Welcome to the Greenprint Greenhouse Gas Calculations

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Executive summary

Overview of Carbon Assessment Framework

The Greenprint carbon model developed by Deborah Adkins evaluates lifecycle greenhouse gas (GHG) emissions associated with verge-side grass management and utilisation pathways.

The methodology follows the UK Green Gas Support Scheme (GGSS) methodology for biomethane systems, using the "actual value" method. It uses the calculated carbon intensity of biomethane as required by the GGSS and aligns with the Renewable Energy Directive (REDII) method for calculating GHG emissions associated with biomethane production through anaerobic digestion (AD).

The model accounts for emissions across the key stages of the biomass supply chain, including:

- Feedstock cultivation and harvesting (e_{ec})
- Transport of feedstock to processing facilities (e_{td})
- Soil carbon changes associated with altered land management (e_{sca})
- Processing emissions from anaerobic digestion (AD) or pyrolysis (e_p)

The project separates biogenic emissions from fossil fuel emissions at each stage. These are reported separately throughout. These emissions are aggregated and normalised to a functional unit of **kg CO_2e per 1000 m^2** of verge area managed. Emissions associated with capital equipment manufacture, biomass combustion, and indirect land-use change are excluded from the analysis in accordance with GGSS accounting conventions.

The cut and leave (C&L) and process emissions from pyrolysis (e_p) (not part of the UK Green Gas Support Scheme (GGSS) methodology for biomethane systems) have been added as part of Greenprint.

Importantly, the model applies a **whole-system perspective** for the **grass feedstock solely**, capturing additional carbon flows associated with soil carbon changes and potential carbon sequestration from biochar.

Further information: To discuss any element of this analysis, please contact Deborah Adkins, deborah.adkins@uwe.ac.uk.

Headline findings

The headline findings from the Greenprint carbon model are:

South Gloucestershire Council (SGC)

- In SGC, the cut-and-collect approach saved up to **34.55 kgCO_2e per 1,000 m^2** compared with cut-and-leave management (assuming 100% of grass is transported to AD by biomethane). If this saving were applied across the 473 hectares of council-maintained grass, it would represent a **total saving of 163.4 tonnes CO_2e**.
- With the feedstock co-mingling scenario (20% grass / 80% food waste sent to AD, transported by diesel), the model indicates carbon emissions **69% higher** than the cut-and-leave baseline, equivalent to an additional **95 tCO_2e across the whole estate**.
- With the feedstock co-mingling scenario (20% grass / 80% food waste sent to AD, transported by biomethane), the model indicates carbon emissions **55% higher** than the cut-and-leave baseline, equivalent to an additional **75 tCO_2e across the whole estate**.

West Sussex County Council (WSCC)

- In WSCC, cut and collect saved up to **39.56 kgCO_2e per 1000m^2** compared with cut & leave (100% grass to AD, with biomethane transport option). Over the **whole estate,** this equates to **184 tonnes of CO_2e saved**.
- With the feedstock co-mingling scenario (20% grass / 80% food waste sent to AD with diesel transport), the model shows carbon emissions 69% higher than the cut and leave baseline, equivalent to an additional **118 tCO_2e across the whole estate**.
- With the feedstock co-mingling scenario (20% grass / 80% food waste sent to AD with biomethane transport), the model shows carbon emissions 55% higher than the cut and leave baseline, equivalent to an additional **94 tCO_2e across the whole estate**.

AD grass and food co-mingling scenarios

- These outcomes are driven by a boundary limitation: the model excludes emissions and avoided emissions associated with the 80% food waste component.
- Note, under REDII accounting rules, wastes such as food waste are treated as zero-burden feedstocks, meaning emissions associated with their original production are not included in lifecycle calculations. Consequently, only the emissions associated with the grass feedstock are counted in the cultivation stage of the analysis.

Fossil fuel consumption during grass feedstock harvesting

- In SGC, fossil fuel carbon emissions for cut and collect harvesting were **7.7 times** that of cut and leave. Across the SGC whole estate, this equates to 83t CO_2e vs 11 tCO_2e baseline emissions.
- In WSCC, fossil fuel carbon emissions for cut and collect harvesting were **2.4 times** that of cut and leave. Across the WSCC whole estate, this equates to 54 t CO_2e vs 22 tCO_2e baseline emissions.
- This is due to a difference in operating method between WSCC and SGC, as tested during the trials.

Pyrolysis scenarios

- In WSCC, studies of fuel mixes containing 10% woody biomass and 90% pyrolysed grass, and 2.7% woody biomass and 97.3% pyrolysed grass, were undertaken by the University of Nottingham.
- In WSCC, diverting grass arisings to pyrolysis for biochar production delivered an estimated saving of **25 $kgCO_2e$ per $1000m^2$** compared with the baseline management scenario. Across the whole estate, this represents an estimated saving of approximately **117 tonnes of CO_2e.** However, this calculation is based on a fuel mix of 2.7% pyrolysed grass and 97.3% woody biomass.
- These pyrolysis scenario outcomes are also driven by boundary limitations, with emissions associated with the 90% or 97.3% green biomass waste component excluded.
- Using 100% pyrolysis-derived grass was found to be neither commercially viable nor environmentally efficient, given that transporting low-energy-density grass to a pyrolysis plant requires additional fossil-fuel consumption.
- An additional scenario for the WSCC full green estate has been modelled by the University of Nottingham, based on a 10,000-tonne-per-year production plant. This scenario assumes a feedstock mix comprising 2.7% grass and 97.3% other green feedstocks.
- Please refer to the Thought Leadership report for a summary of the results, and the UoN Business Case for further details on Pyrolysis scenarios.

Summary

- Based on the initial modelling that has taken place, the 100% grass to AD processing option with biomethane transport results in the lowest emissions of all options modelled
- The highest emissions are associated with the 20% grass/80% food-to-AD processing option.
- Project boundaries have a substantial influence on the calculated emissions. Further modelling is recommended to examine the wider system scope, including transport emissions and potential co-feedstock options.

Baseline Scenario: Cut-and-Leave Verge Management

The baseline scenario represents the current management practice in which verge grass is cut but left on site to decompose. In carbon accounting terms, this practice transfers carbon from the **living biomass pool to the dead organic matter (DOM) pool**.

Over time, this organic material decomposes through microbial processes, producing greenhouse gases, including:

- Carbon dioxide (CO_2)
- Nitrous oxide (N_2O)
- Methane (CH_4)

Although decomposition of thin layers of cut grass is largely aerobic, localised anaerobic conditions can occur, particularly in moist environments, resulting in methane formation. Methane and nitrous oxide have significantly higher global warming potentials than carbon dioxide, meaning even relatively small emissions can substantially increase the overall climate impact.

The model applies an emission factor of approximately **0.206 tCO_2e per tonne of fresh grass biomass** decomposing on site. This value is consistent with laboratory measurements and comparable aerobic composting studies, indicating that unmanaged decomposition can represent a significant source of greenhouse gas emissions.

It should be noted that, with the projects' focus on verge-side grass management and utilisation pathways, the baseline assumption (Cut & Leave) is the business-as-usual scenario of grass feedstock being cut and left. There is no baseline assumption that if Greenprint did not occur, food waste would instead go to landfill. Thus, emissions from food waste decomposition (e.g., methane from landfill) and avoided emissions via food waste-controlled treatment are not included in this initial study.

From a lifecycle perspective, the cut-and-leave baseline therefore represents the **highest-emission management pathway**, as all of the carbon contained in the biomass ultimately returns to the surrounding environment without delivering any energy recovery.

In a wider international context, unmanaged biomass decomposition is widely recognised as a **lost opportunity for climate mitigation**, particularly when compared with pathways that either recover energy from the biomass or stabilise carbon in more durable forms.

Cut-and-Collect Management and Soil Carbon Effects

Transitioning from cut-and-leave to cut-and-collect management alters the carbon balance in two important ways. First, removing biomass from the verge prevents the in situ decomposition of organic residues. This directly eliminates the methane and nitrous oxide emissions associated with unmanaged decomposition.

Second, the model accounts for potential soil carbon improvements associated with improved grassland management practices. Empirical soil measurements taken during the project indicate that changing verge management practices may result in gradual increases in soil organic carbon.

The analysis estimates a soil carbon sequestration benefit equivalent to approximately **−61.9 kg CO_2e per 1000 m^2** annually, based on expected carbon accumulation rates over a 20-year period.

These sequestration rates are broadly consistent with findings from international studies of improved grassland management, which typically report soil carbon increases in the range of 0.1–0.3 tonnes of carbon per hectare per year following improved vegetation management practices.

Consequently, the shift from cut-and-leave to cut-and-collect produces an improvement in carbon performance even before considering the utilisation pathway of the collected biomass.

Anaerobic Digestion Pathway

Carbon performance of AD systems
In the anaerobic digestion pathway, collected grass is processed to produce biogas, which is subsequently upgraded to biomethane for injection into the gas grid.

The lifecycle emissions associated with this process arise primarily from:
- Energy consumption during digestion and upgrading
- Methane leakage from digestion and upgrading equipment
- Digestate storage and handling

Using the GGSS calculation framework, the model estimates a biomethane pathway emission intensity of approximately **26.85 gCO_2e per MJ** of biomethane produced.

For comparison, conventional natural gas typically has lifecycle emissions of approximately **90–100 gCO_2e per MJ,** meaning biomethane produced through AD can deliver substantial emissions reductions relative to fossil fuels.

Feedstock composition and implications for comparison

A key feature of the AD scenario in the model is that grass represents only **20% of the digester feedstock**, with the remaining **80% consisting of food waste**.

Under REDII accounting rules, wastes such as food waste are treated as **zero-burden feedstocks**, meaning emissions associated with their original production are not included in lifecycle accounting. As a result, only the emissions associated with the grass feedstock are included in the cultivation stage of the analysis.

This approach reflects the operational reality of most commercial AD plants, which commonly rely on mixed feedstocks to optimise digestion performance and energy yields. However, it also means that the AD carbon results represent a **co-digestion system rather than a grass-only digestion pathway**.

Nevertheless, even under grass-only scenarios, AD would generally perform significantly better than the baseline cut-and-leave system because methane formation occurs within a controlled process where energy is captured and utilised.

Pyrolysis and Biochar Pathways

Carbon stabilisation through biochar
Pyrolysis converts biomass into three main products:
- Biochar
- Bio-oil
- Syngas

The key climate benefit arises from the formation of biochar, which consists of highly stable carbon structures produced during thermal decomposition in the absence of oxygen.

Unlike untreated biomass, which decomposes within months or years, a significant proportion of biochar carbon can remain stable in soils for hundreds of years. This allows pyrolysis systems to function as a form of long-term carbon removal technology, effectively transferring atmospheric carbon into long-term storage.

As a result, pyrolysis systems are often capable of delivering net-negative greenhouse gas emissions, depending on the feedstock source and energy balance of the system.

Interpretation of the modelled pyrolysis results
Within the Greenprint carbon model, pyrolysis emissions are calculated **for grass feedstock only**, without including complementary biomass streams.

In practice, commercial pyrolysis systems typically process a mixture of biomass types, such as:

- wood residues
- green waste
- agricultural residues

These materials generally contain higher lignin content and lower moisture levels than grass, which can increase biochar yields and enhance the stability of the stored carbon. Consequently, the pyrolysis results presented in the model should be interpreted as a conservative estimate, as the inclusion of woody or residual biomass streams would likely improve the carbon performance of the system further. For a detailed discussion on pyrolysis results, see the separate report and Business Case by the University of Nottingham.

Findings

Option		Harvesting			Transport			Land use change	soil carbon	Processing			Distribution	Use	CCS	CCR	Total
		$e_{ec,n}$			$e_{td,feedstock,n}$			e_{ln}	$e_{sca,n}$	e_p			$e_{td,product}$	e_u	e_{ccs}	e_{ccr}	$kgCO_2e/1000m^2$
		fossil	biogenic	total	fossil	biogenic	total	biogenic	biogenic	fossil	biogenic	total					
Cut and leave	WSCC (C&L)	4.82	34.75	**39.57**													**39.57**
	SGC (C&L)	2.28	26.88	**29.16**													**29.16**
Cut & Collect (100% G AD)	WSCC$_{(diesel\ transport)}$	11.61	0.00	**11.61**	3.51	0	**3.51**	**0.00**	**-61.92**	0.00	50.30	**50.30**	0	0	0	0	**3.49**
	SGC$_{(diesel\ transport)}$	17.62	0.00	**17.62**	2.71	0	**2.71**	**0.00**	**-61.92**	0.00	38.91	**38.91**	0	0	0	0	**-2.68**
Cut & Collect (100% G AD)	WSCC$_{(biomethane\ transport)}$	11.61	0.00	**11.61**	0	0.025	**0.03**	**0.00**	**-61.92**	0.00	50.30	**50.30**	0	0	0	0	**0.01**
	SGC$_{(biomethane\ transport)}$	17.62	0.00	**17.62**	0	0.003	**0.00**	**0.00**	**-61.92**	0.00	38.91	**38.91**	0	0	0	0	**-5.39**
C&C (20% G, 80% F, AD)[1]	WSCC$_{(diesel\ transport)}$	2.32	0.00	**2.32**	5.26	0	**5.26**	**0.00**	**-12.38**	0.00	69.77	**69.77**	0	0	0	0	**64.96**
	SGC$_{(diesel\ transport)}$	3.52	0.00	**3.52**	4.07	0	**4.07**	**0.00**	**-12.38**	0.00	53.97	**53.97**	0	0	0	0	**49.17**
C&C (20% G, 80% F, AD)[1]	WSCC$_{(biomethane\ transport)}$	2.32	0.00	**2.32**	0.00	0.038	**0.04**	**0.00**	**-12.38**	0.00	0.00	**69.77**	0	0	0	0	**59.74**
	SGC$_{(biomethane\ transport)}$	3.52	0.00	**3.52**	0.00	0.004	**0.00**	**0.00**	**-12.38**	0.00	0.00	**53.97**	0	0	0	0	**45.11**
C&C (10% G, 90% W, PYR)[2]	WSCC$_{(diesel\ transport)}$	1.16	0.00	**1.16**	0.73	0	**0.73**	**0.00**	**-6.19**	0.74	15.55	**16.29**	0	0	-1.92	0	**10.07**
C&C (2.7% G, 97.3% W, PYR)[2]	WSCC$_{(diesel\ transport)}$	0.31	0.00	**0.31**	0.14	0	**0.14**	**0.00**	**-1.67**	0.74	15.55	**16.29**	0	0	-0.52	0	**14.55**

Table 1: Summary worksheet: Showing pathway emissions for biomethane and biochar generated from feedstocks classified as products. Units $kgCO_2e$ per 1000 m^2

[1] Food waste is treated as zero-burden feedstocks, meaning emissions associated with their original production are not included in lifecycle accounting

[2] Due to the emerging nature of biochar technology, additional research with academic partner UoN has been undertaken to quantify emissions for these emergent areas. Does not include emissions associated with woody biomass harvesting.

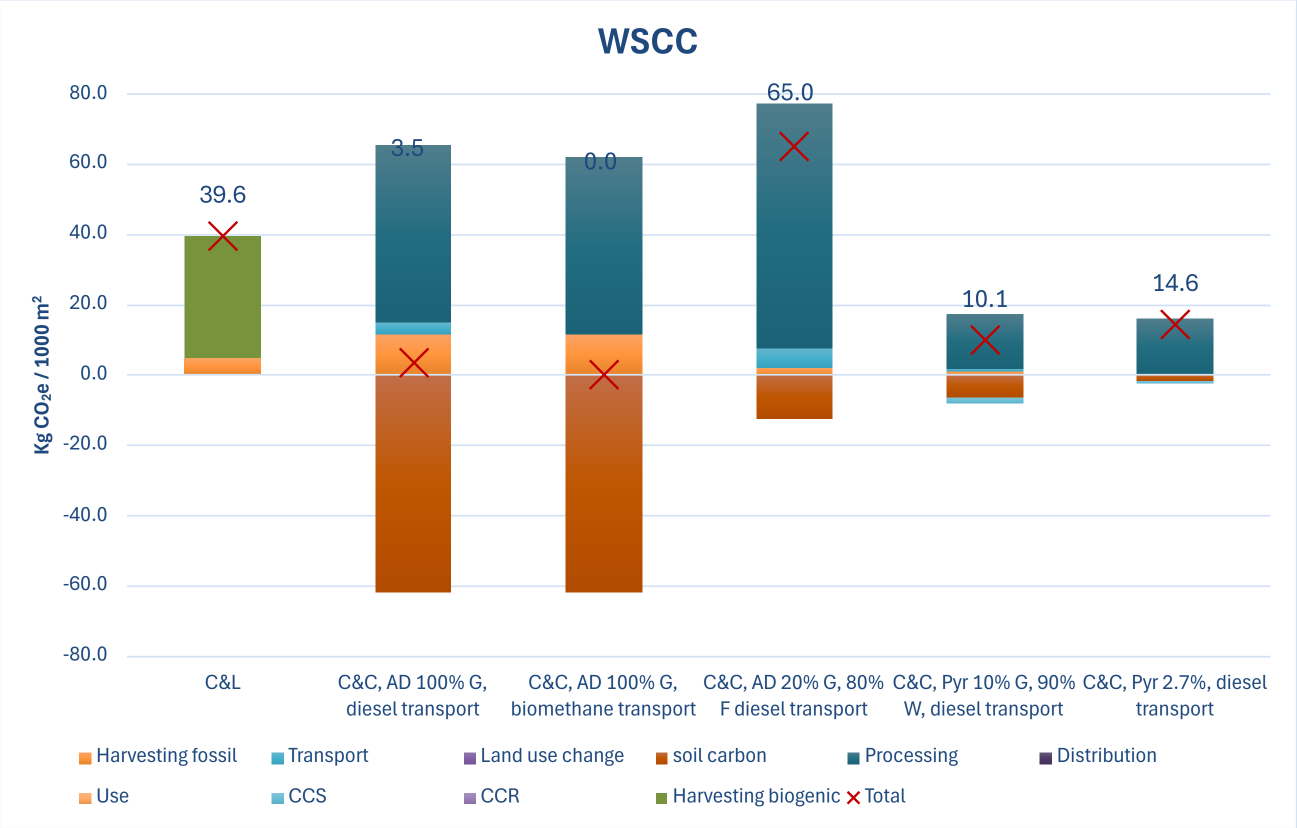

Figure 1: Summary chart for for West Sussex County Council (WSCC) showing pathway emissions for biomethane and biochar generated from feedstocks classified as products. Units kgCO₂e per 1000 m^2

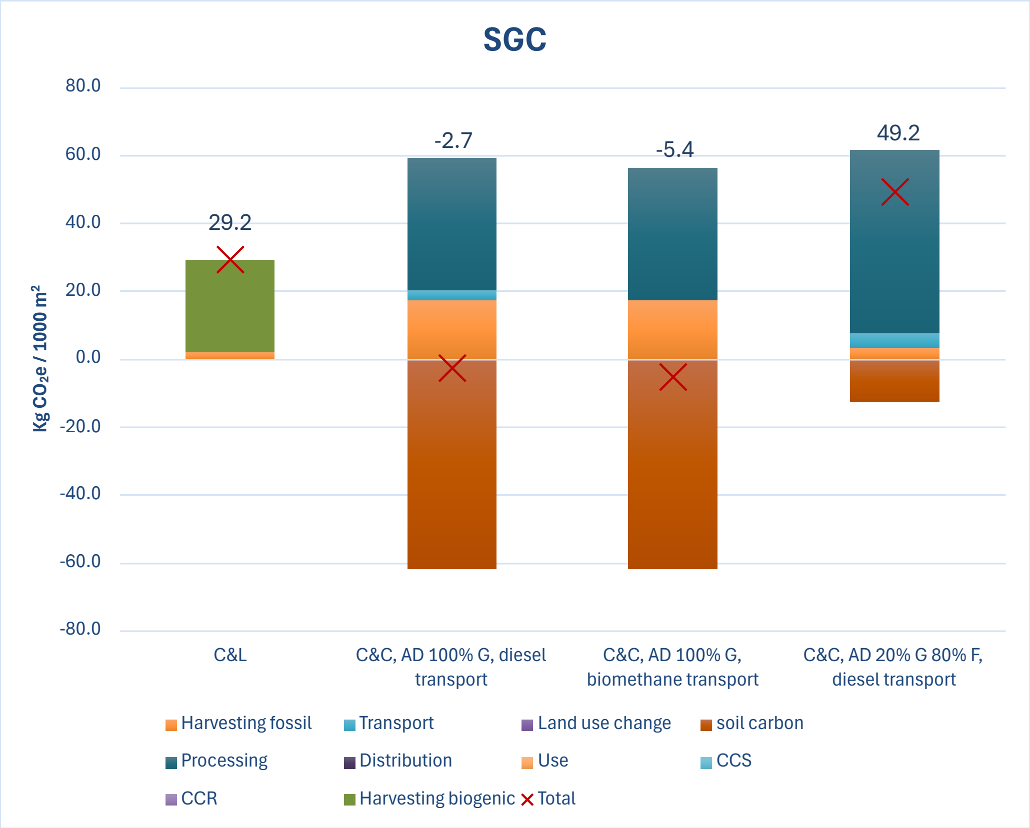

Figure 2: Summary chart for for West Sussex County Council (WSCC) showing pathway emissions for biomethane and biochar generated from feedstocks classified as products. Units kgCO₂e per 1000 m^2

Comparative Interpretation of the Options

Across the options assessed, the overall carbon performance is primarily determined by two key mechanisms:

1. **Energy recovery from biomass**, which displaces fossil fuel use.
2. **Carbon stabilisation**, particularly through biochar production.

The baseline cut-and-leave approach results in the highest lifecycle emissions because biomass carbon is released to the atmosphere without any beneficial use.

Cut-and-collect management improves the carbon balance by preventing these emissions and allowing biomass to be utilised within energy or carbon-storage systems.

The anaerobic digestion pathway provides substantial climate benefits through renewable gas production and fossil fuel displacement, particularly when integrated with waste co-digestion systems.

The pyrolysis pathway has the potential to deliver the greatest climate benefit due to the **long-term stabilisation of carbon in biochar**, effectively converting biomass carbon into a durable carbon sink.

Key Implications

The results indicate that **utilising verge biomass as a resource rather than leaving it to decompose can significantly improve the carbon balance of verge management**.

From a climate mitigation perspective:

- **Cut-and-leave represents the least favourable option**, as it allows biomass carbon to return directly to the atmosphere.
- **Anaerobic digestion provides meaningful emissions reductions**, particularly when integrated with waste feedstocks.
- **Pyrolysis and biochar systems offer the potential for net-negative emissions**, making them a particularly promising pathway for long-term carbon management.

Taken together, the results highlight the potential for verge biomass management to transition from a routine maintenance activity into a **meaningful component of regional climate mitigation strategies**.

Whole-Estate Carbon Implications

To provide a clearer indication of the potential climate impact of each management pathway, the model results can be extrapolated from the functional unit of **$kgCO_2e$ per 1000 m^2** to the scale of the full managed verge estate within the project authorities. For the purposes of this assessment, the total verge area considered is **4,658,735m^2 for West Sussex County Council (WSCC)** and **4,730,000 m^2 for South Gloucestershire Council (SGC)**.

Scaling the lifecycle emissions results to these estate areas allows the comparative carbon implications of each option to be interpreted in terms of total annual emissions or savings associated with verge management across each authority.

While the underlying modelling results are presented per unit area to allow direct comparison between pathways, the whole-estate extrapolation highlights the **strategic magnitude of emissions reductions or removals that could be achieved through changes in biomass management and utilisation pathways**. The values presented below therefore represent the estimated annual greenhouse gas impact for the full verge estate under each option.

This whole-estate perspective demonstrates that even relatively small changes in emissions intensity at the unit level can translate into **substantial carbon impacts when applied across millions of square metres of managed verge habitat**, reinforcing the strategic importance of selecting lower-emission or carbon-removal pathways for verge biomass utilisation.

Option		Total $kgCO_2e/1000m^2$	Whole estate tonnes CO_2e
Cut and leave	WSCC (C&L)	39.57	**184.37**
	SGC (C&L)	29.16	**137.94**
Cut & Collect (100% G AD)	WSCC$_{\text{(diesel transport)}}$	3.49	**16.28**
	SGC$_{\text{(diesel transport)}}$	-2.68	**-12.69**
Cut & Collect (100% G AD)	WSCC$_{\text{(biomethane transport)}}$	0.01	**0.06**
	SGC$_{\text{(biomethane transport)}}$	-5.39	**-25.50**
C&C (20% G, 80% F, AD)[1]	WSCC$_{\text{(diesel transport)}}$	64.96	**302.67**
	SGC$_{\text{(diesel transport)}}$	49.17	**232.59**
C&C (20% G, 80% F, AD)[1]	WSCC$_{\text{(biomethane transport)}}$	59.74	**278.35**
	SGC$_{\text{(biomethane transport)}}$	45.11	**213.37**
C&C (10% G, 90% W, PYR)[2]	WSCC$_{\text{(diesel transport)}}$	10.07	**46.92**
C&C (2.7% G, 97.3% W, PYR)[2]	WSCC$_{\text{(diesel transport)}}$	14.55	**67.81**

Table 2: Summary showing estimated total pathway emissions across the whole estate for biomethane and biochar generated from feedstocks classified as products. Units $kgCO_2e$ per 1000 m^2 and tonnes CO_2e per estate. The total estate area considered is 4,658,735m^2 for West Sussex County Council (WSCC) and 4,730,000 m^2 for South Gloucestershire Council (SGC).

Annex A - Calculating emissions

This model has been developed to determine the Greenprint lifecycle emissions, following the project route map laid out in the project OBC. It follows the procedure and builds upon the 'actual value' method for co-digesting biomethane plants, as laid out in the document 'Methods of calculating greenhouse gas emissions.'[1]

The actual value method for co-digesting biomethane plants is:

$$E = \sum_{1}^{n} s_n \cdot (e_{ec,n} + e_{td,\,feedstock} + e_{l,n} - e_{sca,n}) + e_p + e_{td,product} + e_u - e_{ccs} - e_{ccr}$$

Where:

E is the total emissions from the production of biomethane before energy conversion
$\mathbf{e}_{ec,n}$ is the emissions from the extraction or cultivation of feedstock [harvesting]
$\mathbf{e}_{td,feedstock,n}$ is the emissions from transport of feedstock n to the digester [transport]
$\mathbf{e}_{ln}$ is the annualised emissions from carbon-stock changes caused by land use change for feedstock n;
$\mathbf{e}_{sca,n}$ is the emission savings from improved agricultural management of feedstock n; [soil carbon]
$\mathbf{e}_{p}$ is the emissions from processing [digestion and outputs][2]
$\mathbf{e}_{td,product}$ is the emissions from transport and distribution of biomethane[3]
$\mathbf{e}_{u}$ is the emissions from the fuel in use[4]
$\mathbf{e}_{ccs}$ is the emission savings from carbon capture and geological storage; and
$\mathbf{e}_{ccr}$ is the emission savings from carbon capture and replacement.

For each feedstock, each of these e factors (representing the pathway emissions) is laid out in the Summary worksheet in columns D to N.
Each e factor in the summary is split into either predominantly fossil fuel or predominantly biogenic emissions. The pathway emissions for each feedstock are multiplied by the share of each feedstock Sn, to calculate the weighted emissions. These are summed to generate the total emissions E for each option in column O

Due to the whole-system approach employed in the Greenprint project (see route map), these calculations extend beyond emissions associated solely with biomethane production to include additional sources, such as those linked to biochar use cases.[5]

Where applicable, the method employed uses the calculated carbon intensity of the resultant biomethane as per the requirements of the GGSS and is aligned with the REDII (Renewable Energy Directive) method for calculating GHG emissions associated with biomethane production through anaerobic digestion (AD).

The GGSS calculations were designed to reflect the most common AD configurations in Great Britain, based on existing facilities commissioned under predecessor support schemes and knowledge of ongoing developments. However, as every AD site is bespoke in terms of inputs, processes, and outputs, not all possible configurations are represented in the Greenprint carbon model. Future modifications may be made to reflect the latest Greenprint data, best practice and evolving carbon accounting standards, especially in the areas of emerging less conventional systems such as biochar, whilst remaining aligned with the method and rules for performing such calculations.

Emissions generally excluded

Emissions from capital goods (i.e. manufacture of mowing machinery and equipment).
Combustion emissions for biomass, biogas, biomethane, biofuels and bioliquids.
Indirect land use change emissions from the supply of feedstock.
Decommissioning of the AD/ Biochar power plant and machinery at the End-of-Life (EoL).
Emissions related to employee commuting, business travels and waste generation at the administrative offices. (onsite staff and contractors included)

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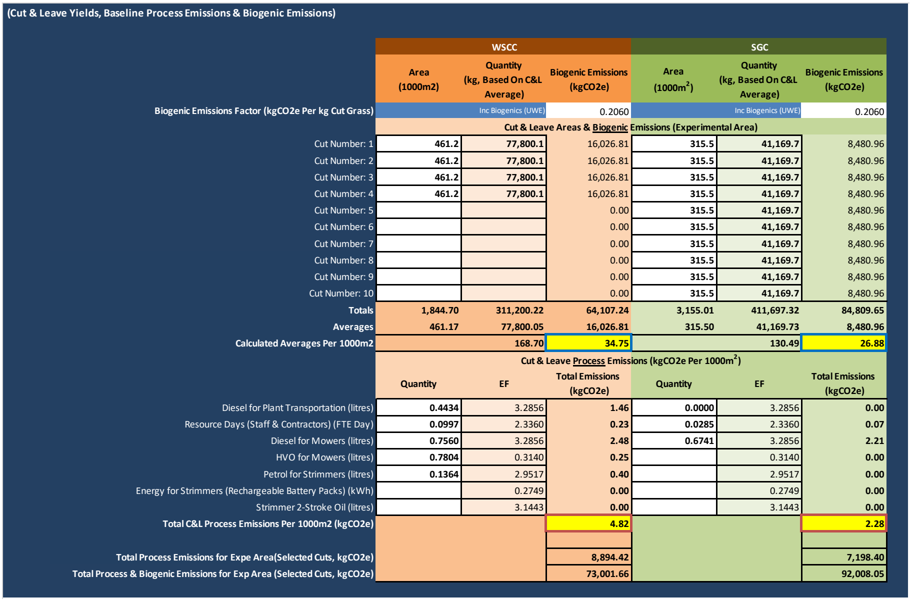
[1] DESNZ (2024) Methods of calculating greenhouse gas emissions. Available at https://www.gov.uk/government/publications/methods-of-calculating-greenhouse-gas-emissions
[2] Which includes anaerobic digestion, biogas upgrading, and biochar
[3] Which is zero in GGSS, as the end distance travelled by the biomethane is not known.
[4] Which is zero in GGSS, as the end use is not known.
[5] Due to the emerging nature of biochar as a negative-emissions technology, additional research with academic partners has been undertaken to quantify emissions for these emergent specialised carbon-accounting areas.

Annex B - Calculating the Baseline: Cut and leave

$e_{ec,c\&l}$ is the emissions from the extraction or cultivation of feedstock left in situ.

This tab has been used to calculate $e_{ec,\ c\&l}$ the emissions from the extraction or cultivation of feedstock, for the cut and leave baseline. In the case of Greenprint, emissions are calculated based on cultivation, harvest and leaving grass in situ (cutting & leaving) for GRASS products only.



(Cut & Leave Yields, Baseline Process Emissions & Biogenic Emissions)

	WSCC			SGC		
	Area (1000m2)	Quantity (kg, Based On C&L Average)	Biogenic Emissions (kgCO2e)	Area (1000m^2)	Quantity (kg, Based On C&L Average)	Biogenic Emissions (kgCO2e)
Biogenic Emissions Factor (kgCO2e Per kg Cut Grass)		Inc Biogenics (UWE)	0.2060		Inc Biogenics (UWE)	0.2060
	Cut & Leave Areas & Biogenic Emissions (Experimental Area)					
Cut Number: 1	461.2	77,800.1	16,026.81	315.5	41,169.7	8,480.96
Cut Number: 2	461.2	77,800.1	16,026.81	315.5	41,169.7	8,480.96
Cut Number: 3	461.2	77,800.1	16,026.81	315.5	41,169.7	8,480.96
Cut Number: 4	461.2	77,800.1	16,026.81	315.5	41,169.7	8,480.96
Cut Number: 5			0.00	315.5	41,169.7	8,480.96
Cut Number: 6			0.00	315.5	41,169.7	8,480.96
Cut Number: 7			0.00	315.5	41,169.7	8,480.96
Cut Number: 8			0.00	315.5	41,169.7	8,480.96
Cut Number: 9			0.00	315.5	41,169.7	8,480.96
Cut Number: 10			0.00	315.5	41,169.7	8,480.96
Totals	1,844.70	311,200.22	64,107.24	3,155.01	411,697.32	84,809.65
Averages	461.17	77,800.05	16,026.81	315.50	41,169.73	8,480.96
Calculated Averages Per 1000m2		168.70	34.75		130.49	26.88
	Cut & Leave Process Emissions (kgCO2e Per 1000m^2)					
	Quantity	EF	Total Emissions (kgCO2e)	Quantity	EF	Total Emissions (kgCO2e)
Diesel for Plant Transportation (litres)	0.4434	3.2856	1.46	0.0000	3.2856	0.00
Resource Days (Staff & Contractors) (FTE Day)	0.0997	2.3360	0.23	0.0285	2.3360	0.07
Diesel for Mowers (litres)	0.7560	3.2856	2.48	0.6741	3.2856	2.21
HVO for Mowers (litres)	0.7804	0.3140	0.25		0.3140	0.00
Petrol for Strimmers (litres)	0.1364	2.9517	0.40		2.9517	0.00
Energy for Strimmers (Rechargeable Battery Packs) (kWh)		0.2749	0.00		0.2749	0.00
Strimmer 2-Stroke Oil (litres)		3.1443	0.00		3.1443	0.00
Total C&L Process Emissions Per 1000m2 (kgCO2e)			4.82			2.28
Total Process Emissions for Expe Area(Selected Cuts, kgCO2e)			8,894.42			7,198.40
Total Process & Biogenic Emissions for Exp Area (Selected Cuts, kgCO2e)			73,001.66			92,008.05

Cut and leave

Is a management practice in which unharvested grass is cut and left on site. In carbon accounting terms, this shifts carbon from living biomass pools into dead organic matter (DOM) pools. Under IPCC guidance, this transition must be tracked because DOM decomposes over time, gradually releasing carbon back to the atmosphere.

IPCC Definition of Dead Organic Matter (DOM) in Grasslands

According to the IPCC 2006 Guidelines and the 2019 Refinement, DOM in grasslands includes all dead wood and litter pools. It comprises non-living plant material that is actively decomposing and functions as a transitional pool between living vegetation and soil organic matter.

Key elements of the IPCC definition:

- Components: DOM includes all non-living woody biomass (dead wood) and non-woody plant debris (litter) that are not classified as living biomass or soil carbon.
- Role in Carbon Cycling: DOM acts as a temporary carbon reservoir in which dead plant material may persist for months to decades before being incorporated into soil organic matter.
- Sensitivity to Management: Activities such as cutting, grazing, and burning influence, both the quantity of material entering DOM pools and the rate at which it decomposes.

Carbon Dynamics of “Cut and Leave”

Carbon Pool Transfer: Cutting moves carbon from the aboveground biomass pool to the litter (DOM) pool. The carbon is not released immediately but follows a time-dependent decomposition pathway.

Carbon Stock Changes: Accounting must capture both the immediate reduction in living biomass and the gradual carbon losses from decomposing residues.

Non-CO_2 Emissions: While CO_2 dominates the emissions profile, decomposition under certain moisture conditions may also generate CH_4 or other non-CO_2 gases.

Importance for Verge-Side Management

For roadside or verge-side grasslands, accurate accounting of “cut and leave” practices is essential. Leaving biomass in place converts what could be a long-term carbon sink into a potential carbon source as the residue decomposes, influencing the overall carbon balance of vegetation management activities.

Cultivation and harvesting summary

$e_{ec,\ c\&l}$ the emissions from the extraction or cultivation of feedstock. Includes the seed, chemical, fuel and fertiliser, relevant to all operations necessary to prepare the land, establish, manage and harvest the crop. Yield is reported on a fresh tonne basis, as harvested.

The emissions have been split into two components: fossil fuel emissions and biogenic emissions from leaving the grass in situ.
In the case of verge side grass, initial grass seed is deemed negligible and excluded. In contrast to other feedstock, e.g., maize. NO fertiliser is applied to establish and manage the GRASS crop.

Fossil fuel emissions

This stage includes emissions from fuel use in plant, mowers and strimmers, emissions from the production of fertilisers, in-field nitrous oxide emissions from fertiliser application.
This stage includes fossil fuel emissions from diesel use in plant transportation to the site and to the depot, diesel or HVO to mowers, petrol or energy for strimmers, and oil for strimmers.

Biogenic emissions

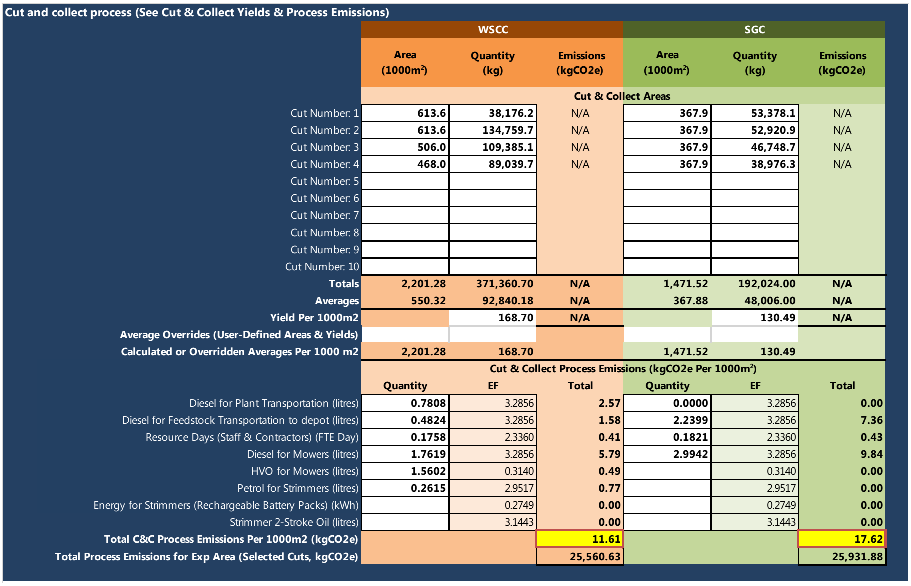
Biogenic emissions are defined as the total emissions (tonnes of CO_2e per ha per year) released when verge clippings are left in situ (as part of 'cut and leave') to break down on site. The 'cut and leave' (C+L) verge biomass material left in situ is subjected to a combination of aerobic (in the presence of oxygen) and anaerobic (absence of oxygen) microbial degradation that results in the release of CO_2, N_2O and CH_4, which are key contributors to greenhouse gas (GHG) emissions. Carbon dioxide (CO_2) and nitrous oxide (N_2O) are the most common GHG products of aerobic digestion, while methane (CH_4) is the main GHG product from anaerobic digestion. While the verge biomass (cut grass) is left in place, the layer deposited over the ground is small, allowing air circulation and aerobic digestion.

The Emission Factor (t-CO_2e/t-FW) used for calculations from the lab estimate of cut and leave (0.206) is within the calculated standard deviation (very similar) to the values obtained in field experiments with composting in aerobic conditions, validating the cut and leave emission estimate.

Annex C - Cultivation and harvesting

e_{ec} is the emissions from the extraction or cultivation of feedstock.

In the case of Greenprint, emissions are calculated based on cultivation and harvest information (cutting & collecting) for all GRASS products only. Emissions excluded are those from the extraction or cultivation of secondary feedstocks, food waste, and green waste.



Cut and collect process (See Cut & Collect Yields & Process Emissions)

	WSCC			SGC		
	Area (1000m²)	**Quantity (kg)**	**Emissions (kgCO2e)**	**Area (1000m²)**	**Quantity (kg)**	**Emissions (kgCO2e)**
	Cut & Collect Areas					
Cut Number: 1	**613.6**	**38,176.2**	N/A	**367.9**	**53,378.1**	N/A
Cut Number: 2	**613.6**	**134,759.7**	N/A	**367.9**	**52,920.9**	N/A
Cut Number: 3	**506.0**	**109,385.1**	N/A	**367.9**	**46,748.7**	N/A
Cut Number: 4	**468.0**	**89,039.7**	N/A	**367.9**	**38,976.3**	N/A
Cut Number: 5						
Cut Number: 6						
Cut Number: 7						
Cut Number: 8						
Cut Number: 9						
Cut Number: 10						
Totals	**2,201.28**	**371,360.70**	**N/A**	**1,471.52**	**192,024.00**	**N/A**
Averages	**550.32**	**92,840.18**	**N/A**	**367.88**	**48,006.00**	**N/A**
Yield Per 1000m2		**168.70**	**N/A**		**130.49**	**N/A**
Average Overrides (User-Defined Areas & Yields)						
Calculated or Overridden Averages Per 1000 m2	**2,201.28**	**168.70**		**1,471.52**	**130.49**	
	Cut & Collect Process Emissions (kgCO2e Per 1000m²)					
	Quantity	**EF**	**Total**	**Quantity**	**EF**	**Total**
Diesel for Plant Transportation (litres)	**0.7808**	3.2856	**2.57**	**0.0000**	3.2856	**0.00**
Diesel for Feedstock Transportation to depot (litres)	**0.4824**	3.2856	**1.58**	**2.2399**	3.2856	**7.36**
Resource Days (Staff & Contractors) (FTE Day)	**0.1758**	2.3360	**0.41**	**0.1821**	2.3360	**0.43**
Diesel for Mowers (litres)	**1.7619**	3.2856	**5.79**	**2.9942**	3.2856	**9.84**
HVO for Mowers (litres)	**1.5602**	0.3140	**0.49**		0.3140	**0.00**
Petrol for Strimmers (litres)	**0.2615**	2.9517	**0.77**		2.9517	**0.00**
Energy for Strimmers (Rechargeable Battery Packs) (kWh)		0.2749	**0.00**		0.2749	**0.00**
Strimmer 2-Stroke Oil (litres)		3.1443	**0.00**		3.1443	**0.00**
Total C&C Process Emissions Per 1000m2 (kgCO2e)			**11.61**			**17.62**
Total Process Emissions for Exp Area (Selected Cuts, kgCO2e)			**25,560.63**			**25,931.88**

Cultivation and harvesting summary

e_{ec}, the emissions from the extraction or cultivation of feedstock. Includes the seed, chemical, fuel and fertiliser, relevant to all operations necessary to prepare the land, establish, manage and harvest the crop.

This stage includes emissions from fuel use in plant, mowers and strimmers, emissions from the production of fertilisers, in-field nitrous oxide emissions from fertiliser application. This stage also includes fossil fuel emissions from diesel use in plant transportation to the site and to the depot, diesel or HVO to mowers, petrol or energy for strimmers, and oil for strimmers.

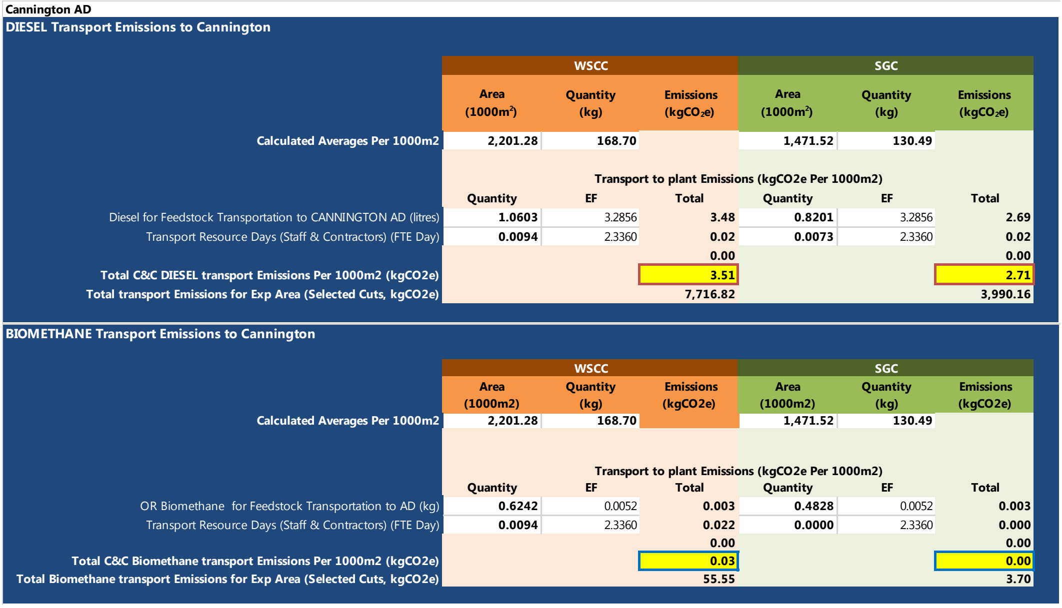
In the case of verge side grass, initial grass seed is deemed negligible and excluded. In contrast to other feedstock, e.g., maize. NO fertiliser is applied to establish and manage the grass crop. Yield is reported on a fresh tonne basis, as harvested.

Calculating emissions from grass collected

Where the land (soil) has been significantly improved by changes in agricultural management, such as cut-and-collect, this is accounted for in greenhouse gas emissions under soil carbon, e_{sca}.

Annex D - Transport (to AD or Biochar plant)

e$_{td,feedstock,n}$ is the emissions from transport of feedstock n to the digester.



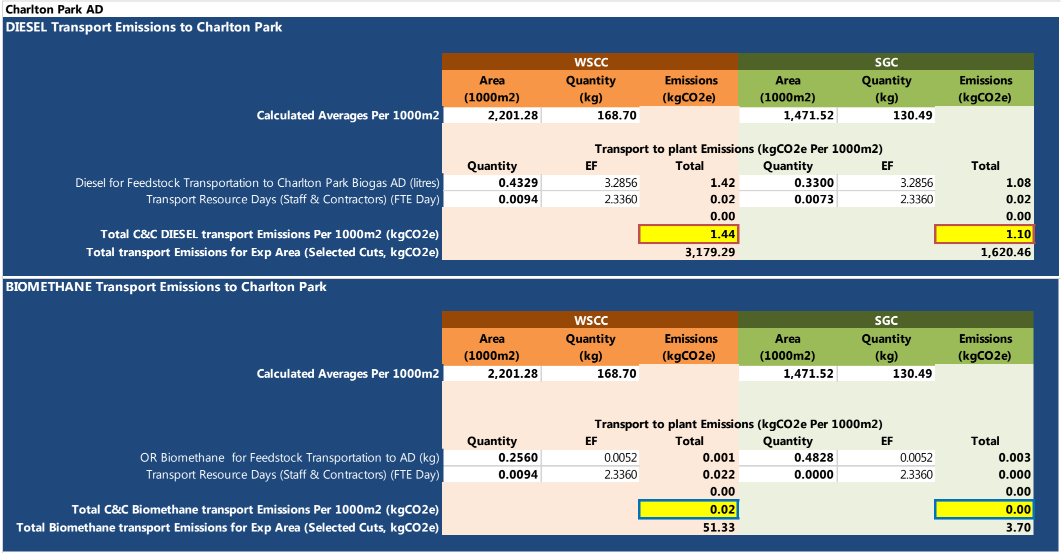
Cannington AD

DIESEL Transport Emissions to Cannington

	WSCC			SGC		
	Area (1000m^2)	Quantity (kg)	Emissions (kgCO$_2$e)	Area (1000m^2)	Quantity (kg)	Emissions (kgCO$_2$e)
Calculated Averages Per 1000m2	2,201.28	168.70		1,471.52	130.49	
	Transport to plant Emissions (kgCO2e Per 1000m2)					
	Quantity	EF	Total	Quantity	EF	Total
Diesel for Feedstock Transportation to CANNINGTON AD (litres)	1.0603	3.2856	3.48	0.8201	3.2856	2.69
Transport Resource Days (Staff & Contractors) (FTE Day)	0.0094	2.3360	0.02	0.0073	2.3360	0.02
			0.00			0.00
Total C&C DIESEL transport Emissions Per 1000m2 (kgCO2e)			3.51			2.71
Total transport Emissions for Exp Area (Selected Cuts, kgCO2e)			7,716.82			3,990.16

BIOMETHANE Transport Emissions to Cannington

	WSCC			SGC		
	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)
Calculated Averages Per 1000m2	2,201.28	168.70		1,471.52	130.49	
	Transport to plant Emissions (kgCO2e Per 1000m2)					
	Quantity	EF	Total	Quantity	EF	Total
OR Biomethane for Feedstock Transportation to AD (kg)	0.6242	0.0052	0.003	0.4828	0.0052	0.003
Transport Resource Days (Staff & Contractors) (FTE Day)	0.0094	2.3360	0.022	0.0000	2.3360	0.000
			0.00			0.00
Total C&C Biomethane transport Emissions Per 1000m2 (kgCO2e)			0.03			0.00
Total Biomethane transport Emissions for Exp Area (Selected Cuts, kgCO2e)			55.55			3.70



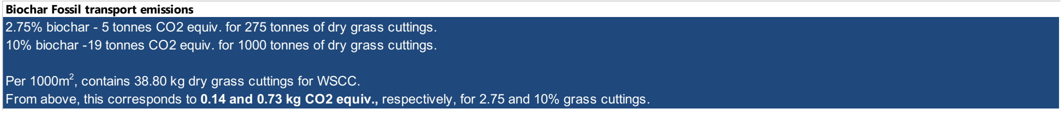
Charlton Park AD

DIESEL Transport Emissions to Charlton Park

	WSCC			SGC		
	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)
Calculated Averages Per 1000m2	2,201.28	168.70		1,471.52	130.49	
	Transport to plant Emissions (kgCO2e Per 1000m2)					
	Quantity	EF	Total	Quantity	EF	Total
Diesel for Feedstock Transportation to Charlton Park Biogas AD (litres)	0.4329	3.2856	1.42	0.3300	3.2856	1.08
Transport Resource Days (Staff & Contractors) (FTE Day)	0.0094	2.3360	0.02	0.0073	2.3360	0.02
			0.00			0.00
Total C&C DIESEL transport Emissions Per 1000m2 (kgCO2e)			1.44			1.10
Total transport Emissions for Exp Area (Selected Cuts, kgCO2e)			3,179.29			1,620.46

BIOMETHANE Transport Emissions to Charlton Park

	WSCC			SGC		
	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)	Area (1000m2)	Quantity (kg)	Emissions (kgCO2e)
Calculated Averages Per 1000m2	2,201.28	168.70		1,471.52	130.49	
	Transport to plant Emissions (kgCO2e Per 1000m2)					
	Quantity	EF	Total	Quantity	EF	Total
OR Biomethane for Feedstock Transportation to AD (kg)	0.2560	0.0052	0.001	0.4828	0.0052	0.003
Transport Resource Days (Staff & Contractors) (FTE Day)	0.0094	2.3360	0.022	0.0000	2.3360	0.000
			0.00			0.00
Total C&C Biomethane transport Emissions Per 1000m2 (kgCO2e)			0.02			0.00
Total Biomethane transport Emissions for Exp Area (Selected Cuts, kgCO2e)			51.33			3.70



Biochar Fossil transport emissions

2.75% biochar - 5 tonnes CO2 equiv. for 275 tonnes of dry grass cuttings.
10% biochar -19 tonnes CO2 equiv. for 1000 tonnes of dry grass cuttings.

Per 1000m^2, contains 38.80 kg dry grass cuttings for WSCC.
From above, this corresponds to **0.14 and 0.73 kg CO2 equiv.**, respectively, for 2.75 and 10% grass cuttings.

Annex E - Land use change emissions

e$_{ln}$ is the annualised emissions from carbon-stock changes caused by land use change for feedstock n

This should only be used if a change in land use has occurred, where land use is defined by the IPCC as forest land, grassland, cropland, wetlands, settlements, and other land. In this case, the land's carbon stock before land-use change (CS Reference) and current carbon stock (CSActual) can be used in order to calculate emissions or emissions savings from land-use change.

In Greenprint, no change in land use has occurred so this value is 0

Land criteria restricts the use of biomass sourced from land with high biodiversity or high carbon stock value such as primary forest, peatland or wetland.

Annex F - Calculating the emissions from soil carbon accumulation

e_{sca} is the annualised greenhouse gas emissions savings from improved agricultural management of feedstock (measured as mass of CO_2-equivalent per hectare).

Where crop (grass) cultivation is carried out on land significantly improved by changes in agricultural management, (from cut and leave to cut and collect), carbon savings can be taken into account if solid and verifiable evidence is provided that the soil carbon has increased or that it is reasonable to expect to have increased over the period in which the raw materials (grass) were calculated.

The analysis of land carbon stocks draws on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4[1], which serves as the basis for the calculation of land carbon stocks.

Consignment name	$CS_{Reference}$ t_{carbon}/ha	CS_{Actual} t_{carbon}/ha	Time period Years	e_{sca} t/ha	e_{sca} $kg_{carbon}/1000m^2$
Greenprint Cut & Collect	42.5	45.88	20	-0.619	-61.922

Calculating emissions from soil carbon accumulation

Where the land has been significantly improved by changes in agricultural management, such as cut-and-collect, this should be accounted for in greenhouse gas emissions under soil carbon, e_{sca}.

e_{sca} = 3.664 x (CSR-CSA)/20

e_{sca} = annualised greenhouse gas emissions from improved agricultural management of feedstock, in this case, moving from cut and collect and cut and leave (measured as mass of CO_2-equivalent per hectare).

3.664 is the conversion factor to convert the mass of carbon into carbon dioxide, obtained by dividing the molecular mass of carbon dioxide by the molecular mass of carbon, 44.01 / 12.011. The number has no units.

C_{SR} = is the carbon stock per unit area associated with the reference land use (measured as tonnes of carbon per hectare, including both soil and vegetation). As the emissions are annualised over 20 years, the reference year must be 20 years before the actual year.

C_{SA} = is the carbon stock per unit area associated with the actual land use (measured as tonnes of carbon per hectare, including both soil and vegetation).

In cases where the soil carbon stock accumulates over more than one year, the value attributed to C_{SA} shall be the estimated stock per unit area after 20 years.

For Greenprint, CSR is the measured (deep) carbon stock per unit area in the first year of the study (2024). Values for soil organic carbon, and therefore carbon stock, were obtained through laboratory measurements. In February 2024, shallow soil samples tend to contain a higher soil carbon content. Shallow soils (to 30cm) contain, on average, 75t/ha organic C in W Sussex and 100t/ha organic C in S Glos.
Deep soil samples (samples between 30-60cm where depth permits) held an average of 40-45t/ha organic C in both counties. To take into account the entire depth of the organic soil layer and for robust carbon auditing, the average carbon stock per unit measured from deep soil is used, giving a C_{SR} value of 42.5t/ha.

For Greenprint, C_{SA} is the estimated (deep) carbon stock per unit area in the study year 2044. Values for soil organic carbon, and therefore carbon stock, were obtained through extrapolation, with an expected upper limit of increase of carbon sequestration of 0.26 t C ha^{-1} y^{-1} for the first 6 years, followed by half this (0.13 t C ha^{-1} y^{-1}) for the next 14 years, giving a CSA value of 45.88t/ha.

e_{sca} = 3.664 x (42.5-45.88)/20 = -0.619 t/ha

Moving to the functional units of the study ($kg/1000m^2$) gives a value of -61.92 kg C/1,000m^2 annualised greenhouse gas emissions from improved agricultural management of feedstock, in this case, moving from cut and collect and cut and leave (measured as mass of CO_2-equivalent per 1000m^2).

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[1] 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4 https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Annex G - Feedstocks

The GHG reporting requirements depend on the feedstock category.

Consignment name	Average yield kg/1000m^2/year	Average yield Tonnes/h/year	Feedstock dry matter content (%)*	Volatile solid content (% of dry matter)	Biomethane yield (Nm3/t volatile solid)
WSCC grass	168.70	1.69	23	90	310
SGC grass	130.49	1.30	23	90	310
SGC food waste[1]	521.96	5.22	35	92	450

Products and co-products. When using products and co-products, GHG reporting must cover the full supply chain, from cultivation to biogas upgrading.

Residues. When using residues, it is usually not possible to determine the emissions associated with their generation, so emissions are only counted from the point of collection.

Wastes (excluding manures). When using wastes, it is usually not possible to determine the emissions associated with their generation, so emissions are only counted from the point of collection.

Manures. Manures are wastes, but as their use is associated with a carbon credit, they are handled separately in this section of the carbon calculator.

Ineligible for GGSS. Feedstocks may be ineligible for GGSS, i.e. if they fall outside the definition of sustainable biomethane listed in the GGSS Regulations (i.e. liquid non-wastes). The category of each feedstock must be approved by Ofgem on each site’s Fuel Measurement and Sampling Questionnaire (FMSQ).

In the Greenprint project, two feedstocks were considered. Firstly, grass, and secondly, food waste (in AD).

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[1] Food waste yield calculated based on 20%, 80% mix

Annex H - Digestion and outputs

e_p is the emissions from processing [digestion and outputs]
This includes emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing, including the carbon dioxide emissions corresponding to the carbon contents of fossil inputs, whether or not actually combusted in the process, and emissions from processing biogas into biomethane. All values should be supported by meter readings, where appropriate.

Based on the trial AD plant setup, following the GGSS standard questions, the biomethane Pathway emissions (gCO2eq/MJ biomethane) were calculated as 26.85.

Plant setup

Is a biogas boiler used to generate heat?	yes
Is a biogas CHP used?	yes
Is a natural gas boiler used to generate heat?	no
Is a natural gas CHP used?	no
Is a diesel generator used	no
Is the digestate storage covered or open	covered
Do you measure total crude biogas generation	yes

Total biogas generated

	Unit	Value	Energy (MJ$_{LHV}$)
Total biogas generated	Nm^3	12030000	241,081,200
% methane in biogas	%	60%	

Biomethane Injected

	Unit	Value	Energy (MJ$_{LHV}$)
Total gas injected into grid	kWh (GCV o	48180000	156,103,200
Propane to be deducted	kWh (GCV o	963600	3,122,064
Biomethane injected into grid	kWh (GCV o	4721640000	152,981,136

Fugitive methane emissions as part of the GHG Calculation Methodology.[1]

Methane leak (digestate)

Use standard or actual methane leak for digestate?	Covered	Open	Actual	Value
Standard (Covered)	0.0%	6%		

Methane leak (digestion)

Use standard or actual methane leak for digestion?	LDAR	Open	Actual	Value
Standard (LDAR)	1%	20%	1.56%	

gCO2eq/MJ biomethane	**26.85**

WSCC yield/1000m^2	168.70
SGC yield/1000m^2	130.49

WSCC Grass Biomethane yield Nm^3	47.07	WSCC Food Biomethane yield Nm^3	69.84
SSC Grass Biomethane yield Nm^3	36.41	SSC Food Biomethane yield Nm^3	54.02

WSCC Grass Energy content	1873.30	WSCC food energy content	2779.74	74.64
SGC Grass Energy content	1448.99	SGC food energy content	2150.11	57.73

WSCC emissions 100% grass	50.30	WSCC emissions 20% grass & 80% f	69.77
SGC emissions 100% grass	38.91	SGC emissions 20% grass & 80% f	53.97

Digestion and outputs summary

This stage builds upon a calculator designed to reflect the most common AD configurations in Great Britain, based on existing facilities commissioned under GGSS predecessor support schemes and knowledge of planned GGSS developments, with consideration of expected future changes and improvements. However, because every AD site is bespoke in its inputs, processes, and outputs, it will become evident that not all possible configurations are represented from the outset. This is based on the theoretical biomethane yield of each feedstock and the volumes used.

Glossary

CHP	combined heat and power unit, providing heat and electricity from biogas or other fuels.
CH_4	Methane, a greenhouse gas.
CO_2	Carbon dioxide, a greenhouse gas.
CO_2eq	Carbon dioxide equivalents (relating to the global warming potential).
(FMSQ)	Fuel, Measurement and Sampling Questionnaire
DM	Dry matter, typically in the context of dry matter content, the percentage of feedstock that is not moisture.
EHO	'Eligible Heat Output' calculated by gas injected to the grid minus propane blended and any external heat supplied to the biogas production process.
g	grams, a unit of mass.
GHG	greenhouse gas; for the purposes of this calculator, this is carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
GGSS	Green Gas Support Scheme.
kWh	Kilowatt hour, a unit of energy. There are 3.6 MJ in a kWh.
Methane leak	the unintended release of methane regardless of the duration of the release.
Methane slip	in the context of biogas upgrading, slip refers to the release or loss of methane from the upgrading units, typically through the off-gas stream, resulting from inefficiencies in the separation of methane contained in biogas.
m^3	Cubic meters, a unit of volume.
MJ	Megajoule, a unit of energy. There are 3.6 MJ in a kWh.
N_2O	Nitrous oxide, a greenhouse gas.
SGC	South Gloucestershire Council
VS	Volatile solids, typically in the context of volatile solids content, the percentage of feedstock that is not moisture or ash/inorganic matter.
WSCC	West Sussex County Council