The Bioeconomy Consultants

NNFCC

Assessment of impact on biogas producers of proposed changes to sustainability criteria

Project Number: 16-015.6

February 2016

A report for DECC

Author(s)

Michael Goldsworthy

Reviewer(s)

Lucy Hopwood

Disclaimer

NNFCC

NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and bio-based products.

NNFCC, Biocentre,
York Science Park,
Innovation Way,
Heslington, York,
YO10 5DG.

Phone: +44 (0)1904 435182
Fax: +44 (0)1904 435345
E: enquiries@nnfcc.co.uk
Web: www.nnfcc.co.uk

Contents

1 Introduction

1.1 Objectives

Sustainability criteria were introduced in the RHI in October 2015 and are now being considered for the FIT Scheme. DECC wishes to align the criteria across schemes and is trying to understand, in the interests of achieving maximum value for money and decarbonisation at least cost, what the impact on biogas and biomethane producers would be if the GHG limit were tightened or the underlying assumptions changed. DECC wish to understand:

- What the impacts are of applying alternative fossil-fuel comparators for biomethane and biogas combustion
- What the impacts are of applying alternative end-use efficiency assumptions for biomethane and biogas combustion
- The costs/benefits of harmonising the lifecycle GHG emissions limit between schemes
- The extent to which farm AD plants are resilient to fluctuations in crop yield
- The key factors which could drive industry behaviour towards lowest carbon abatement costs

1.2 Methodology

1.2.1 GHG thresholds

NNFCC first established a range of potential GHG thresholds for the modelling. These thresholds were based on the existing criteria under the RHI (60% GHG saving on an EU fossil heat comparator of 87gCO_{2eq}/MJ) and RO (60% GHG saving on an EU electricity comparator of 198gCO_{2eq}/MJ) and a recent communication from the Commission on the "State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU"[1], which suggested new, marginal fossil fuel comparators for electricity (186gCO_{2eq}/MJ), heat (80gCO_{2eq}/MJ) and biomethane (72gCO_{2eq}/MJ) and indicated that at least a 70% GHG saving should be targeted by biomass energy facilities, with further improvement made post-2020.

Thresholds are outlined in Table 1.

[1] http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf

Table 1. GHG thresholds for anaerobic digestion

Output	GHG saving and comparator	Threshold (gCO_{2eq}/MJ)	Matrix colour code
Biomethane GHG threshold	Above threshold		>34.8
	60% saving at 87gCO_{2eq}/MJ	34.8	>28.8-34.8
	60% saving at 72 gCO_{2eq}/MJ	28.8	>26.1-28.8
	70% saving at 87gCO_{2eq}/MJ	26.1	>21.6-26.1
	70% saving at 72gCO_{2eq}/MJ	21.6	>17.4-21.6
	80% saving at 87gCO_{2eq}/MJ	17.4	>14.4-17.4
	80% saving at 72gCO_{2eq} /MJ	14.4	<=14.4
Electricity GHG threshold	Above threshold		>79.2
	60% saving at 198gCO_{2eq}/MJ	79.2	>74.4-79.2
	60% saving at 186gCO_{2eq}/MJ	74.4	>59.4-74.4
	70% saving at 198gCO_{2eq}/MJ	59.4	>55.8-59.4
	70% saving at 186gCO_{2eq}/MJ	55.8	>39.6-55.8
	80% saving at 198gCO_{2eq}/MJ	39.6	>37.2-39.6
	80% saving at 186gCO_{2eq}/MJ	37.2	<=37.2
Heat GHG threshold	Above threshold		>34.8
	60% saving at 87gCO_{2eq}/MJ	34.8	>32.0-34.8
	60% saving at 80gCO_{2eq}/MJ	32	>26.1-32.0
	70% saving at 87gCO_{2eq}/MJ	26.1	>24.0-26.1
	70% saving at 80gCO_{2eq}/MJ	24	>17.4-24.0
	80% saving at 87gCO_{2eq}/MJ	17.4	>16.0-17.4
	80% saving at 80gCO_{2eq}/MJ	16	<=16.0

1.2.2 Default supply chains

NNFCC established a set of default supply chains for injection of biomethane, export of electricity and heat (from a gas CHP), export of electricity only (from a gas CHP) and export of heat only (from a gas boiler) in its 'Anaerobic Digestion Carbon Calculator'. It should be noted that AD operators typically install a heat recovery system when generating electricity, regardless of whether there is a local demand for heat suitable for claiming incentives. This is because the anaerobic digester has a relatively large heat demand[2] that is more economical to supply using the heat output from the engine as opposed to a grid natural gas supply.

Five crop groups were modelled: grass silage, sugar beet, maize, wholecrop rye and wholecrop wheat. Default values for these chains were established based on those contained within Ofgem's UK Solid and Gaseous Biomass Carbon Calculator - Version 2.0, build 36

[2] Known as the parasitic heat demand for the process, which is not suitable for claiming incentives

(B2C2)[3]. Conservative factors used in processing modules to encourage operator use of actual values were removed to ensure that supply chain emissions were not overestimated.

Notable attention was given to biogas output values from digestion to ensure correlation. This was important because the B2C2 is structured such that the biogas yield from digestion represents net yield (i.e. all output is used downstream for biomethane/combustion) rather than gross yield (i.e. output is split between downstream use and internal energy requirements). Once default supply chains were established in the 'Anaerobic Digestion Carbon Calculator' they were compared against those within B2C2 to ensure consistency.

For biogas combustion supply chains where default values for end use efficiency and final product use were unavailable, typical industry values were used. These values included:

- Electrical CHP efficiency of 35%
- Thermal CHP efficiency of 40%
- Thermal boiler efficiency of 85%
- Temperature of delivered heat of 150°C[4]
- All potential exportable heat from CHP (for "CHP; electricity and heat" scenarios) is used in valid process

1.2.3 Sensitivities

Once default supply chains were established in the calculator a range of variables were modelled in an independent manner to analyse their impact on overall supply chain emissions when compared to the relevant default chain.

A complete list of the variables analysed for each anaerobic digestion output technology is shown in Table 2. Further details on the crop-specific variables and underlying calculations are provided in the 'Variables calculations' worksheet of the complementing Microsoft Excel file.

Table 2. Variables for sensitivity analysis

Variable	Scenario	Value
All outputs		
Crop yield	Default	B2C2 default yield
	High	+20%
	Low	-20%
	Very Low	-50%
Fertiliser application	Default	B2C2 default yield
	High	+20% Nitrogen application

[3] https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator
[4] While ordinarily delivered heat will be of a lower temperature than 150°C, this temperature is used as a minimum value for emission allocations between heat and power, in accordance with RHI guidance

Variable	Scenario	Value
	Low	-20% Nitrogen application
Transport distance	Default High	20 km 50 km
Biomethane		
Carbon capture	Default Partial CO_2 capture CO_2 capture	No CO_2 capture 50% CO_2 captured[4] All CO_2 captured[5]
Digestate storage	Default (closed) Open	Digestate emissions contained Digestate emissions emitted[6]
Methane slip	Default Low (off gases oxidised) High (off gases not oxidised)	2% 0% 3%
Digestate drying (with co-product allocation to digestate)	Default (not dried) Mechanically separated Dried	12% dry matter 40% dry matter 90% dry matter
Co-digestion approach (including methane credit for manures)	High crop/low manure Equal crop and manure Low crop/high manure	80% crop/20% manure (by mass) 50% crop/50% manure (by mass) 20% crop/80% manure (by mass)
Electricity and heat (CHP)		
CHP electrical efficiency	Typical High Low	35% 40% 30%
CHP thermal efficiency	Typical High Low	40% 45% 35%
Heat utilisation	Typical High Medium Low	100% exportable heat utilised 75% exportable heat utilised 50% exportable heat utilised 25% exportable heat utilised
Electricity (CHP)		
Electrical CHP efficiency	Typical High Low	35% 40% 30%
Co-digestion approach (including methane credit for manures)	High crop/low manure Equal crop and manure Low crop/high manure	80% crop/20% manure (by mass) 50% crop/50% manure (by mass) 20% crop/80% manure (by mass)

[5] Assumes 39.1gCO_{2eq}/$MJ_{biomethane}$ of CO_2 captured (60% CH_4 and 40% CO_2 in biogas by volume)
[6] Assumes 16.4gCO_{2eq}/MJ_{biogas}, based on 80% of biogas used for injection and value of 13.1gCO_{2eq}/MJ_{biogas} storage emission (default from Biograce II for maize)

Variable	Scenario	Value
Heat (boiler)		
Boiler thermal efficiency	Typical	85%
	High	90%
	Low	80%

Values for each scenario were chosen to represent the range of variance in typical industry practices and in performance of anaerobic digestion equipment.

While for the majority of the variables the means by which they will impact supply chain emissions is clear, there are some variables that will impact supply chains emissions by more indirect means. These include:

- **Digestate drying** – According to the methodology adopted under the Renewable Energy Directive, upstream supply chain emissions should be allocated to products and co-products of a multi-output process based on their respective absolute energy contents. There is currently very little guidance on whether digestate should be treated as a co-product or as a process residue. In the event digestate can be considered a co-product, supply chain emissions can be allocated from the biogas to the digestate, thereby reducing emissions of the resulting biogas product (i.e. biomethane/heat/electricity). However, the energy in the digestate depends upon its moisture content. At 88% moisture digestate is calculated to have no energy when using the CEN approach for determining the calorific values of fuels. However, digestate at 0% moisture has an energy content of 17.83 MJ/kg[7]. Consequently, drying digestate can increase its energy content and thereby reduce the supply chain emissions allocated to the biogas product. In order for such an allocation to be allowed the digestate should not be reused within the same supply chain e.g. as a fertiliser, on account that digestate is provided with a zero emissions factor.
- **Co-digestion approach** – Under the RHI, supply chain emissions for anaerobic digestion technologies should be calculated for each individual consignment. For co-digestion plants using multiple feedstocks, plant outputs should be allocated to each feedstock based on their respective biogas production potentials. As such, any out-of-specification consignment will not meet the GHG threshold. However, the Commission has announced its intention to adopt an alternative methodology for anaerobic digestion plants, whereby supply chain emissions are averaged across feedstocks based on their respective biogas production potentials[8]. This results in a single GHG intensity for the biomethane produced, rather than multiple GHG intensities for each feedstock used in the plant. This would mean that out-of-

[7] B2C2
[8] http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf

specification consignments could be balanced against consignments that perform well below the threshold to enable all output to comply with the sustainability criteria. This is notably important when considering the potential savings that can be achieved through utilisation of manures/slurries, with the Commission proposing a GHG credit of 45.05gCO_{2eq}/MJ manure.

2 Outputs

2.1 Biomethane

Default pathways: Supply chain emissions for default grass silage and wholecrop wheat pathways exceed the existing GHG threshold under the RHI of 34.8gCO_{2eq}/MJ. Meanwhile, wholecrop maize and rye default supply chains would not meet any of the more stringent thresholds assessed in this study. The default chain for sugar beet would meanwhile be able to achieve a 70% GHG saving at the current fossil fuel comparator of 87gCO_{2eq}/MJ, though not this level of saving on the 80gCO_{2eq}/MJ proposed by the Commission.

Default values should be considered as somewhat conservative given that they should encourage the use of actual data. However, based on NNFCC experience in modelling GHG emission from anaerobic digestion these values should be fairly representative, possibly in the region of 5-15% higher than typical GHG intensities.

These supply chains assume that grid electricity is used for upgrading and injecting the biomethane into the grid. In many instances it is likely that onsite CHP will be used for this purpose, thereby lowering the GHG intensity of the electricity requirement. However, this would result in a consequential loss in yield that is roughly equivalent, from a GHG perspective, as the use of grid electricity.

Crop yield: An increased crop yield of 20% would enable all pathways to meet the highest GHG threshold of 34.8gCO_{2eq}/MJ, although only maize and sugar beet would be able to meet any of the higher thresholds assessed. Maize would meet a threshold of 28.8gCO_{2eq}/MJ, representing a 60% GHG saving on 80gCO_{2eq}/MJ fossil fuel comparator proposed by the Commission, while sugar beet would continue to meet the 26.1 gCO_{2eq}/MJ threshold.

A reduced crop yield of 20% would prevent all but maize and sugar beet meeting the highest 34.8 gCO_{2eq}/MJ threshold, while a 50% reduction would prevent all crops assessed meeting this target.

Fertiliser application: An increased fertiliser application of 20% would prevent the majority of crop supply chains assessed from meeting the 34.8gCO_{2eq}/MJ threshold, with again only maize and sugar beet meeting the target.

Meanwhile, a reduced fertiliser application of 20% would have much the same impact on supply chain emissions as a 20% increase in crop yield, with all pathways meeting the 34.8 gCO_{2eq}/MJ threshold but only maize and sugar beet able to perform below any of the lower targets.

Assuming a high fertiliser application rate has a very similar impact on pathway GHG emissions as a low crop yield, as does assuming a low fertiliser application rate compared to a high crop yield. This is because the relative use of nitrogen per tonne of feedstock is the most important factor in determining cultivation emissions.

Carbon capture: Carbon capture provides operators with a huge opportunity to reduce supply chain emissions. If all CO_2 produced during upgrading was captured and either stored or used in a useful process, not only would operators be able to meet all of the assessed thresholds but they would be able to achieve GHG savings in excess of 100%.

If only 50% of CO_2 captured could be used usefully then sugar beet, maize and rye would achieve all GHG thresholds assessed, grass silage could achieve the 21.6 CO_2 threshold (70% GHG saving on the 80gCO_{2eq}/MJ comparator), and wheat would achieve the 17.4 gCO_2/MJ target (80% GHG saving on the 87 gCO_{2eq}/MJ comparator).

Digestate storage: Closed digestate storage is likely to be necessary in order for any crop to meet the sustainability criteria, with open storage preventing any of the pathways from meeting the highest GHG threshold. However, this factor is unlikely to have a significant bearing on industrial practices as closed digestate storage is already common practice in the UK.

Transport: Feedstock transport distances have a very minor bearing on supply chain emissions. Increasing transport distances from 20km to 50km has no bearing on the thresholds achieved by the default chains, only adding 0.6-0.7gCO_{2eq}/MJ of biomethane to overall supply chain emissions.

Methane leakage: Fugitive methane emissions make a significant contribution towards overall supply chain emissions, with the default values of 1% slip for fermentation and 1% slip for upgrading contributing just under 10gCO_{2eq}/MJ.

If no methane slip is assumed – as would be the case using the Biograce II default for the majority of technologies that ensure off-gases are oxidised through flaring or catalytic oxidation - rye and wheat chains would meet a 26.1gCO_{2eq}/MJ threshold, maize would meet a 21.6gCO_{2eq}/MJ threshold, sugar beet would meet a 17.4gCO_{2eq}/MJ while grass silage would only just exceed the 28.8gCO_{2eq}/MJ target.

Meanwhile, if we assume 3% methane slip – representing the default value in Biograce II if off-gases are not oxidised – only sugar beet and maize chains would be able to meet the 34.8gCO_{2eq}/MJ threshold.

Digestate drying: Mechanical separation of digestate to 40% dry matter would enable operators to allocate 25% of supply chain emissions to the digestate. This would enable all feedstocks assessed to meet the 34.8gCO_{2eq}/MJ threshold, with rye also meeting the 28.8gCO_{2eq}/MJ target and sugar beet and maize meeting the 26.1gCO_{2eq}/MJ threshold

Thermal treatment (drying) of digestate to 10% moisture increases the allocation to 38% and would mean that all feedstock would meet the 26.1gCO_{2eq}/MJ threshold with the exception of grass silage, which would still meet the 28.8gCO_{2eq}/MJ target.

Co-digestion: Co-digestion of crops with manures could have a huge bearing on calculation of lifecycle emissions provided the Commission recommendations on this matter are accounted for. Use of manures and slurries allows operators to claim a very significant GHG credit of -45.05gCO_{2eq}/MJ manure due to mitigated CH_4 and N_2O emissions (i.e. emissions that would have otherwise been emitted to the atmosphere if the waste was left on the field). This credit would allow a plant utilising 80% manure and 20% crop to achieve in excess of a 100% GHG saving, regardless of the crop used.

A 50:50 split would enable a plant to achieve a 26.1gCO_{2eq}/MJ threshold, with rye, maize and sugar beet all capable of meeting higher targets when used alongside manure. For a plant that uses 80% crop and 20% manure, only the 34.8gCO_{2eq}/MJ threshold would be met for grass, wheat and rye, while maize and sugar beet could achieve slightly higher GHG savings.

It should be noted that while these scenarios are fixed based on input, the output would be vastly different. A 20,000 tonne plant using 80% manures and 20% maize would produce around 6,000MWh biomethane annually, while a plant of the same input capacity utilising 80% crop and 20% manures would produce almost 17,000MWh biomethane. This is because manure produces far less biogas per tonne than crop feedstock.

Lowest potential scenario: To evaluate the maximum possible GHG savings that an operator might be able to achieve using crops alone, a scenario was run assuming no methane leakage, drying of digestate to 10% moisture, high crop yields and carbon capture from upgrading. In this eventuality, operators would achieve carbon savings well in excess of 100% (-21.4 to -27.8gCO_{2eq}/MJ).

For operators that utilise manures alone, it would be possible to achieve GHG savings in excess of 200% (-171.3gCO_{2eq}/MJ), depending on the fossil comparator used and providing that all internal energy requirements are provided by onsite CHP.

Carbon intensities and achievable thresholds for all biomethane supply chains under all scenarios are shown in Table 3.

Table 3. GHG intensities of crop supply chains for production of biomethane via anaerobic digestion (all values in gCO_{2eq}/MJ biomethane). Colour codes are shown in Section 1.2.1.

		Grass	Sugar beet	Maize	Rye	Wheat
Default		38.1	25.8	29.5	33.2	35.3
Crop yield	High	34.4	24.1	27.2	30.3	32.0
	Low	43.7	28.5	33.0	37.6	40.3
	Very Low	60.5	36.3	43.4	50.8	55.1
Fertiliser application	High	42.1	26.8	31.7	35.7	38.4
	Low	34.1	24.9	27.3	30.7	32.2
Carbon capture	All CO_2 captured	-1.4	-13.7	-10.0	-6.3	-4.2
	50% CO_2 captured	18.4	6.1	9.7	13.4	15.6
Digestate storage	Open	54.5	42.2	45.9	49.6	51.7
Transport	High	38.8	26.5	30.1	33.8	35.9
Methane leakage	Low	28.8	16.5	20.2	23.9	26.0
	High	42.6	30.3	34.0	37.7	39.8
Digestate drying	Mechanically separated	31.2	22.0	24.7	27.5	29.1
	Dried	27.6	19.9	22.2	24.5	25.8
Co-digestion	80% crop/20% manure	33.7	21.8	26.1	29.8	31.9
	50% crop/50% manure	21.7	11.0	16.8	20.4	22.4
	20% crop/80% manure	-12.2	-19.9	-11.1	-7.8	-6.3
Lowest crop scenario	Carbon capture/digestate dried/high yield/0% methane leakage	-21.4	-27.8	-25.9	-24.0	-22.9

2.2 CHP; electricity only

Default pathways: All default pathways for production of electricity from anaerobic digestion (35% electrical efficiency; no exported heat) would meet the current GHG threshold under the RO for plants operating prior to April 2013 of 79.2gCO_{2eq}/MJ. Wholecrop rye and wheat would be able to meet a 60% GHG saving on the proposed EU fossil comparator for electricity (74.4gCO_{2eq}/MJ). However, wheat – along with grass silage -would not meet the current threshold under the RO for 'post-2013 dedicated biomass stations' of 66.7gCO_{2eq}/MJ. Maize and sugar beet would offer further improvements, able to meet a 70% GHG saving on the proposed EU fossil comparator (55.8gCO_{2eq}/MJ threshold).

Crop yield: High crop yields (+20%) would enable all crops to meet a 74.4gCO_{2eq}/MJ threshold, with grass silage, wholecrop wheat, rye and sugar beet all able to meet a higher GHG threshold than their respective default chains.

In the event of a low crop yield (-20%), neither grass nor wheat would meet the RO GHG threshold. Wholecrop rye would only just achieve this target, while maize and sugar beet would continue to meet lower thresholds. A very low yield (-50%) would prevent all but sugar beet from meeting the highest GHG threshold assessed.

Fertiliser application: A high nitrogen fertiliser application rate (+20%) would prevent wholecrop rye and grass from meeting the RO GHG threshold, while sugar beet, maize and rye would continue to meet a 74.4gCO_{2eq}/MJ target. Meanwhile, a low fertiliser application rate would enable all pathways to achieve the 74.4gCO_{2eq}/MJ threshold, with sugar beet, maize and rye all capable of meeting lower thresholds. In similarity to the impact on biomethane supply chains, a high fertiliser impact has a very similar impact on GHG emissions as assuming a low crop yield (and vice versa).

Transport: Increasing feedstock transport distances to 50km has a small impact on overall supply chain emissions. However, the default chain for grass silage is close enough to the current RO GHG threshold that a high transport distance would push supply chain emissions above the 79.2gCO_{2eq}/MJ target.

Co-digestion: Co-digestion would have a significant impact on the GHG performance of anaerobic digestion plants producing electricity, provided that the Commission approach is adopted. Any plant using 50% manures (by mass) and above would meet the lowest threshold of 37.2gCO_{2eq}/MJ regardless of crop used; use of 80% manures would achieve carbon savings well in excess of 100%. At 20% manure and 80% crop grass and wheat would only meet the 74.4gCO_{2eq}/MJ threshold, maize and rye the 55.8gCO_{2eq}/MJ threshold and sugar beet the lowest 37.2gCO_{2eq}/MJ target.

End use efficiency: A high end use electrical efficiency (40%) typically reduces supply chain GHG intensities by around 10-20gCO_{2eq}/MJ. The vast majority of scenarios would then meet a GHG threshold of 74.4gCO_{2eq}/MJ with the exception of those assuming very low crop yields.

Conversely, poor end use efficiency (30%) will typically add 10-20gCO_{2eq}/MJ to overall emissions, preventing the majority of grass silage and wheat supply chains meeting the highest threshold of 79.2gCO_{2eq}/MJ under the scenarios analysed.

Carbon intensities and achievable thresholds for all supply chains under all electricity from CHP scenarios are shown in Table 4.

Table 4. GHG intensities of crop supply chains for production of electricity via anaerobic digestion CHP (all values in gCO_{2eq}/MJ electricity). Colour codes are shown in Section 1.2.1.

Electricity (typical efficiency -35%)		Grass	Sugar beet	Maize	Rye	Wheat
Default		79.1	44.3	54.7	65.1	71.1
Crop yield	High	68.5	39.4	48.1	56.8	61.8
	Low	94.9	51.7	64.5	77.6	85.1
	Very Low	142.3	74.0	94.1	115.0	127.0
Fertiliser application	High	90.4	46.9	60.8	72.2	79.8
	Low	67.7	41.7	48.6	58.1	62.4
Transport	High	81.1	46.3	56.3	66.7	72.7
Co-digestion	80% crop/20% manure	66.5	32.9	45.2	55.5	61.4
	50% crop/50% manure	32.6	2.3	18.9	29.0	34.5
	20% crop/80% manure	-63.2	-85.1	-60.2	-50.9	-46.5
Electricity (high efficiency - 40%)		**Grass**	**Sugar beet**	**Maize**	**Rye**	**Wheat**
Default		69.2	38.8	47.8	57.0	62.2
Crop yield	High	59.9	34.4	42.1	49.7	54.1
	Low	83.0	45.3	56.4	67.9	74.5
	Very Low	124.5	64.8	82.3	100.7	111.1
Fertiliser application	High	79.1	41.0	53.2	63.1	69.8
	Low	59.3	36.5	42.5	50.8	54.6
Transport	High	70.9	40.5	49.2	58.4	63.6
Electricity (low efficiency - 30%)		**Grass**	**Sugar beet**	**Maize**	**Rye**	**Wheat**
Default		92.2	51.7	63.8	76.0	83.0
Crop yield	High	79.9	45.9	56.1	66.3	72.1
	Low	110.7	60.4	75.3	90.5	99.3
	Very Low	166.1	86.4	109.7	134.2	148.2
Fertiliser application	High	105.4	54.7	70.9	84.2	93.1
	Low	79.0	48.7	56.6	67.8	72.9
Transport	High	94.6	54.0	65.6	77.8	84.8

2.3 CHP; electricity and heat

Default pathways: Anaerobic digestion supply chains using CHP will typically find it easier to meet the GHG thresholds than any other technology, despite the total energy in the products (electricity and heat) being less (75% of energy in biogas) than if upgrading the biomethane (99% of energy in biogas) or producing heat alone (85% of energy in biogas). This can be explained by the following:

- While upgrading to biomethane harnesses more energy from the biogas than CHP, it also produces more emissions due to energy required for compression and additional methane slip during the process.
- While the production of heat also harnesses more energy from the biogas, allocation of emissions for CHP depends upon the useful amount of work that can be performed by the heat which is less than the thermal output - 35% when heat is delivered at 150°C. This means that for a plant exporting equal power output and thermal output, 74% of supply chain emissions are allocated to electricity and 26% allocated to heat. Therefore, even though the end use thermal efficiency for CHP (40%) is far lower than for heat only (85%), the low heat emission allocation factor typically results in lower supply chain emissions for producing heat from CHP than from a boiler.
- While electricity is burdened by a greater share of the supply chain emissions for CHP, the end use efficiency is the same as if the plant produced only electricity. Using the above allocation, a CHP plant exporting equal power output and thermal output would allocate 65% of supply chain emissions to the electricity, while for electricity only it would allocate 100% of supply chain emissions to the electricity.

Default supply chains for CHP where all exportable heat is utilised would meet thresholds below those currently adopted in the RO and RHI. For heat, all default pathways would meet a threshold of 24.0gCO_{2eq}/MJ with both sugar beet and maize achieving the lowest threshold assessed of 16gCO_{2eq}/MJ. For electricity, all default pathways would meet a threshold of 59.4gCO_{2eq}/MJ with rye and wheat achieving a lower threshold of 59.4gCO_{2eq}/MJ and maize and sugar beet capable of meeting even lower targets.

Crop yield: An increased crop yield of 20% would enable all pathways to meet the lowest threshold of 16gCO_{2eq}/MJ for heat with the exception of grass silage which would meet the higher 24.0gCO_{2eq}/MJ target. Meanwhile, all pathways for electricity would meet the 55.8gCO_{2eq}/MJ threshold, with maize and sugar beet achieving the lowest threshold for electricity of 37.2gCO_{2eq}/MJ.

For crop yields reduced by 20%, all pathways for both heat and electricity produced from CHP would meet a 60% GHG saving on the proposed Commission fossil comparators, with sugar beet, maize and rye able to meet lower thresholds.

Crop yield reductions of 50% would prevent grass silage from meeting the current RO and RHI thresholds for electricity and heat respectively when used for CHP, while it would further prevent rye and wheat from achieving the electricity threshold. Sugar beet and maize would continue to meet thresholds lower than those currently adopted.

Fertiliser application: As with pathways for other outputs, a high nitrogen fertiliser application (+20%) has a very similar impact to a low (-20%) crop yield, while a low nitrogen fertiliser application (-20%) has a very similar impact to a high crop yield (+20%).

Transport: Increasing feedstock transport to 50km does not impact the threshold achieved by any of the default pathways, with the exception of CHP electricity from maize which is no longer able to meet the 39.6gCO_{2eq}/MJ threshold.

Heat utilisation: CHP heat produced from sugar beet and maize would meet the same threshold as the default whether 100% of the exportable heat was used or only 25% was used. Grass and rye would meet the threshold above that achieved by default chains if only 25% of heat was used (compared to 100%), while the threshold achieved by maize would increase from the 16gCO_{2eq}/MJ target to the 24gCO_{2eq}/MJ target.

If only 25% of the exportable heat was used, all pathways for CHP electricity would meet higher thresholds than the default chains. However, they would all remain able to meet the 74.4gCO_{2eq}/MJ threshold, with sugar beet, maize and rye all able to meet lower thresholds.

End use efficiency: The range of end use efficiencies analysed (±10% for both heat and electricity) have a very modest impact on the ability of pathways to meet their GHG thresholds. Many of the pathways continue to meet the same threshold as the default regardless of the end use efficiency selected (grass, sugar beet and maize (heat); sugar beet and rye (electricity)) while thresholds for others are only one either side of that achieved by the default pathway.

Carbon intensities and achievable thresholds for all supply chains under all CHP scenarios are shown in Table 5.

Table 5. GHG intensities of crop supply chains for co-production of heat and electricity via anaerobic digestion CHP (all values in gCO_{2eq}/MJ output). Colour codes are shown in Section 1.2.1.

		Heat					Electricity				
		Grass	Sugar beet	Maize	Rye	Wheat	Grass	Sugar beet	Maize	Rye	Wheat
Default		20.0	11.2	13.8	16.4	18.0	56.3	31.5	38.9	46.4	50.6
Crop yield	High	17.3	9.9	12.1	14.3	15.6	48.8	28.0	34.2	40.4	44.0
	Low	23.9	13.1	16.3	19.6	21.5	67.5	36.8	45.9	55.2	60.6
	Very Low	35.9	18.7	23.7	29.0	32.1	101.3	52.7	66.9	81.9	90.4
Fertiliser application	High	22.8	11.8	15.3	18.2	20.1	64.3	33.4	43.3	51.4	56.8
	Low	17.1	10.5	12.3	14.7	15.8	48.2	29.7	34.6	41.3	44.4
Transport	High	20.5	11.7	14.2	16.8	18.3	57.7	32.9	40.0	47.5	51.7
Heat utilisation	75% exportable heat utilised	21.5	12.1	14.9	17.7	19.3	60.6	34.0	41.9	50.0	54.5
	50% exportable heat utilised	23.3	13.1	16.1	19.2	21.0	65.7	36.8	45.5	54.2	59.1
	25% exportable heat utilised	25.5	14.3	17.6	21.0	22.9	71.8	40.2	49.6	59.1	64.6
40% electrical efficiency; 40% thermal efficiency; 150°C heat; 100% exportable heat utilised		18.1	10.2	12.5	14.9	16.3	51.1	28.6	35.3	42.1	45.9
30% electrical efficiency; 40% thermal efficiency; 150°C heat; 100% exportable heat utilised		22.2	12.5	15.4	18.3	20.0	62.6	35.1	43.3	51.6	56.3
35% electrical efficiency; 45% thermal efficiency; 150°C heat; 100% exportable heat utilised		19.3	10.8	13.3	15.9	17.3	54.3	30.4	37.6	44.7	48.9
35% electrical efficiency; 35% thermal efficiency; 150°C heat; 100% exportable heat utilised		20.7	11.6	14.3	17.1	18.6	58.4	32.7	40.4	48.1	52.5
30% electrical efficiency; 35% thermal efficiency; 150°C heat; 100% exportable heat utilised		23.1	13.0	16.0	19.1	20.8	65.2	36.6	45.1	53.8	58.7
40% electrical efficiency; 45% thermal efficiency; 150°C heat; 100% exportable heat utilised		17.5	9.8	12.1	14.5	15.8	49.4	27.7	34.2	40.7	44.5

2.4 Boiler; heat only

Default pathways: All default pathways for heat from anaerobic digestion (85% thermal efficiency) are able to meet the 34.8gCO_{2eq}/MJ threshold under the RHI, with rye and wheat able to meet a 60% GHG saving on the proposed EU fossil comparator for heat (32.0gCO_{2eq}/MJ) and maize and sugar beet able to meet a 70% GHG saving on the proposed EU fossil comparator (24.0gCO_{2eq}/MJ).

Crop yield: A high crop yield (+20%) would enable grass silage pathways to meet the 32.0gCO_{2eq}/MJ threshold, while pathways for wheat, rye and sugar beet would all be able meet higher thresholds than their respective default chains.

A low crop yield (-20%) would prevent both grass silage and wheat pathways from meeting the 34.8gCO_{2eq}/MJ threshold under the RHI. Maize and rye would still be able to meet a 32.0gCO_{2eq}/MJ threshold while sugar beet would meet a 24.0gCO_{2eq}/MJ target. When assuming very low yields (-50%) only sugar beet could meet the RHI threshold, with all other crops failing to meet this target.

Fertiliser application: As is the case for all other technologies, high nitrogen fertiliser application scenarios provide similar supply chain emissions to low crop yield scenario and vice versa. The only significantly different outcome would be for wheat with a high nitrogen application rate where the 34.4gCO_{2eq}/MJ threshold would be achieved (which it would not be for the low yield scenario).

Transport: Increasing feedstock transport to 50km does not impact the threshold achieved by any of the default chains.

End use efficiency: Adjusting the end use efficiency by 5% away from the typical value has a far lesser impact on overall GHG emissions than it does for electricity on account that, relatively, it represents a smaller increase/decrease in efficiency. As such, the thresholds achieved under the high efficiency or low efficiency scenarios are not largely different to those when assuming a typical efficiency.

Carbon intensities and achievable thresholds for all supply chains under all heat-only scenarios are shown in Table 6.

Table 6. GHG intensities of crop supply chains for production of heat via anaerobic digestion (all values in gCO_{2eq}/MJ heat). Colour codes are shown in Section 1.2.1.

Boiler (typical efficiency - 85%)		Grass	Sugar beet	Maize	Rye	Wheat
Default		32.6	18.3	22.5	26.8	29.3
Crop yield	High	28.2	16.2	19.8	23.4	25.5
	Low	39.1	21.3	26.6	32.0	35.1
	Very Low	58.6	30.5	38.7	47.4	52.3
Fertiliser application	High	37.2	19.3	25.0	29.7	32.9
	Low	27.9	17.2	20.0	23.9	25.7
Transport	High	33.4	19.1	23.2	27.5	29.9
Boiler (high efficiency - 90%)		**Grass**	**Sugar beet**	**Maize**	**Rye**	**Wheat**
Default		30.7	17.2	21.3	25.3	27.7
Crop yield	High	26.6	15.3	18.7	22.1	24.0
	Low	36.9	20.1	25.1	30.2	33.1
	Very Low	55.4	28.8	36.6	44.7	49.4
Fertiliser application	High	35.1	18.2	23.7	28.1	31.0
	Low	26.3	13.2	18.9	22.6	24.3
Transport	High	31.5	18.0	21.9	25.9	28.3
Boiler (low efficiency - 80%)		**Grass**	**Sugar beet**	**Maize**	**Rye**	**Wheat**
Default		34.6	19.4	23.9	28.5	31.1
Crop yield	High	30.0	17.2	21.0	24.9	27.0
	Low	41.5	22.6	28.2	34.0	37.2
	Very Low	62.3	32.4	41.2	50.3	55.6
Fertiliser application	High	39.5	20.5	26.6	31.6	34.9
	Low	29.6	18.3	21.2	25.4	27.3
Transport	High	35.5	20.2	24.6	29.2	31.8

3 Summary and discussion

3.1 Summary

When using default or proportionally adjusted cultivation values, sugar beet and maize supply chains are typically able to achieve higher carbon savings than the other crops assessed in this study, and in many circumstances will be able to meet a 70% GHG saving on the EU fossil comparator for heat or electricity. Supply chains for grass silage are typically the poorest performing due to an assumed high nitrogen demand relative to yield and fails to meet even the highest thresholds under a substantial number of the scenarios assessed outside of CHP.

Nitrogen fertiliser application and crop yields have a similarly important impact on supply chain emissions. Assuming a low crop yield (-20%) or high fertilizer application rate (+20%) typically increases overall supply chain emissions by 10-20%, while assuming a high crop yield or low fertilizer application rate has the opposite effect. A very low crop yield (-50%) would prevent many pathways from meeting even the highest GHG thresholds assessed, although this is likely to be a very rare occurrence.

In the majority of instances, transport of feedstock has a negligible impact on overall supply chain emissions when considering realistic journey distances.

Carbon capture and storage/utilisation largely negates any other supply chain variables as it would allow almost any pathway to meet the lowest GHG thresholds assessed in this study, provided that a significant amount of the CO_2 produced was captured and either stored or used in a suitable application.

Co-digestion provides a valuable means to reduce GHG emissions of plants although this approach is only likely to have meaningful impact when used in significant volumes e.g. above 20% total plant tonnage. While some smaller plants (<250kWe output or equivalent) might use such a feedstock profile, this is unlikely to be the case for the vast majority of larger plants (>500kWe output or equivalent). This is because the provision of such an output would require the digestion of very large volume of manures that would typically not be available onsite or nearby.

3.2 Discussion

This analysis demonstrates that use of CHP provides the easiest means for AD operators to meet the existing GHG thresholds under the RHI and RO, provided that at least some of the exportable heat can be utilised. The vast majority of CHP pathways analysed in this study would be able to meet a 70% GHG saving on the fossil comparators for heat and electricity proposed by the Commission, both of which are lower than the comparators currently used in the RHI and RO respectively.

Meanwhile, achieving the RHI threshold for biomethane provides greatest difficulties, largely on account of the significant energy requirements for upgrading and injection. In the event that the fossil comparator changes from EU heat average to the marginal gas supply, as proposed by the Commission, biomethane pathways would become even more difficult to meet relative to the heat or electricity thresholds. However, if operators can demonstrate that all off-gases are oxidised and the upgrading equipment does not result in fugitive methane emissions (as is becoming more frequent with modern technologies) it is likely that the criteria would not be significantly more difficult to meet than for heat and power.

The existing GHG thresholds for heat (34.8gCO_{2eq}/MJ) and electricity (79.2gCO_{2eq}/MJ) under the RHI and RO largely correspond. It is not possible to provide a completely accurate comparison on account that assumptions need to be made about end use efficiency to compare the criteria. However, if a plant that exactly met the 34.8gCO_{2eq}/MJ threshold under the RHI when using an 85% efficient boiler was to instead install a CHP to export electricity (with no heat export), it would require a 37.3% efficient engine to meet the 79.2gCO_{2eq}/MJ threshold under the RO. These efficiencies are both fairly typical of industry values, suggesting that the targets are complementary. However, as thresholds under the RO tighten over time it will become progressively more difficult to meet the electricity target relative to the heat target.

The above calculations provide a basic means to ensure that GHG thresholds remain complementary. However, this relies on making assumptions about end use efficiencies for heat and power. For biomethane, further assumptions would need to be made regarding downstream processing of the biogas.

Unless life cycle analysis (LCA) is adopted in policy using a strictly attributional approach - whereby a uniform GHG threshold is placed on the fuel (e.g. biogas) used to produce the final product (e.g. heat/electricity) rather than determining a GHG saving for each application based on the assumed fossil product(s) displaced - it will not be possible to perfectly harmonise sustainability criteria across the power sectors. This is because each sector (heat, power or gas) needs to account for differing end use efficiencies and each uses a different fossil fuel comparator. Additionally, comparators are liable to change over time as markets evolve which could therefore disrupt any attempt to improve consistency of carbon accounting across sectors.

A fully attributional approach to LCA in policy could improve cross-sector harmonisation, enabling a threshold to be placed on the fuel used to produce the energy rather than the energy itself[9]. As such, the biogas would have a consistent GHG threshold regardless of how it is finally used. However, an important aspect of renewable energy policy is to understand the impact of market interventions resulting from legislation. Because of this fact, consequential approaches to LCA – whereby GHG savings are predicted based upon

[9] Though such an approach would likely require further restrictions on minimum end use efficiency

comparison to counterfactual scenarios (i.e. what would otherwise happen) - are becoming more prevalent in Commission methodologies for carbon accounting. This is evidenced by the recent attempts to model indirect land use change in the biofuel sector as well as many of the approaches discussed in this study, such as developing emission factors for the marginal energy supply and allowing carbon credits for manures and slurries used in anaerobic digestion. While this progress will inevitably prove valuable in informing policy of the potential real world carbon savings that could be achieved by bioenergy, it risks creating greater uncertainty in the market and will likely disrupt attempts to harmonise sustainability across sectors.

NNFCC

NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and bio-based products.

NNFCC, Biocentre,
York Science Park,
Innovation Way,
Heslington, York,
YO10 5DG.

Phone: +44 (0)1904 435182
Fax: +44 (0)1904 435345
E: enquiries@nnfcc.co.uk
Web: www.nnfcc.co.uk