

## **Anaerobic Digestion in an Integrated Farming Environment**

### **AD on farm energy tool – R4**

**An energy and emissions - based tool for anaerobic digestion within a farming context.**

### **Manual for use of the spreadsheet based tool**

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Revision [R7]

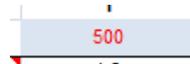


<http://www.bioenergy.soton.ac.uk>

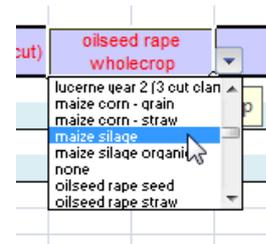
## 1. Introduction

The various aspects of the energy tool developed in the RELU project - AD in an integrated farming environment (<http://www.AD4RD.soton.ac.uk>) - have been combined into a spreadsheet based tool in order to allow for the calculation of potential energy balances and emissions using a crop based AD system. The tool enables the user to get a 'snap shot' view based on a single year but with the flexibility to easily change crops and yields.

User inputs are indicated in the tool by **red text**



or drop down lists (**red text**, blue background and thick border).



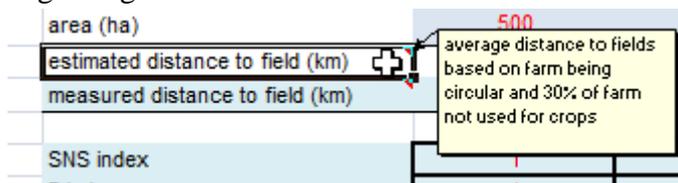
In some cases 'estimated' values are available (calculated from average values or approximations) to simplify use.

The tool includes the possibility to replace these with known or measured values. This is done by changing the **e** in the relevant adjoining cell to the required value. It should be noted that these values will remain if other factors are changed so it is important to check that they are correct for the crop shown. To return to the estimated value replace the **e** in the relevant cell.

number/year		
estimated	actual	esti
1	e	
1	e	
1	e	
0	e	
n	e	

Some cells have a small red triangle in the top right corner. Placing the mouse pointer over the cell will cause a comment box to appear providing some help regarding the information in that row.

area (ha)
estimated distance to field (km)
measured distance to field (km)



There are also various 'help' links which when selected lead to a help page.

13		main cro
14	<a href="#">help</a>	crop
15		average U

Clicking on the relevant 'return' link from this page returns the user to the selected input sheet.

29	
30	<b>animal slurries</b>
31	This sheet is used to estimate the amount of manures and slurries from animals
32	Manure or alurry is assumed to be collected from housed animals, grazing anim
33	
34	<a href="#">return to animal slurry sheet</a>
35	

## 2. Crop production

The first stage is to specify some basic details of the farm; to identify the crops being grown, the areas involved and the anticipated yields. A number of pre-specified crops and cropping systems are included and can be selected from the drop down list. This part of the tool allows for the inclusion of crop residues and second crops within the same year (for example catch crops). Details of the field data and crop selection sheet are shown in Figure 1. This version of the tool is restricted to 20 ‘fields’. For larger farms it will be required to use these to represent total crop areas.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		On-farm AD energy balance						<a href="#">general help</a>											
2																			
3	<a href="#">help</a>	Crop production																	
4		Field/crop type	1	2	3	4	5	6	7	8	9								
5		area (ha)	500	500	100	0	0	0	0	0	0								
6		estimated distance to field (km)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6								
7		measured distance to field (km)	e	e	e	e	e	e	e	e	e								
8		SNS index	1	1	1	1	1	1	1	1	1								
9		P index	1	1	1	1	1	1	1	1	1								
10		K index	1	1	1	1	1	1	1	1	1								
11																			
12																			
13		main crop																	
14	<a href="#">help</a>	crop	maize silage	grass silage (3 cut)	oilseed rape straw	none	none	none	none	none	none								
15		average UK yield (tFM/ha)	45	45	6	0	0	0	0	0	0								
16		yield (tFM/ha)	37	37	0	0	0	0	0	0	0								
17		estimated dry matter content (%)	30	19.9	90.7	0	0	0	0	0	0								
18		measured dry matter content (%)	e	e	e	e	e	e	e	e	e								
19		total yield (tFM)	18500	18500	0	0	0	0	0	0	0								
20																			
21																			
22		residues / second crop																	
23	<a href="#">help</a>	output	none	none	salad crop	none	none	none	none	none	none								
24		average UK yield (tFM/ha)	0	0	15	0	0	0	0	0	0								
25		yield (tFM/ha)	0	0	15	0	0	0	0	0	0								
26		estimated dry matter content (%)	0	0	3	0	0	0	0	0	0								
27		measured dry matter content (%)	e	e	e	e	e	e	e	e	e								
28		total yield (tFM)	0	0	1500	0	0	0	0	0	0								

Figure 1: Field data and crop selection

The area of each field or crop is given in the first row.

Average distance to each ‘field’ is either estimated by the tool (calculated on the farm being circular and evenly distributed around the AD unit and assuming that 30% of the farm area is unavailable for crop growth) or can be specified (as an average distance where more than one field is included in a crop ‘area’).

Nutrient status for each field/crop area can be selected from the drop down lists (Figure 2). these include soil nitrogen status, P and K indices. (0-1 indicate low nutrient values – requiring more nutrient inputs, 4-5 indicate high nutrient values requiring low nutrient inputs).

Crop				
Field/crop type	1	2	3	4
area (ha)	50	37	6	10
estimated distance to field (km)	0.6	0.6	0.6	0.6
measured distance to field (km)	0	0	0	0
SNS index	2	1	2	3
P index	1	1	2	1
K index	3	0	1	1
		1		
		2		
		3		
main crop				
crop	grass for grazing	grass silage (3 cut)	winter wheat - grain	sugar beet - beet
average UK yield (tFM/ha)	35	45	8.5	62

Figure 2: Input nutrient status

The crops themselves can then be selected from the drop-down lists (Figure 3). A yield figure has to be entered, a zero value will show up as errors in later calculations. As each crop is selected there will appear an average UK yield for that crop, this value can be used or the known value for the farm input. The dry matter content of the harvested crop can also be input. variations in dry matter content will have considerable effect on the potential biogas yield. If no value is input the estimated value will be used in the calculations.

main crop		maize silage	grass silage (3 cut)	oilseed rape straw	none	none
help	crop					
	average UK yield (tFM/ha)	45	45	6	grass silage year 1	0
	yield (tFM/ha)	37	37	0	kale	0
	estimated dry matter content (%)	30	19.9	90.7	lucerne year 1	0
	measured dry matter content (%)	e	25	e	lucerne year 2 (3 cut clari	0
	total yield (tFM)	18500	18500	0	maize corn - grain	e
					maize corn - straw	0
					maize silage	
					maize silage organic	

Figure 3: Crop selection

The direct and indirect energy requirements for each crop are modelled based on the operations required for the production of the crop and collection and transport of any residues. The list of operations assumed for each crop is indicated as shown in Figure 4. The tool presents a list of estimated operation numbers for each crop. These can be changed by entering the actual number (including 0) in the relevant ‘actual’ cell. This can also be used to model organic farming (by removing the spraying operations and replacing them with mechanical ones) or to change the number of annual harvests in the case of grass silage crops.

Note: remember that if values are entered in the ‘actual’ column these will remain if the crop is changed and so will need to be altered or reset to e. If using the macro version these values will be automatically reset when ‘none’ is selected as the crop type.

The transport requirement is based on the average distance to the field, the area and yield, assuming that material is transported in average 8 tonne loads.

crop operation details		maize silage		grass silage (3 cut)		oilseed rape straw		none									
	number/year	estimated	actual	estimated	actual	estimated	actual	estimated	actual	estimated	actual	estimated	actual	estimated	actual	estimated	actual
operations																	
subsoiler	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
plough	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
harrow	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
disc	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
drill	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
precision drill	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
roll	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
spray	2	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
fertilise (mineral)	2	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
mechanical hoe	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
maize hoe	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
combine	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
forage harvester	1	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
ensile	1	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
mow	0	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
turn	0	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
load forage	0	e	3	e	0	e	0	e	0	e	0	e	0	e	0	e	0
bale	0	e	0	e	1	e	0	e	0	e	0	e	0	e	0	e	0
beet harvester	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0	e	0
crop transport																	
transport (harvests/year)	1		3		0		0		0		0		0		0		0
distance to field (km)	1.58		1.58		1.58		1.58		1.58		1.58		1.58		1.58		1.58
cart journeys (assume 8t load)	2313		2313		0		0		0		0		0		0		0
total distance (km)	7315.8		7315.8		0.0		0.0		0.0		0.0		0.0		0.0		0.0
fuel (l/ha)	5.7		5.7		0.0		0.0		0.0		0.0		0.0		0.0		0.0

Figure 4: Crop production operations

The total direct and indirect energy requirement for crop production and transport for each crop area (excluding fertiliser application) is calculated based on the various operations performed on the crop and the amount of transport required (Figure 5).

Crop production excluding fertiliser application						
	1	2	3	4	5	6
total fuel use (Vha)	0	57	60	113	71	0
crop production fuel (MJ/ha)	0	2279	2389	4542	2861	0
total fuel use (Vcrop area)	0	2104	358	1133	928	0
total fuel (MJ/crop area)	0	84333	14335	45424	37187	0
indirect energy (MJ/ha)	0	1798	1078	1666	1323	0
total (MJ/crop area)	0	66515	6471	16658	17203	0

**Figure 5: Crop energy requirements**

The fuel requirement for each of the crop operations is shown in a table at the bottom of the worksheet, Figure 6.

Fuel consumption figures used	fuel required (Vha)
subsoiler	15.1
plough	23.2
harrow	5.7
disc	6.8
drill	2.8
precision drill	1.5
roll	1.1
spray	0.9
fertilise (mineral)	0.7
mechanical hoe	2.6
maize hoe	3.3
combine	18
forage harvester	25.1
ensile	4.6
mow	3.3
turn	2.9
load forage	6.5
bale	4.6
beet harvester	44.3

**Figure 6: Fuel consumption figures**

### 3. Animal slurries

If animal slurry is produced on-farm and added to the digester then the number of cattle and pigs can be specified along with the proportion of time that they are housed. The tool assumes that (if selected) all cattle slurry produced in house is added to the digester and all pig manure (Figure 7). Cattle slurry produced outside of the housing is assumed to be returned directly to the field. The cattle slurry can be in the form of slurry (assumed at 9% solids) or farm yard manure (FYM, assumed to be 25% solids and based on a combination of cattle slurry and straw).

The volume of wash water or waste water that is added to the slurry is input in the relevant box, this is important as it affects storage capacity and, if used, digester design as it leads to increased capacity required in order to maintain retention period.

The numbers of sheep can be selected but will only be considered as grazing.

	A	B	C	D	E	F	G	X
1		<b>On-farm AD energy balance</b>				<a href="#">general help</a>		
2								
3		<b>help animal slurries</b>						
4						excreta per animal		
5		<b>cattle</b>	number	housing (%)	estimated	actual		
6		dairy cattle - slurry	100	50	19.3	e	tonnes/year	
7		other cattle - FYM	50	50	11.6	e	tonnes/year	
8		waste/wash water from in house/dairy		0			tonnes/year	
9								
10		<b>total</b>	in house	in field				
11		dairy cattle - slurry	965.0	965.0	tonnes			
12		other cattle - FYM	367.1	290.0	tonnes			
13			1332.1	1255.0	tonnes			
14								
15		<b>pigs</b>	number	manure per animal - 100% housing	total manure			
16	a	-none-	0	0	0	tonnes		
17	b	-none-	0	0	0	tonnes		
18	c	- none -	0	0	0	tonnes		
19					0	tonnes		
20								
21		<b>sheep</b>	number	manure per animal - per year	total manure			
22		sheep - ewes	100	1.625	162.5	tonnes		
23		sheep - lambs	50	0.375	18.75	tonnes		
24					181.25	tonnes		
25								
26		click on cell then select from drop down list						
27								
28								

Figure 7: Animal slurry calculation

### 4. Imported materials

A number of specified import streams including wastes can be entered (Figure 8). Selection can be made from a range of animal slurries including cattle pigs and poultry. Once selected the only other inputs required are the amount and the distance. A range of preselected crop and other waste streams are also available. These also require tonnage and distance.

Finally the user is able to enter up to 3 waste streams of their own specification in which case the user is required to specify the amount, total solids, volatile solids (as proportion of total solids), methane yield and %methane in biogas. Anticipated nutrient values (N, P and K) for these streams are also required in order to provide information for the digestate analysis. The waste type is either liquid (up to 15% solids) or solid (>15%). The reason for this selection is that it affects the parasitic electrical requirement as more solid materials require extra processing.

Imported slurries and wastes														
	imported animal slurry				imported crop inputs			imported v aste inputs			user inputs			
5 select type	cattle - FYM	poultry - broiler	-none-	total animal slurries	fodder beet	-none-	-none-	card packaging	-none-	-none-	1	2	3	total (excluding animal slurries)
6 tonnage	10	100	0	110	0	0	0	0	0	0	0	0	0	0 tonnes
7 TS (%)	25	60	0	56.8	20	0	0	93.9	0	0	0	0	0	0.0 %
9 VS (% of TS)	80	75	0	75.2	88	0	0	83.6	0	0	0	0	0	0 % of TS
11 methane yield	0.19	0.3	0	0.295	0.4	0	0	0.266	0	0	0	0	0	0.000 m <sup>3</sup> /kgVS <sub>std</sub>
12 % methane in biogas	60	60	0	60	55	0	0	60	0	0	0	0	0	0 %
13											waste type			
14											liquid	liquid	liquid	
15 pasteurise	no	no	no		no	no	no	no	no	no	no	no	no	
16	0	0	0		0	0	0	0	0	0	0	0	0	0 tonnes
17														
18 transport distance (km)	0	0	0		0	0	0	0	0	0	0	0	0	0 km
19 transport method	select	select	select		select	select	select	select	select	select	select	select	select	
20 energy for transport	0	0	0		0	0	0	0	0	0	0	0	0	0 GJ
21														
22 digestate values														
23 N	6	30	0	27.8	1.8	0	0	1.35	0	0	0	0	0	0.00 g/kg fresh weight
24 P	3.5	10.9	0	10.2	0.39	0.00	0.00	0.126	0	0	0	0	0	0.00 g/kg fresh weight
25 K	8	15	0	14.4	4.17	0.00	0.00	0.21	0	0	0	0	0	0.00 g/kg fresh weight
26														
27 N	6	30	0	27.8	1.8	0	0	1.35	0	0	0	0	0	0.00 kgh fresh weight
28 P <sub>2</sub> O <sub>5</sub>	8.05	25.07	0	23.5	0.9	0	0	0.2898	0	0	0	0	0	0.00 kgh fresh weight
29 K <sub>2</sub> O	9.6	18	0	17.2	5	0	0	0.252	0	0	0	0	0	0.00 kgh fresh weight

Figure 8: Imported material streams

If transport energy is to be considered then distance over which the waste is transported to the digester can be specified. The amount of energy required will vary according to the type of transport used. It is possible to select from a range of lorry types based on the DEFRA/DECC guidelines for GHG factors for company reporting (DEFRA, 2009, AEA, 2010). Energy requirements for tractor transport are based on values from KTBL (2009). The type of transport is selected using the relevant drop down list as shown in Figure 9.

	20	50	0
	Artic >33t	tractor & trailer	select
4			0
		select	
		Artic <33t	
		Artic >33t	
		Riquid < 7.5t	
		Riquid > 17t	
		Riquid > 7.5-17t	
		tractor & trailer	
3.8			0
0.70		0.48	0.00
3.75		3.75	0.00

Figure 9: Selecting transport type

Imported animal slurries may or may not be selected as digester input. If they are not selected as inputs then they are assumed to be directly applied to land.

**Note:** if using the macro version all values, including tonnage, distance and transportation type will be reset to zero if ‘none’ is selected as the input type.

### 5. The digester(s)

Having specified the crops, cattle slurries and wastes the user can specify which of these materials are included as feedstock to the digester. From the amount of feedstock materials specified as being included, the tool calculates the required digester size and energy requirements as shown in

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Z	AA	AB	AC	
1	On-farm AD energy balance																			
2	general help																			
3	Digester																			
4	Inputs																			
5	available substrate	animal slurries	imported animal slurries	other imported materials	fresh water	grass silage (5 cut)	winter wheat - straw	grass for grazing	oilseed rape seed	fodder crop for grazing	none	none	none	none	none	20	total			
6	input to digester?	yes	no	no	no	yes	no	no	yes	no	no	no	no	no	no	no	no			
7	Fresh matter (tFM/year)	1332	0	0	0	3000	0	0	150	0	0	0	0	0	0	0	10,482	tonnes FM		
8	dry matter (tDS/year)	178.6	0	0	0	1791	0	0	138	0	0	0	0	0	0	0	2,108	tonnes DM		
9	volatile solids (tVS/day)	0.40	0.00	0.00	0.00	4.42	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.17	tVS/day		
10	potential methane (m <sup>3</sup> /year)	27285	0	0	0	56581	0	0	4366	0	0	0	0	0	0	0	586,833	m <sup>3</sup>		
11	potential biogas (m <sup>3</sup> /year)	45475	0	0	0	938875	0	0	78484	0	0	0	0	0	0	0	1,062,834	m <sup>3</sup>		
12																				
13				available substrates - 2nd crop/residues		none	winter wheat - straw	none	none	none	none	none	none	none	none	none	total			
14	input to digester?	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no			
15	Fresh matter (tFM/year)	0	0	0	0	0	3000	0	0	0	0	0	0	0	0	0	1,000	tonnes FM		
16	dry matter (tDS/year)	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	300	tonnes DM		
17	volatile solids (tVS/day)	0.00	2.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	tVS/day		
18	potential methane (m <sup>3</sup> )	0	14125	0	0	0	0	0	0	0	0	0	0	0	0	0	14125	m <sup>3</sup>		
19	potential biogas (m <sup>3</sup> )	0	25738	0	0	0	0	0	0	0	0	0	0	0	0	0	25738	m <sup>3</sup>		
20																				
21	basis for calculating capacity																			
22	capacity	click on box and select from list				capacity +10%	daily input	individual digesters			below									
23	total digester capacity required	600 m <sup>3</sup>				660 m <sup>3</sup>	tonnes FM	to width ratio	diameter (m)	height (m)	ground (%)									
24	number of digesters	1				660	315	0.25	15.0	3.7	0									
25																				
26																				
27	loading rate	12 kg/m <sup>3</sup> /day																		
28	retention time	18.07 days																		
29	operating temp	35 °C																		
30	operational lifespan	30 years																		
31																				
32	methane produced	728,358	1936	83.1																
33	biogas	1,320,153	3617	150.7																
34																				
35	digestate	3,802 tonnes																		
36	average VS destruction	53.1 %																		
37																				
38																				
39																				
40	post-fermenter																			
41	operating temp	70 °C																		
42	time in post-fermenter	1 hour																		
43	material processed	10482 (tFM/year)																		
44	capacity	2.4 m <sup>3</sup>																		
45																				
46																				

Figure 10 – note some columns are missing from the figure for clarity.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Z	AA	AB	AC	
1	On-farm AD energy balance																			
2	general help																			
3	Digester																			
4	Inputs																			
5	available substrate	animal slurries	imported animal slurries	other imported materials	fresh water	grass silage (5 cut)	winter wheat - straw	grass for grazing	oilseed rape seed	fodder crop for grazing	none	none	none	none	none	20	total			
6	input to digester?	yes	no	no	no	yes	no	no	yes	no	no	no	no	no	no	no	no			
7	Fresh matter (tFM/year)	1332	0	0	0	3000	0	0	150	0	0	0	0	0	0	0	10,482	tonnes FM		
8	dry matter (tDS/year)	178.6	0	0	0	1791	0	0	138	0	0	0	0	0	0	0	2,108	tonnes DM		
9	volatile solids (tVS/day)	0.40	0.00	0.00	0.00	4.42	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.17	tVS/day		
10	potential methane (m <sup>3</sup> /year)	27285	0	0	0	56581	0	0	4366	0	0	0	0	0	0	0	586,833	m <sup>3</sup>		
11	potential biogas (m <sup>3</sup> /year)	45475	0	0	0	938875	0	0	78484	0	0	0	0	0	0	0	1,062,834	m <sup>3</sup>		
12																				
13				available substrates - 2nd crop/residues		none	winter wheat - straw	none	none	none	none	none	none	none	none	none	total			
14	input to digester?	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no			
15	Fresh matter (tFM/year)	0	0	0	0	0	3000	0	0	0	0	0	0	0	0	0	1,000	tonnes FM		
16	dry matter (tDS/year)	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	300	tonnes DM		
17	volatile solids (tVS/day)	0.00	2.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	tVS/day		
18	potential methane (m <sup>3</sup> )	0	14125	0	0	0	0	0	0	0	0	0	0	0	0	0	14125	m <sup>3</sup>		
19	potential biogas (m <sup>3</sup> )	0	25738	0	0	0	0	0	0	0	0	0	0	0	0	0	25738	m <sup>3</sup>		
20																				
21	basis for calculating capacity																			
22	capacity	click on box and select from list				capacity +10%	daily input	individual digesters			below									
23	total digester capacity required	600 m <sup>3</sup>				660 m <sup>3</sup>	tonnes FM	to width ratio	diameter (m)	height (m)	ground (%)									
24	number of digesters	1				660	315	0.25	15.0	3.7	0									
25																				
26																				
27	loading rate	12 kg/m <sup>3</sup> /day																		
28	retention time	18.07 days																		
29	operating temp	35 °C																		
30	operational lifespan	30 years																		
31																				
32	methane produced	728,358	1936	83.1																
33	biogas	1,320,153	3617	150.7																
34																				
35	digestate	3,802 tonnes																		
36	average VS destruction	53.1 %																		
37																				
38																				
39																				
40	post-fermenter																			
41	operating temp	70 °C																		
42	time in post-fermenter	1 hour																		
43	material processed	10482 (tFM/year)																		
44	capacity	2.4 m <sup>3</sup>																		
45																				
46																				

Figure 10: Digester capacity and energy requirements

Overall digester capacity here is calculated based on three options; capacity, loading rate or retention time. Research has shown that a loading rate in the region of 3kg VS/m<sup>3</sup>/day is good for CSTR digesters using these types of feedstock materials. Overloading the digester can lead to a reduction in efficiency, methane output and stability. Retention time is also important because it determines the average length of time over which the material is held in the digester. If the retention time is too short then not all of the potential biogas will be released, leading to biogas being produced in the following stages of digestion, storage or after the digestate has been applied to fields. The capacity, loading rate or retention time can be selected as shown in Figure 11. If the selection criteria leads to unreasonable values these are indicated by warning messages. The values should then be reconsidered.

Anaerobic Digestion in an integrated farming environment

			potential methane (m <sup>3</sup> )				potential methane (m <sup>3</sup> )
			potential biogas (m <sup>3</sup> )				potential biogas (m <sup>3</sup> )
basis for calculating capacity	capacity	click on box and select from list		basis for calculating capacity	retention time	click on box and select from list	
capacity	600 m <sup>3</sup>			retention time	50 days		
total digester capacity required	600 m <sup>3</sup>			total digester capacity required	1573 m <sup>3</sup>		
number of digesters	1			number of digesters	1		
loading rate	12 kg/m <sup>3</sup> /day			loading rate	5 kg/m <sup>3</sup> /day		
retention time	19.07 days			retention time	50.00 days		
operating temp	35 °C			operating temp	35 °C		
operational lifespan	30 years			operational lifespan	30 years		
methane produced	m <sup>3</sup> /year: 728,358	m <sup>3</sup> /day: 1996	m <sup>3</sup> /hour: 83.1				

**Figure 11: Selection of capacity criteria**

The number of digesters over which this capacity is spread can also be specified, typically a single digester will not be larger than 3500 m<sup>3</sup>. The user can specify if the digester is of steel or concrete construction and whether a pasteuriser is included. Energy requirement will be affected by the temperature the digester is operated at (which can be specified), embodied energy is calculated per year based on expected lifespan (which can also be specified).

A number of design options are available using the various input boxes.

The construction materials for the digester can be selected as either concrete based or steel based. A concrete digester is modelled as having a reinforced concrete wall and floor surrounded by an insulation layer and protective sheet metal skin. A flexible gas dome is modelled as the roof for the digester. A steel digester is modelled as a cylinder constructed of two layers of steel separated by a layer of insulation. The floor of the digester is constructed from reinforced concrete. In both designs 10% of the volume is added to the working volume for gas storage.

The height to width ratio and amount of digester buried below ground level can be input.

individual digesters					
capacity +10%	daily input	digester height	diameter (m)	height (m)	below ground (%)
gas space (m <sup>3</sup> )	tonnes FM	to width ratio			
2731	31.5	0.25	24.0	6.0	0
construction	concrete click on box and select from list				

**Figure 12: inputs for digester dimensions**

Pasteurisation is an option either before digestion for materials selected as requiring pasteurisation in the imported materials sheet or for after digestion in which case all of the digestate is pasteurised. The heat requirements are calculated based on the different options, in the case of pre-pasteurisation it is assumed that the material requires no further heat before being added to the digester.

Biogas storage can be done either in the digester, in which case 30% is added to the digester volume to allow for this or in a separate gas storage unit, in which case 10% is added to the working volume of the digester as freeboard. If a separate gas storage unit is specified then it is assumed to be spherical, constructed of two layers of PVC and situated on a reinforced concrete base. The size of the unit is determined by the maximum storage period required.

Separate gas storage						
storage period	2 hours	(spherical gas holder on concrete base)			embodied energy	
volume	166 m <sup>3</sup>	concrete	steel	PVC		
		23.0	2.0	31.8	56.7 GJ	1.9 GJ/year

**Figure 13: Biogas storage**

Digestate storage facilities can also be specified. The storage period determines the volume of storage required and it is possible to specify the construction materials and whether a roof is

included and, if so, its construction. The digestate storage is taken to be a cylindrical tank on a reinforced concrete base without insulation or heating.

Digestate storage				materials (tonnes)			embodied energy	
				concrete	steel	PVC	GJ	GJ/year
storage period	6 months							
storage requirement	4901 m <sup>3</sup>	(digestate - assumes production even throughout year)						
number of tanks	1	individual tank height to width ratio		tank	535.2	34.6	1283.4	42.8
construction	steel	0.2		roof		0.0	175.0	0.5
roof	membrane					total	1458.3	43.3

**Figure 14: Digestate storage**

## 6. Fertiliser & digestate

Fertiliser application is a complex issue. Crops require inputs of nutrients to produce the expected yields and these can be supplied in the form of mineral fertiliser or through the application of digestate. The fertiliser value of the digestate is calculated on the basis of nutrients contained in the materials used for digestion with no losses. Any undigested slurry is added to the digestate in terms of amount of nutrients available. The tool calculates the fertiliser value of the digestate and the required fertiliser for crop production (Figure 15). The area designated as grass for grazing receives fertiliser directly from manure dropped by cattle, this can be topped up with digestate and slurry. This value is shown for that area of crop and deducted from the required fertiliser input.

	A	B	C	D	E	F	G	H	X	Y	Z	AA	AB
1		On-farm AD energy balance						general help					
2													
3		help: Fertiliser											
4				1	2	3	4	5					
5		fertiliser value of digestate and undigested slurry		crops for digestion grass silage (3 cut)	winter wheat - grain	grass for grazing	none	none	animal slurries	imported animal slurries	imported materials	total	kg/ha
6													
7		N (kg)	8,550	43,200	0	0	0	7,203	0	0	58,953	131	
8		P <sub>2</sub> O <sub>5</sub> (kg)	3,600	19,200	0	0	0	3,435	0	0	26,235	58	
9		K <sub>2</sub> O (kg)	10,125	14,400	0	0	0	6,772	0	0	31,297	70	
10													
11		second crop / residues		none	winter wheat - straw	none	none	none					
12		N (kg)	0	0	0	0	0	0					
13		P <sub>2</sub> O <sub>5</sub> (kg)	0	0	0	0	0	0					
14		K <sub>2</sub> O (kg)	0	0	0	0	0	0					
15													
16		Digestate	available	4,072	tonnes								
17			Total solids	26.0	%								
18													
19				N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O							
20		nutrient content of digestate and undigested slurries		14.5	6.4	7.7	kg/tonne						
21													
22													

Figure 15: Fertiliser availability from slurry and digestate

The inclusion of a separator for use on the digestate/slurry can be made, selecting from a number of types. Values are given for solids, N,P and K for the solid fraction and liquid fraction, Figure 16.

select separator type	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	TS	tonnes	TS (%)	energy required kWh/year
screw press	1224	687	813	58	192	30.5	1660.1
solid fraction (kg)	5978	2748	5959	71	1085	6.6	
liquid fraction (kg)							

Figure 16: Selection of separator

Crop fertiliser requirements are based on the RB209 (DEFRA, 2010) and are assessed on the basis of the soil nutrient status for each field as given on the crop production sheet. Fertiliser requirements can also be selected other than the recommended by entering a value in the relevant box. To go back to the recommended value make sure that the letter **e** is entered in the relevant cell, Figure 17.

Note - if the crop is reset to 'none' on the crop production sheet then the user values will be reset to e. All of the values can be reset by clicking on the reset button. These will only work if the macro's are enabled.



Anaerobic Digestion in an integrated farming environment

solid fraction transport and application		application method					
		splash plate (select from list)					
	crop	1	2	3	4	5	
		grass silage (3 cut)	winter wheat - grain	grass for grazing	none	none	total
	t/ha	13.8	0.0	0.0	0.0	0.0	
	fuel required (l/crop area)	634.2	0.0	0.0	0.0	0.0	634.2 litres
	fuel required (GJ/crop area)	25.4	0.0	0.0	0.0	0.0	25.4 GJ
	indirect energy (GJ/crop area)	6.4	0.0	0.0	0.0	0.0	6.4 GJ
liquid fraction transport and application		application method					
		trailed hose (select from list)					
	crop	1	2	3	4	5	
		grass silage (3 cut)	winter wheat - grain	grass for grazing	none	none	total
	t/ha	3.4	10.7	0.0	0.0	0.0	
	fuel required (l/crop area)	219.4	1818.0	0.0	0.0	0.0	2037.4 litres
	fuel required (GJ/crop area)	8.8	72.9	0.0	0.0	0.0	81.7 GJ
	indirect energy (GJ/crop area)	6.1	36.8	0.0	0.0	0.0	43.0 GJ
mineral fertiliser applications							total
	number of required applications	1	3	4	0	0	
	fuel required (l/crop area)	35.0	630.0	280.0	0.0	0.0	945.0 litres
	total fuel (MJ/crop area)	1404	25263	11228	0	0	37.9 GJ
	total indirect (MJ/crop area)	425	7850	3400	0	0	11 GJ

Figure 19: Energy for fertiliser application

### 7. Biogas use

Energy production is determined from the production and use of the biogas. energy requirement on-site can be supplied from the grid or through the use of on-site combined heat and power (CHP). The user can specify if the biogas is upgraded and compressed. If on-site CHP is selected and no upgrading then it is assumed that all of the biogas is used for CHP (Figure 20).

If CHP is selected then there is the potential for heat generated to be used. The tool assumes that heat will initially be used for maintaining digester temperature and heating feedstock materials – any remaining heat is available for export. In this case it is possible to specify the expected heat utilisation (as a percentage of the heat available for export).

On-farm AD energy balance		<a href="#">general help</a>													
<b>Biogas use</b>															
Biogas produced	1,320,153 m <sup>3</sup>														
process losses	0 %														
Biogas available	1,320,153 m <sup>3</sup>														
methane available	728,358 m <sup>3</sup>														
on-site biogas use CHP	CHP (select from list)														
upgrade	none														
methane lost in upgrading	2 %														
exported biogas	0 m <sup>3</sup>														
upgraded CH4	0 m <sup>3</sup>														
<b>Electricity</b>															
CHP electrical efficiency	35 %														
CHP electricity produced	9,131 GJ	number of CHP units installed	1												
	2,536,709 kWh	output per unit	306 kW												
load factor	8,300 hours														
total CHP electrical capacity	306 kW generator														
lifespan of CHP	15 years														
electricity for digester	366.5 GJ	101798 kWh													
electricity for upgrade & compression	0.0 GJ	0 kWh													
electricity requirement total	366.5 GJ	101798 kWh													
grid supplied electricity	0 GJ	0 kWh													
<table border="1"> <thead> <tr> <th colspan="2">CHP embodied energy per unit</th> <th>total for all units</th> </tr> <tr> <th>concrete (GJ)</th> <th>steel (GJ)</th> <th></th> </tr> </thead> <tbody> <tr> <td>11.68</td> <td>142.0</td> <td>153.7 GJ</td> </tr> <tr> <td colspan="2"></td> <td>10.2 GJ/year</td> </tr> </tbody> </table>				CHP embodied energy per unit		total for all units	concrete (GJ)	steel (GJ)		11.68	142.0	153.7 GJ			10.2 GJ/year
CHP embodied energy per unit		total for all units													
concrete (GJ)	steel (GJ)														
11.68	142.0	153.7 GJ													
		10.2 GJ/year													
<b>Heat</b>															
CHP / boiler heat efficiency	50 %														
CHP / boiler heat produced	13,045 GJ														
	3,623,869 kWh														

Figure 20: Use of biogas

Where CHP is not included it is assumed that heat and electricity are imported. In the case of electricity this is assumed to be from the national grid, in the case of heat the source can be selected from the drop down list (Figure 21).

The potential size of the CHP unit is calculated on the basis of the total amount methane produced, the efficiency of the CHP in converting the energy of the methane into electricity and the load factor - the number of hours per year during which the CHP will operate. This allows for maintenance and other non-operating periods.

6,146,789 KWh	
imported energy for heat	0 GJ
heat energy source	natural gas
volume required	LPG diesel oil natural gas

**Figure 21: Heat energy sources**

This worksheet also includes the energy requirements for crop drying Figure 22.

Crop drying							
	1	2	3	4	20		
crop	grass silage (3 cut)	winter wheat - grain	grass for grazing	none	none		
FM (tonnes)	2250	2400	2400	0	0		
moisture content (%)	80.1	20	100	0	0		
storage moisture (%)	80.1	15	100	0	0		
dry	no	yes	no	no	no	total	
drying method	heat required (GJ)	0.00	814.80	0.00	0.00	0.00	814.80 heat (GJ)
CHP heat	MJ	0	814800.0	0	0	0	814800 MJ
CHP electricity	fan electricity (GJ)	0	60.48	0	0	0	60.48 electricity (GJ)
electric							
diesel oil							
electric							
natural gas							

**Figure 22: Crop drying**

The method of drying can be selected from a range. The energy required depends on the moisture content of the selected crop. Note: if drying has been selected but the energy requirement is 0 then check that the harvest moisture is greater than the recommended storage moisture content (dry matter is less than recommended) shown on the crop production work sheet.

### 8. Summary sheet

Finally, a summary is given of the energy requirements and balances and emissions produced and potentially saved (Figure 23 and Figure 24).

A	B	C	D	E	F	G	H	I
1	<b>On-farm AD energy balance</b>							
2								
3	<a href="#">help</a> Summary							
4								
5	<b>Energy</b>			<b>Energy balance (/year)</b>				
6	land area	450 ha		crop production direct		1604 GJ		
7	dairy cattle	100 head		crop production indirect		529 GJ		
8	other cattle	50 head		waste transport		0 GJ		
9	pigs	0 head		fertiliser manufacture		1728 GJ		
10	digester slurry input	1332.1 tonnes		fertiliser application direct		38 GJ		
11	digester crop input	4650 tonnes		fertiliser application indirect		11 GJ		
12	digester waste input	0 tonnes		digestate transp't & app direct		26 GJ		
13	digester loading	3 kg/m3/day		digestate transp't & app indirect		6 GJ		
14	digester capacity required	2364 m <sup>3</sup>		CHP supplied parasitic electricity		197 GJ		
15	digester retention time	131.2 days		imported electricity		0 GJ		
16	methane produced	788060 m <sup>3</sup>		CHP supplied drier electricity		60 GJ		
17	biogas	1428703 m <sup>3</sup>		imported drier electricity		0 GJ		
18	=	1818 tonnes		CHP drier electric heat		0.0 GJ		
19	digestate	4164 tonnes		imported drier electric heat		0.0 GJ		
20				CHP supplied separator electricity		19 GJ		
21	CHP electricity produced	9880 GJ		imported separator electricity		0 GJ		
22		2744640 kWh		CHP supplied dairy electricity		119 GJ		
23		330 kW generator		imported dairy electricity		0 GJ		
24	CHP heat produced	14114 GJ		CHP supplied parasitic heat		1415 GJ		
25	upgraded biogas	0 m <sup>3</sup>		imported gas for heat		0 GJ		
26	mineral fertiliser requirement			CHP supplied heat for drier		815 GJ		
27	N	36.9 tonnes		imported heat for drier		0 GJ		
28	P <sub>2</sub> O <sub>5</sub>	8.1 tonnes		imported heat type		natural gas		
29	K <sub>2</sub> O	9.7 tonnes		digester embodied		70 GJ		
30	direct fuel use			pasteuriser inclusion		none		
31	crop use diesel	40012 litres		pasteuriser heat		0 MJ		
32	fertiliser & digestate diesel	1583 litres		pasteuriser embodied		0 GJ		
33	waste transport diesel	0 litres				<b>total</b> 6638 GJ		
34	dairy electricity	119 GJ		on-site CHP		yes		
35	source	CHP		energy in methane produced		28228 GJ		
36	separator electricity	19.5 GJ		generated electricity		9880 GJ		
37	source	CHP		generated heat		14114 GJ		
38	drier electricity	60.48 GJ		exportable electricity		9484 GJ		
39	source	CHP				2635 MWh		
40	drier heat	814.80 GJ		exportable heat		11885 GJ		
41	source	CHP heat				3302 MWh		
42		814800 MJ		energy in upgraded CH <sub>4</sub>		0 GJ		
43								

Figure 23: Energy balances

Emissions from fossil fuel sources			
diesel fuel use in crop production	138527	kg CO <sub>2</sub> eq	
waste transport diesel	0	kg CO <sub>2</sub> eq	
fertiliser manufacture	282942	kg CO <sub>2</sub> eq	
pesticide manufacture & transport	4850	kg CO <sub>2</sub> eq	
imported electricity for AD	0	kg CO <sub>2</sub> eq	
imported electricity for separator	0	kg CO <sub>2</sub> eq	
imported electricity for drier	0	kg CO <sub>2</sub> eq	
imported electricity for dairy	0	kg CO <sub>2</sub> eq	
imported heat for AD	0	kg CO <sub>2</sub> eq	
imported heat for drying	0	kg CO <sub>2</sub> eq	
Energy source of grid based electricity generation	All fuels (including nuclear and renewables)		
energy source of heat used	natural gas		+
<b>total</b>	<b>426</b>	<b>tonnes CO<sub>2</sub> eq</b>	
Emissions saved from energy exported		Energy exported	
electricity generation	1336724	kg CO <sub>2</sub> eq	2635 MWh
heat used	810560	kg CO <sub>2</sub> eq	2748 MWh
upgraded gas	0	kg CO <sub>2</sub> eq	
<b>total</b>	<b>2147</b>	<b>tonnes CO<sub>2</sub> eq</b>	
exported nitrogen	0	kg	
potential emission savings	0	tonnes CO <sub>2</sub> eq	

Figure 24: Emissions

If no CHP is provided it is assumed that all heat and electricity for the AD plant is imported from the national grid for electricity and selectable source for the heat (i.e natural gas, LPG, or diesel oil). When calculating the emissions resulting from the generation of electricity for the national grid, various options can be selected including generation from coal to all sources including renewable (Figure 25).

Energy source of grid based electricity generation	All fuels (including nuclear and renewables)
energy source of heat used	<ul style="list-style-type: none"> <li>All fossil fuels</li> <li>All fuels (including nuclear and renewables)</li> <li>Coal</li> <li>Gas</li> <li>Oil</li> </ul>

Figure 25: Sources for electricity generation

The emissions saved from exported energy are based on the same selected fuel sources.

Emissions saved from the use of heat captured from the CHP are based on the amount of heat utilised as determined on the biogas use sheet. In both the case of electricity and heat the amount available for export is assumed to be that generated less the amount required for use at the AD plant including any biogas upgrading specified.

## 9. Temperatures

The temperatures sheet contains information relating to average monthly temperatures for the chosen location. The values used are those contained in column B. These values can be altered to match the users location. If the soil temperatures are unknown then a close estimate can be made by using the average air temperatures. Enter the required values in the blue cells on the left, Figure 26.

1	This sheet contains climate data for the chosen digester site.						Enter the required values in column B			
2	help									
3	month	York	Greenlaw, Dunfrieshire	Cambridge	York	Yeovil	Southamp ton			
4		air								
5	Jan	-1	3.8	2	-1	7	5			
6	Feb	3	4.1	3	3	8	5			
7	Mar	6	4.7	4	6	11	7			
8	Apr	7	6.8	8	7	13	9			
9	May	10	12.2	11	10	15	12			
10	Jun	12	13.4	14	12	19	15			
11	Jul	15	15.7	15	15	18	17			
12	Aug	15	14.7	15	15	21	17			
13	Sep	13	11.9	13	13	18	15			
14	Oct	9	7.8	9	9	14	11			
15	Nov	5	5.6	6	5	10	8			
16	Dec	2	2.6	3	2	6	6			
7		soil								
8	Jan	-1	3.8	2	-1	7	5			
9	Feb	3	4.1	3	3	8	5			
10	Mar	6	4.7	4	6	11	7			
11	Apr	7	6.8	8	7	13	9			
12	May	10	12.2	11	10	15	12			
13	Jun	12	13.4	14	12	19	15			
14	Jul	15	15.7	15	15	18	17			
15	Aug	15	14.7	15	15	21	17			
16	Sep	13	11.9	13	13	18	15			
17	Oct	9	7.8	9	9	14	11			
18	Nov	5	5.6	6	5	10	8			
19	Dec	2	2.6	3	2	6	6			

Figure 26: Temperatures

## 10. References

- AEA (2010) 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. London, DEFRA.
- DEFRA (2009) Guidance on How to Measure and Report Your Greenhouse Gas Emissions. London, DEFRA.
- DEFRA (2010) *Fertiliser Manual (RB209)*, Norwich, TSO.
- KTBL (2009) *Betriebsplanung Landwirtschaft 2008/09*, Darmstadt, KTBL.