. The label must be attached on the outside of the barrel and additionally on the inside of the barrel by putting a piece of paper or plastic with waterproof written sample number on top of the biomass. The label must state the date of harvest, the weather conditions, location, and weight. It is not enough to simply put a sign on the outside of the barrel, as this can easily get lost during transport.

Transporting the Samples

TBC

Life cycle analysis

As the public awareness of the environmental pollution has increased significantly over the last few years, there is a need to provide a “greener” product than before. A product’s life cycle comprises raw material extraction, production, use, maintenance, and end of life. In each stage, a product consumes energy and natural resources and, at the same time, emits emissions and waste to the environment. The life-cycle assessment (LCA) method is a tool for assessing the environmental impacts of a product by collecting the information about material, energy consumption and emissions throughout the whole life cycle. By LCA method, both emissions and environmental impacts of a product could be clarified

An LCA study comprises four stages: (source https://journals.sagepub.com/doi/full/10.1177/1475090219858810)

- *Goal and scope definition*. The intended application, the reasons for carrying out the study, the functional unit, the system boundary and so on are defined at this first stage.
- *Inventory analysis*. Information about inputs (energy and materials) and outputs (emissions) is collected.
- *Impact assessment*. The environmental indicator results are obtained at this stage. Normalization, grouping, and weighting are optional elements.
- *Interpretation*. The results are interpreted to help decision-makers make the final decision.

Fuel consumption of vehicles

To provide information to complete a lifecycle analysis, it is necessary to obtain details of fuel consumption on the day that samples are collected along with details of machinery used. The simplest way to collect this day is to fill vehicle/machinery fuel tanks up at the start and end of the day and record the amount of fuel required to top up. If filling is required during the day, this should be added to the total figure for each vehicle or piece of machinery. Data should be recorded for each vehicle used on the day for the specific mowing round that the sample is taken. Data should also be collected on the mileage travelled or hours recorded on the machinery and key sites mown to give an indication of the size of the mowing round.

Data should be collected for the round on both cut and collect and cut and fly to give an indication of the different scenarios.

Quantity of biomass

To measure the biomass potential of each local authority we want to measure the total grass cut and collected. The potential value of cut and collected biomass will be affected by moisture content and quality. These factors are variable depending on time of year and weather conditions. To provide the necessary data from the trial, the total quantity of collected grass needs to be measured by weight. Moisture content and other values can be taken from samples and used to assess the value of the total weight of biomass.

For each sample round, the cut and collected biomass needs to be weighed and data recorded. For example, tipped onto a trailer and taken to a weigh bridge.

Analysis of biomass

Analysis will be conducted and could include an assessment of: Dry matter content, ash, mineral content (K, Mg, Ca, Na, P, S, Cl) and C, fixed C, H, N and pH value and organic constituents (protein, fat, non-fibre carbohydrates, cellulose, hemicellulose, lignin) and moisture content.

Conclusion

On completion of these trials, a detailed report on volumes of potential grassland will be available along with LCA and cost analysis to determine the mechanisms needed for the effective management of grasslands addressing barriers and identifying different treatments to utilise grass cuttings.

Any queries please email dafyddt@severnwye.org.uk

Appendix A- Trial methodology

Before any trial begins, we must first know how many local authorities are willing to take part. Once we know this, we will then distribute the record sheets for the data collection, ensure each region has the correct equipment needed for the trials, such as the sample barrels to collect the biomass for analysis and click counter to measure fuel consumption. The local authorities must also provide information to us on the planned route so that we can map it out. Additionally, before any trials are conducted the local authorities must all decide on 4 separate dates for when we will conduct the trials which will be done at the same time to ensure reliable results.

Step by step method statement for trial days

Fuel consumption of vehicles

- Specify model and manufacture of vehicle.
- Clock current fuel level at start of day. If not full, fill vehicle to max capacity.
- Record mileage start of day
- Conduct days' work of grass cutting
- Log each location on record sheet provided
- Record mileage end of day
- End of day refuel vehicle to measure total fuel consumption of vehicles
- Complete record sheet

Fuel consumption of machinery

- Specify model and manufacture of equipment used and fuel used
- Fill equipment with fuel start of day
- Fill empty jerry can with fuel and log the amount
- Record machinery hours at start of day
- If possible, quantify size of area cut
- Log number of times had to refuel
- Record machinery hours end of day
- Record total fuel consumption at the end of the day by refiling jerry can

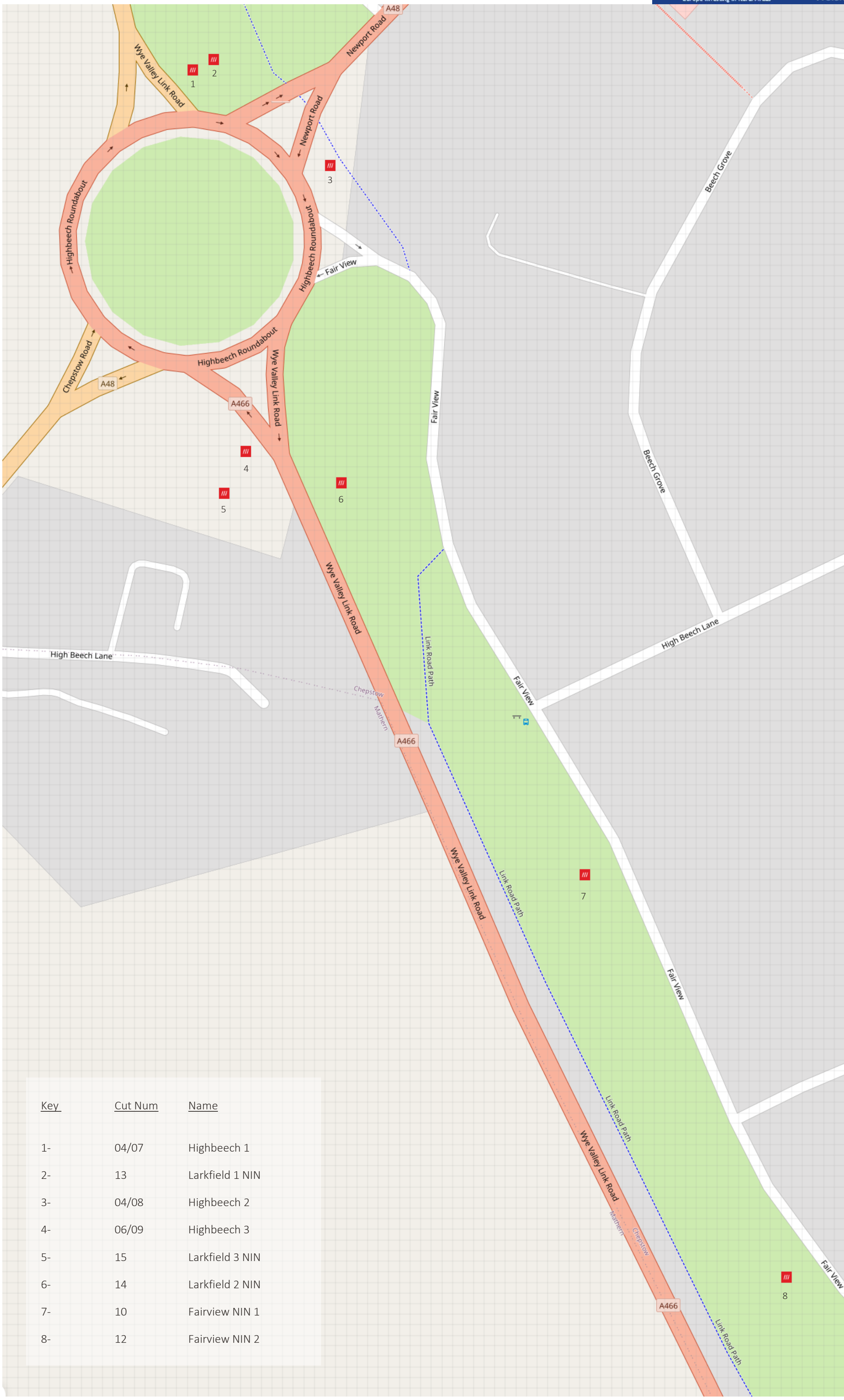
Weight of biomass

- Depending on how grass will be collected- trailer or back of van
- But first, must know the starting weight
- Cut and collect grass
- Weight at the end of the day

Analysis of biomass

- After weighting of the biomass
- Each contractor will have a sample barrel
- Fill the barrel with biomass
- Press down on the barrel by using either hand or foot to compact it
- Assign the samples with a clear label
- One on the inside and one on the outside
- Label must state date of harvest, weather conditions, location, and weight
- Ensure lid is fastened securely
- Store back at yard in a cool dry place ready for collection

14.2 Detailed map of Chepstow Rd roundabout collection points



Key	Cut Num	Name
1-	04/07	Highbeech 1
2-	13	Larkfield 1 NIN
3-	04/08	Highbeech 2
4-	06/09	Highbeech 3
5-	15	Larkfield 3 NIN
6-	14	Larkfield 2 NIN
7-	10	Fairview NIN 1
8-	12	Fairview NIN 2

Figure 14.1 Magnified version of map showing collection sites

14.3 Laboratory analysis of biomass samples

		Outfall Lane	Rogiet MOD	Peterstone	Highbeech 1	Highbeech 2	Highbeech 3	Larkfield 1	Larkfield 2	Larkfield 3	Fairview NIN 1	Denby Drive	Fairview NIN 2	Larkfield 1 NIN	Larkfield 2 NIN	Larkfield 3 NIN
	Date Cut	04/10/2022	12/10/2022	TBC	07/07/2022	07/07/2022	07/07/2022	02/09/2022	02/09/2022	02/09/2022	16/08/2022	16/08/2022	04/11/2022	04/11/2022	04/11/2022	04/11/2022
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
	Unit	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass
Crude Protein	%	4.3	3.4	3.6	4.5	4.0	4.5	7.1	5.1	5.0	9.2	3.6	2.4	2.3	1.9	3.0
Crude Fibre	%	14.0	23.3	10.3	6.0	5.2	5.3	7.2	11.2	4.5	18.0	20.9	4.7	7.9	6.5	7.0
Oven Dry Matter	%	41.3	58.7	39.7	28.0	25.0	31.1	45.0	37.3	32.6	62.5	56.8	18.1	26.3	23.8	27.7
Moisture	%	58.7	41.3	60.3	72.0	75.0	68.9	55.0	62.7	67.4	37.5	43.2	81.9	73.7	76.2	72.3
Ash	%	5.2	4.8	7.4	4.6	3.4	9.2	12.3	4.2	11.6	6.6	4.5	2.4	2.2	4.7	4.8
Oil-B	%	0.9	1.3	1.4	1.3	1.3	1.1	1.8	1.5	1.3	3.4	1.7	1.0	0.8	0.8	1.1
Total Gas Yield [Fresh Material]	M³/t	203.0	306.0	183.0	131.0	121.0	122.0	182.0	186.0	116.0	316.0	298.0	88.9	136.0	108.0	129.0
Total Methane Content	%	53.0	52.0	53.0	55.0	55.0	55.0	55.0	54.0	56.0	54.0	52.0	54.0	53.0	53.0	54.0

Table 14.1 Gas yield analysis of samples sent to laboratory

		Outfall Lane	Rogiet MOD range	NRW1 - Peterstone	Highbeech 1	Highbeech 2	Highbeech 3	Larkfield 1	Larkfield 2	Larkfield 3	Fairview NIN 1	Denby Drive	Fairview NIN 2	Larkfield 1 NIN	Larkfield 2 NIN	Larkfield 2 NIN 3
	Date Cut	04/10/2022	12/10/2022	TBC	07/07/2022	07/07/2022	07/07/2022	02/09/2022	02/09/2022	02/09/2022	16/08/2022	16/08/2022	04/11/2022	04/11/2022	04/11/2022	04/11/2022
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
	Unit	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass
Fresh PH		6.61	7.19	4.29	4.49	6.45	4.80	6.18	6.61	6.72	4.78	6.58	6.05	6.17	6.43	6.31
Organic Matter by LOI	%	82.20	86.40	78.90	84.00	86.30	63.00	72.80	87.10	86.20	85.10	90.50	84.00	85.50	88.30	75.50
Organic Carbon	%	47.70	50.10	45.80	48.70	50.00	36.60	42.20	50.50	50.00	49.40	52.50	48.70	49.60	51.20	43.80
Water Soluble Boron	mg/l	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
Copper (Cu)	mg/kg	10.00	6.60	8.30	9.80	15.70	27.30	26.80	14.80	27.80	8.30	5.70	5.50	11.50	10.40	8.50
Zinc (Zn)	mg/kg	59.40	40.50	55.90	128.00	166.00	278.00	298.00	149.00	235.00	76.50	43.80	30.30	77.10	73.30	51.40
lead (Pb)	mg/kg	5.00	5.00	5.50	5.50	6.90	47.40	38.00	5.50	55.80	9.80	5.00	9.00	10.10	5.00	5.00
Arsenic	mg/kg	3.00	3.00	3.00	3.00	3.00	6.10	6.60	3.00	5.60	3.00	3.00	3.00	3.00	3.00	3.00
Cadmium (Cd)	mg/kg	0.13	0.10	0.15	0.13	0.20	0.37	0.55	0.14	0.39	0.12	0.10	0.10	0.21	0.12	0.13
Nickel (Ni)	mg/kg	10.00	10.00	10.00	10.00	10.00	10.90	10.70	10.00	10.30	11.30	10.00	10.00	10.00	10.00	10.00
Vanadium	mg/kg	10.00	10.00	10.00	10.00	10.00	10.40	11.90	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Chromium (Cr)	mg/kg	10.30	10.00	10.00	10.00	10.00	15.70	17.50	10.00	15.20	25.10	10.00	10.00	10.00	10.00	10.00
Mercury (Hg)	mg/kg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Selenium	mg/kg	<0.09	<0.09	<0.09	0.10	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09
Iron	mg/kg	3509.00	1012.00	4448.00	1093.00	1496.00	7540.00	7810.00	1291.00	6554.00	1710.00	772.00	972.00	2961.00	1092.00	1025.00
Antimony	mg/kg	0.10	0.20	0.10	0.50	0.70	1.30	1.40	0.80	1.60	0.30	0.10	0.10	0.40	0.40	0.20
Manganese	mg/kg	115.00	35.80	149.00	116.00	97.60	394.00	573.00	110.00	376.00	132.00	86.10	73.30	323.00	119.00	122.00
Molybdenum	mg/kg	1.20	1.20	1.50	3.10	7.80	5.20	3.40	3.60	4.20	6.50	3.60	2.80	1.20	2.70	1.00
Tin	mg/kg	1.00	1.00	1.00	1.00	1.20	2.50	3.00	1.20	5.80	1.00	1.00	1.00	1.00	1.10	1.00
Cobalt	mg/kg	1.30	1.00	1.70	1.00	1.00	2.80	2.70	1.00	2.90	1.10	1.00	1.00	1.10	1.00	1.00
Total Sulphate	mg/kg	6585.00	3340.00	6869.00	6496.00	8631.00	5471.00	4416.00	5647.00	4409.00	3592.00	2015.00	2796.00	4070.00	1877.00	1274.00
Water Soluble Suplphate	g/l	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
Elemental Sulphur	mg/kg	<5	<5	<5	6.60	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Cyanide	mg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Complex Cyanide	mg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Table 14.2 Laboratory waste characterisation package results

Literature in red is Optimising UK urban road verge contributions to biodiversity and ecosystem services with cost-effective management paper.