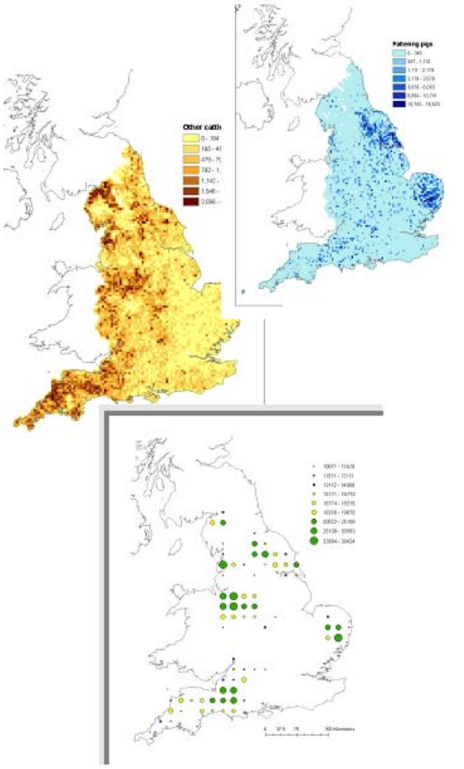
AEAT/ENV/R/2104

Assessment of Methane Management and Recovery Options for Livestock Manures and Slurries

Report for:

Sustainable Agriculture Strategy Division,
Department for Environment Food and Rural Affairs,
London SW1P 3JR



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Executive Summary

This report examines the current levels of methane emission from livestock manures and slurries in the UK and then explores possible options and routes for reducing the greenhouse gas emissions within a methane generation and recovery strategy for England.

Methane emissions from manures and slurry management make up 14% of the total methane emissions from livestock husbandry in the UK. Although slurry based management systems make up less than 40% of the manure management infrastructure, they account for 74% of methane emissions from manures and slurries. .

The most promising option for the exploitation of manures and slurries to reduce greenhouse gas emissions is the controlled generation and recovery of methane from slurry systems through anaerobic digestion (AD), either on farm or in a centralised facility. Experience from other countries is that AD can be made attractive to farmers, through a combination of financial incentives and the right technological developments. The financial incentives in other countries are generally related to promotion of renewable energy. The important technological developments have been in allowing the co-digestion of other wastes that are available all year round (slurry from some livestock tends to be seasonal as they are not housed in summer).

In the UK, historically economic returns have been poor for AD plants and farmer operators have encountered technical problems, compounded by their lack of operational knowledge and the poor availability of technical assistance. With the introduction of the Renewables Obligation and the Landfill Tax, the economics for centralised AD plants have improved but not to the point where a significant number would be economic without support. There are still the barriers associated with acceptance of the technology and these will need to be addressed in any strategy for methane recovery.

In this study, we have looked in detail at the economics for options for on-farm AD and centralised AD in England. All the options proved uneconomic without some extra Government support. However, a small number of larger CAD may be economic, especially if higher levels of industrial waste (up to 20%) were treated in the CAD. A cost benefit analysis based on the options and assuming Government support in the form of capital grants suggests that greenhouse gas emissions equivalent to up to 0.03MtC could be saved annually at a cost of £60/tC, if 20 CAD plants were built. However, this would result in lifetime costs to Government of £143M. On-farm AD would need significant support to be economic.

The main challenge to AD in the UK is therefore still an economic one. For CAD, high capital costs and an uncertain supply chain and market for products gives rise to high levels of project risk. A combination of actions involving financial incentives and engagement with farmers and technology suppliers would be needed to stimulate the market.

The experience from Germany suggests the main route to market for on-farm AD is to set incentives at a level such that it becomes a recognised source of extra income for farmers. Our analysis suggests that this will be an expensive option.

Contents

Appendices

1 Introduction

Methane emissions from livestock come mainly from two sources, enteric fermentation and manure. For the UK as a whole they were reported for 2003 (Baggot et al, 2005) as:

- Enteric methane emission = 764.9 kt (86%)
- Livestock waste management = 124.8 kt (14%)

This report deals with assessment of the latter category and examines options and routes for reducing the greenhouse gas emissions through within a methane generation and recovery from manure.

In this report, we estimate the quantity of methane currently emitted from the UK and England livestock manures and slurries, and identify and analyse likely options for significant GHG abatement through sluury and manure management. The basis of the overall analysis is the technical and economic evaluation of on-farm and large centralised AD plants that form the key part of the solution.

The report comprises six more sections, as outlined below:

Section 2 provides information on current practices associated with livestock manures and slurries and the associated methane emissions in the UK.

Section 3 reviews the UK and international experience with AD, aimed at methane abatement but also at energy recovery. It shows that although the technical potential for energy recovery is high in the UK, only a small amount of this resource is exploited.

Section 4 outlines the basis of and choice of options to address mitigation of methane from livestock manures and slurries. It also provides the basis for the underlying economic and GHG analysis.

Section 5 describes the role of AD towards meeting wider environmental, social and implementation challenges.

Section 6 provides a summary of the report and some recommendations of the next steps, should the options considered within this study provide a good basis for the methane mitigation strategy to emerge.

Section 7 provides glossary of terms, references and background information used to support the analysis presented in the report.

Appendix 1 is designed to provide the information required for the Methane to Markets questionnaire.

2 Current Situation

2.1 CURRENT MANURE AND SLURRY MANAGEMENT SYSTEMS

Manure and slurry management systems applied in the UK (based on the categories given in the IPCC guidelines, 1997) are shown in Figure 1.

- **Liquid (slurry) systems** are typically used for dairy cattle and pigs. The manure collected while the animals are housed is stored in a slurry pit or lagoon for a substantial period of time (months).

- **Daily spread systems** - these are slurry or solid manure systems, which have little or no manure storage (generally regarded as 1 month or less).

- **Solid 'deep litter' storage** – this is straw based cattle, pig and sheep housing systems.

- **Pasture range and paddock** is excreta from grazing animal directly deposited in the field; almost all sheep excreta falls into this category.

- **Other** – poultry manure tends to be drier than pig, cattle and sheep farmyard manure and is therefore categorised as other.

- **Incineration** – a substantial amount of poultry waste (mainly from fattening poultry) is incinerated for energy production. The waste is typically mixed with bedding (sawdust/shavings) and is relatively dry with a high calorific value, so is suitable for combustion.

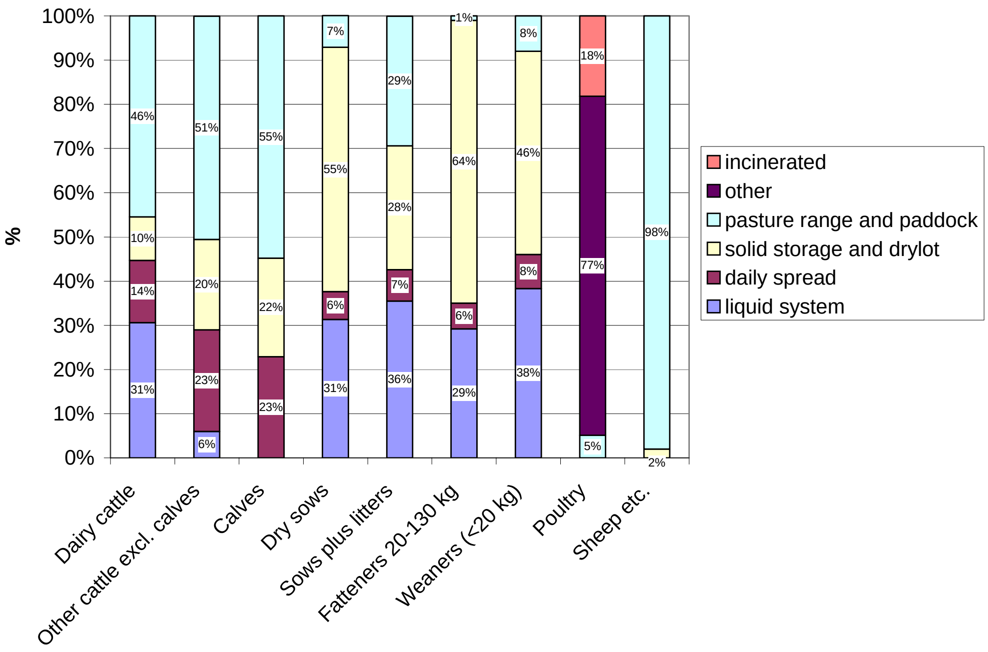

Figure 1: Proportion of wastes managed under different management systems

Dairy cattle are predominantly housed on slurry-based systems and beef cattle mostly housed on straw-based systems producing farmyard manure. Pig production in the UK is a mixture of slurry and straw-based housing systems.

2.2 MANURE PRODUCTION BY LIVESTOCK IN THE UK

Figure 2, shows that approximately 88 million tonnes per year are produced, of which just under one third is in liquid slurry form and just over two-thirds is solid farmyard manure (FYM) or poultry litter.

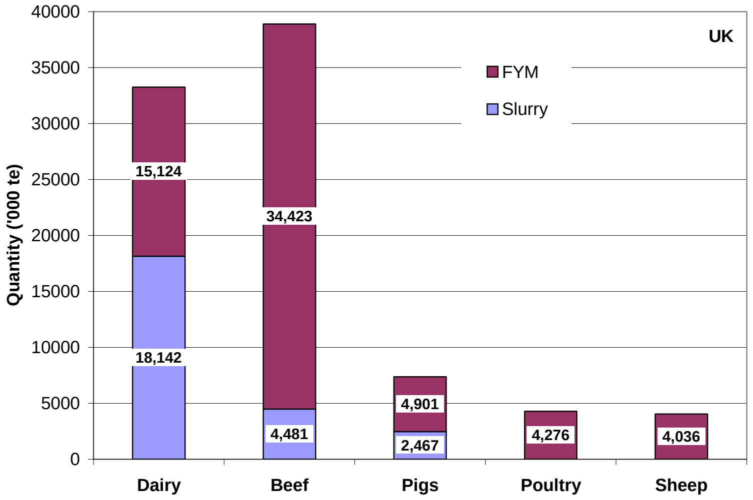

Figure 2: Slurry and FYM in UK, by main livestock categories

2.3 CURRENT METHANE EMISSIONS

Livestock manure is composed principally of organic material that can decompose in an anaerobic environment to produce methane. The amount of methane emissions from manure depend on the quality and quantity of the manure and on the proportion that decomposes anaerobically. Storage of slurry or manure in liquid form in lagoons, ponds or tanks tends to promote anaerobic decomposition and release methane to the atmosphere. When it is handled as a solid and/or deposited on pastures it decomposes aerobically, producing little or no methane.

Methane emissions from the current manure management practices in the UK were estimated using a Tier 2 IPCC methodology (IPCC, 1997) (see Appendix 2). The majority of emissions (74%) arise form slurry based systems, as these generate substantially more methane per tonne manure than other types of management systems (Table 1).

Table 1 Annual UK methane emissions by manure management practice[1]

Manure management practice	Kt CH_4/y	%
Slurry based systems	96.7	74
Solid manure systems	14.5	11
Daily spread and pasture	19.1	15
Total	**130.3**	**100**

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[1] The total value is different from the number in the UK Greenhouse gas inventory due to the more detailed estimation methodology used in this study (see Appendix 2)

3 Technology options

3.1 INTRODUCTION

To effectively control methane the breakdown of the animal manures and slurries must either be an entirely aerobic process (as with most sewage treatment) or one where the natural anaerobic breakdown of the waste is controlled such that the methane production is optimised and the methane captured for beneficial use. Both require engineered solutions but aerobic plant need significant investment in aeration systems and involve higher operating costs making the more ‘passive’ anaerobic digestion (AD) option more cost effective making it the system of choice for commercial application.

AD involves harnessing the natural process of conversion of organic matter to energy by microbiological organisms in the absence of oxygen. The biogas produced in the process is a mixture of methane and carbon dioxide and can be used as a fuel source for heating and/or electricity production. The treatment leaves behind liquor, which can be used as liquid fertiliser and so returned to farms from where the slurry has come. In certain circumstances, it may prove attractive to separate fibre, from the treated slurry, and sell this as a nutrient-rich soil conditioner. AD can be carried out in small scale systems located on the farm and operated by farmers or in large centralised systems, operated as commercial concerns. These will collect slurries from several farms in the region and will probably also use industrial organic waste as a feedstock.

There are a number of technological advancements that can improve the biogas yield of an AD system. These include the use of solar power to worm the digestion, especially for smaller systems, as well as heat recovery systems to elevate digestion temperature to enhance methane recovery (El Mashad et al., 2004). Heat pre-treatment of the slurry at 70^{o}C can also enhance methane generation and recovery through denaturation of the fibrous material in the in-feed (Skiadas et al., 2005), and can be achieved by using heat produced as a by-product of electricity generation from biogas. This can provide added advantage in centralised plant taking industrial waste, where heating for 1 hr at 70^{o}C is a requirement for sterilisation of food and other low risk wastes (Defra Guidance).

The anaerobic digestion of solid animal manures and slurries in an accumulation system, which is a form of fed-batch rather than a continuous system, has been studied. The system takes some 60 days to load, followed by about 50 days of batch digestion at 40-50^{o}C (El Mashad et al., 2003). However poor mixing conditions lead to poor performance. Another alternative for FYM, which is a mixture of solid manure and straw or other bedding materials, is to utilise it in a plant where the feedstock is municipal solid waste. This has been found to lead to a better inoculation and greater methane yield (Vavilin and Angelidaki, 2005).

3.2 UK EXPERIENCE WITH AD

Over the last 20 years interest in the UK in AD of livestock manures has fluctuated considerably. However, in practice there has never been more than a very small uptake by the agricultural industry. Estimates of the number of plant (Table 2) suggest that there is currently one centralised AD plant (at Holsworthy in Devon) exporting electricity and 15 to 20 operational on farm AD units, mostly producing heat only.

Table 2 Estimated number of AD plant in UK

Review	Estimate of Units in UK	Estimate of Energy Production
Baldwin (1993)	40 (on farm)	
AD-NETT, (2000)	31	
Restats review (www.restats.org.uk),	15 (including 1 CAD)	31, 600 MWh (mostly heat)
European review (Kottner, 2005)	< 20	Total capacity <2 MW
Recent discussions with industry	40 of which 20 operational	

On-farm AD units in the UK are mesophilic (i.e. operating at 35 – 37 ºC) and designed for the digestion of liquid manure (slurries). The majority produce heat for use on the farm and farmhouse, and unless there is a good demand for heat on farm, the full potential of the energy produced by AD may not be realised. There is at least one site, which has a combined heat and power unit and also produces electricity. Detailed energy output and efficiency data are not available for the majority of installations, but a Defra funded study aimed at estimating fugitive emissions from on-farm AD (Project CC0222) provides data for two units. Results from the study suggested that on-farm units have a poor efficiency when compared with theoretical methane yields. At one site the operating temperature was often far below the ideal. Fugitive emissions were measured to be between 3 and 8 % of the biogas yield and depended on the proportion of gas being produced that could be used immediately, indicating methane leakage from storage. In addition, there were methane emissions from the uncovered digestate store. This means that the overall reduction in methane emission (i.e. compared to conventional slurry storage systems) achieved in actual installations depends on a number of factors including how the plant is maintained and operated, the fitting of slurry store covers and the biogas utilisation scheme.

The possible reasons for the poor uptake of on-farm AD was explored with some of the existing operators. The primary barrier to adoption was the poor economic return due to high capital costs of the installation, no soft loans and little or no income to support the debt. In addition, there is a distinct lack of any incentives through agri-environmental schemes under CAP reform or any benefits to operators through carbon credits. A second important barrier was identified as the technical problems encountered by farmer operators, compounded by their lack of operational knowledge and poor availability of technical assistance. Operators were not always aware of how to obtain the best yields from the system. Most of the farmer operators had faced mechanical problems, often resulting from the corrosive sulphide gases in biogas. These barriers concur with those reported elsewhere (e.g. Morse et al., 1995; Garrison and Richard, 2005). Garrison and Richard (2005) also identified grid connection difficulties as a major barrier. These are therefore the key problems that need to be overcome in order to increase the adoption of on-farm systems within the UK.

Reviews in the 1990s (Baldwin, 1993a, b) suggested that centralised anaerobic digestion (CAD) of livestock manures might be more attractive economically than on-farm systems. In addition to the economies of scale, CAD plants could also incorporate other agro-industrial waste streams, further enhancing the economic viability of such plants. One CAD plant is operating in the UK. It has a 2.1 MW capacity, utilising manure from 30 surrounding livestock farms together with imported food waste. It produces electricity, which is exported to the grid and heat, which is not yet fully utilised as the infrastructure to enable the heat to be utilised in a local district heating scheme needs to be developed. The lack of such infrastructure was highlighted as a major difference from the situation in Denmark, where such district heating schemes exist and CAD has been successful, and the UK (Dagnall et al., 2000).

3.3 INTERNATIONAL EXPERIENCE

Table 3 provides the number of agricultural AD plants in EU countries and their electricity generation capacities. It is clear from the table that there are a number of European countries in which the uptake of AD, either on-farm or centralised, by the agricultural industry has been much greater than in the UK.

Table 3: Numbers of biogas plants in EU-countries producing electricity (Source: Michael Kőttner, November 2005)

Country	Agricultural AD plants	Installed capacity MW_e
Austria	159 +150 to end 2007	29 + 40 to end 2007
Belgium	6	12.3
Denmark	58 on-farm 20 CAD	40
France	3	n/a
Germany	> 3000	550
Great Britain	<20	<2
Ireland	5	0.2
Italy	80	62
Netherlands	12	3.8
Switzerland	71	n/a

In Germany, in particular, there has been a very large increase in the uptake of on-farm units since the mid-1990s, with over 3000 units now operating (although this reportedly still only represents <3% of the potential for biogas production). The economics of producing renewable electricity in Germany have favoured the uptake of these on-farm AD systems by farmers seeking to enhance their income. For small-scale AD the additional tariff is nearly twice that of renewable obligation certificates in the UK, with extra available for CHP. In addition, technological advances made in Germany, enable dry fermentation and co-digestion with energy crops, increasing the potential for biogas production. The industry is also backed up by a large number of suppliers and good technical support. In summary, the German experience (Kottner, 2005) highlights a number of areas that are in contrast with the situation in the UK.

These are:

- Guaranteed feed in tariffs for the electricity exported (methane generation contributed by energy crops receive an additional tariff, making it the highest in Europe at ~21.3 cents/kWh, which is nearly twice that in the UK);
- Downward sliding scale applied to the tariffs, with time (this tends to lead to a higher rate of implementation at the start of the scheme);
- A great deal of preparatory and foundation work was carried out prior to the introduction of the legislative drivers in the nineties;
- A good AD plant supply chain exists, which is also active in exporting the technology supply;
- Farmers have been trained and prefer to operate and manage the on farm plant themselves, with minimal purchased maintenance for pumps, mixers etc; and
- Financial assistance offered for AD plant investments, such as soft loans.

In Denmark, the uptake in technology has largely been through the development of CAD plants. Technological advancement and co-digestion of manure with other waste streams to enhance gas production have led to the production price of biogas falling dramatically (Maeng et al., 1999). However, the continued success of the biogas industry does rely on policies favouring renewable energy.

Technologically, therefore, there are no reasons why uptake of on-farm AD or CAD should not increase in the UK. However, it is important that systems being promoted in the UK represent the best in terms of technological advancement and that the industry is underpinned with sound and accessible technical support.

3.4 TECHNICAL METHANE RECOVERY POTENTIAL

AD represents the best available methane recovery technology for widespread utilisation at either an on-farm or centralised scale. Methane recovery from solid manures would do little to mitigate current methane emissions from manure management, but could contribute to the production of renewable energy, offsetting greenhouse gas emissions from current energy production from fossil fuels.

As mentioned in Section 2, there has been poor uptake of AD technology for treating livestock manure in the UK and statistics on existing facilities are sparse. For the UK, there is one centralised AD plant, taking slurry from approximately 30 dairy farms, and perhaps 20 on-farm AD units. Making some generalisations (that all farms where AD is applied are large dairy farms of 150 cattle, that the IPCC methane conversion factors apply and AD recovery efficiency is 60%) it can be estimated that less than 0.1% of methane produced is being recovered through the current AD systems in the UK.

A number of factors contribute to the technical potential for AD. Some animals such as pigs and poultry are kept as free range and animals such as cattle and calves are only housed for around half the year. While the animals are on pasture fields, the manure is dropped on the field and is unavailable for methane recovery. In addition, the proportion of farms that collect slurry varies from around 18% for beef cattle to around 66% for dairy cattle. Some of the intensively farmed pigs are housed for as much as 100% of the year.

The methane producing potential of manures from these animals depends on the amount and nature of the accessible organic material, which is sometimes referred to as the volatile solids (VS). This means that the ultimate methane yield will be dependent on the livestock type and growth stage, feed characteristics, amount and type of bedding material used and any degradation processes during pre-storage.

Table 4: Estimates of methane recovery potentials by anaerobic digestion

Livestock type	**Theoretical potential**	**Technical potential**
	kt CH_4/y	**kt CH_4/y**
Dairy cattle	435	127
Other cattle excl. calves	632	43
Calves	172	-
Dry sows	34	9
Sows plus litters	8	5
Fatteners 20-130 kg	167	37
Weaners (<20 kg)	37	13
Poultry	1,407	770
Sheep etc.	669	-
Total	**3,563 (100%)**	**1,004 (28.2%)**

Table 4 shows the theoretical and technical potential of methane generation by anaerobic digestion. For the purpose of this study we have defined them as follows:

Theoretical Potential:	This assumes all livestock manures (i.e. including those excreted in pastures) could be collected and treated by AD and the full theoretical methane yield could be realised (i.e. 100% of Bo as defined in the IPCC methodology).
Technical Potential:	This assumes only collectable manures are treated by anaerobic digestion, and that 75% of the theoretical methane generation potential is realised. This methane could be used to generate about 5 TWh of electricity, which is around 15% of the current renewables obligation, set for 2010.

The estimate of economic potential is dependent on factors such as the current energy price and a detailed analysis is presented in Section 4.

4 Options for Greenhouse Gas Mitigation

4.1 INTRODUCTION

To develop a strategy for greenhouse gas mitigation through AD, we first defined the practical options for introducing AD namely the number of plants that might be considered for AD and a reasonable level of targeting of livestock manures that give rise to methane emissions. The likely economics of these plants at the project level were then calculated and options for policies to encourage development considered. Finally, we calculated the broad costs and benefits of such a policy.

Both types of AD plants require sufficient manure to be available to supply enough feedstock for the plant i.e. they are dependent on the density of the livestock population in localities. The necessary data were not available for the UK as a whole so the following analysis concentrates on England only.

4.2 CHOICE OF OPTIONS FOR ENGLAND

The livestock data and holdings structure for England are shown in Table 5. Dairy cattle in England are about 65% of the UK total and pigs around 80%.

Table 5: Livestock data used in options evaluation for England

Livestock type (by herd size)	Numbers 2004	Number of holdings	Average herd size	Proportion of year housed	Proportion of the waste as slurry
1-49 dairy cattle	151,672	5,459	28	59%	66%
50-99 dairy cattle	404,900	5,220	78	59%	66%
100+ dairy cattle	817,884	4,875	168	59%	66%
Total dairy cattle	**1,374,456**	**15,554**	**-**	**59%**	**66%**
1-49 other cattle*	316,654	18,669	17	50%	18%
50-99 other cattle*	845,332	17,852	47	50%	18%
100+ other cattle*	1,707,541	16,672	102	50%	18%
Total other cattle	**2,869,527**	**53,193**	**-**	**50%**	**18%**
<300 fattening pigs*	124,153	4,663	27	90%	33%
300-999 fattening pigs*	658,918	1,200	549	90%	33%
1000+ fattening pigs*	1,719,280	783	2,196	90%	33%
Total fattening pigs	**2,502,351**	**6,646**	**-**	**90%**	**33%**
Poultry – layers	29,695,042	27,655	(27% is free range)		
* The livestock holding numbers have been extrapolated from the UK data.					

The proportion of methane emissions from the different livestock types is shown in Figure 3. The largest contributions from slurry-based emissions are from dairy and other cattle and from fattening pigs. The strategy for mitigation studied therefore targets these emissions.

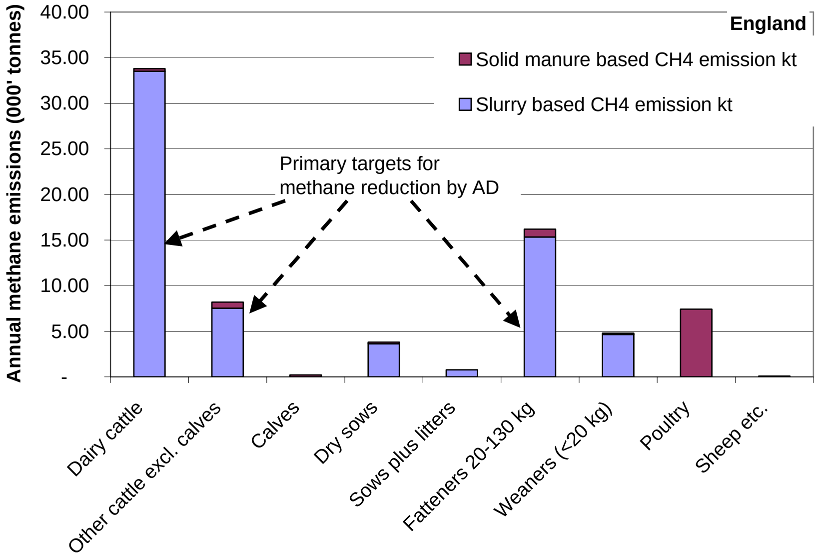

Figure 3: Annual methane emission from manure management in England, and those specifically assessed for reduction

The economics for CAD will depend on the volumes of manures and the distance the manure has to be transported. CAD plants will therefore ideally be sited where there is a high density of livestock. Figure 4 shows the relative distribution of dairy cattle, other cattle and fattening pigs in England. The figure also provides the distribution of egg layers in England, as the characteristics of manure from egg layers makes it suitable for anaerobic digestion. This material is important as it can provide a base load of the feedstock throughout the year. The figure shows that the concentration of cattle is in the West of England, whereas that of pig is in the East of England. This means that the centralised plants are likely to be dominated by either pig population or cattle population in any given area.

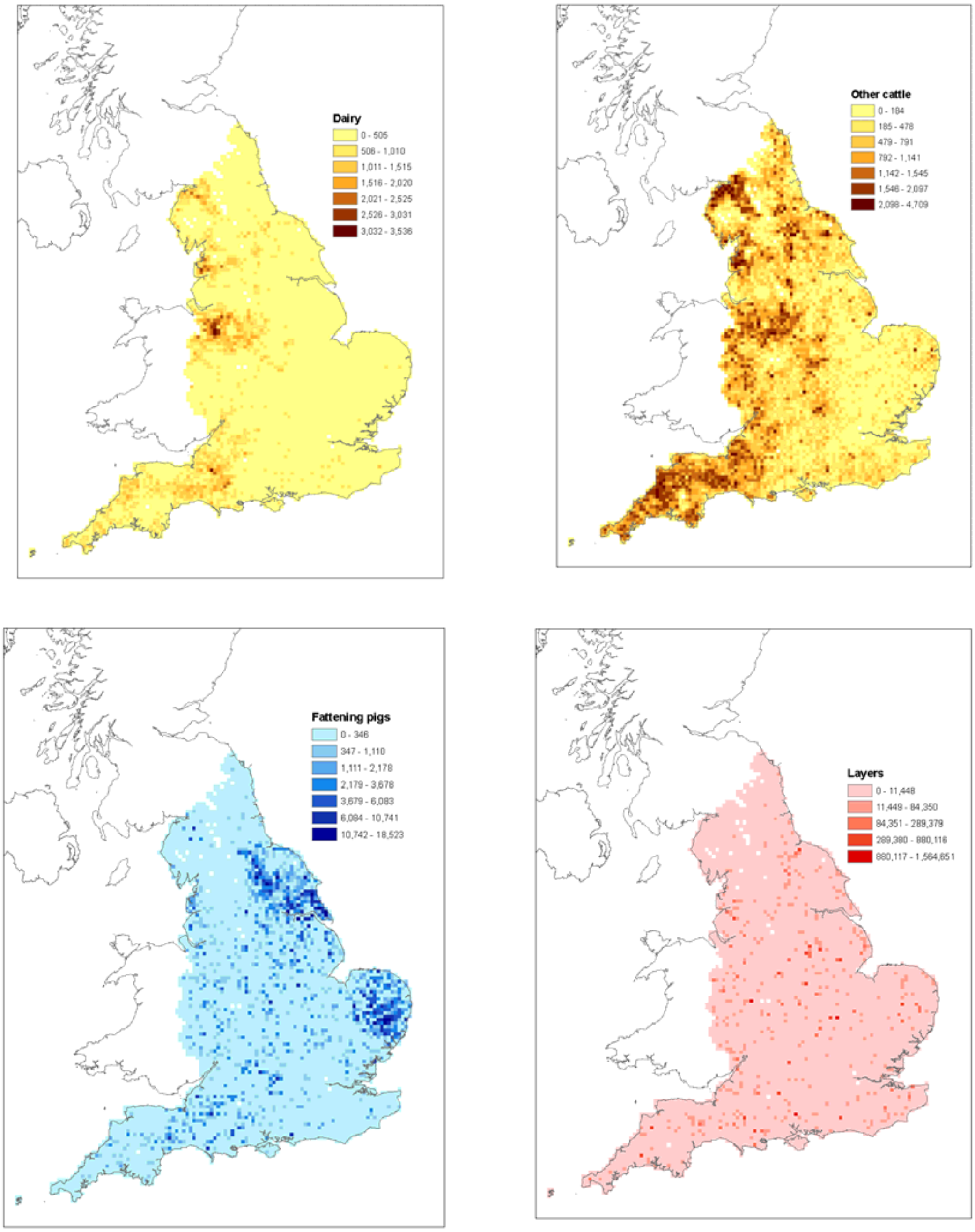

Figure 4: Distribution of dairy cattle, other cattle, fattening pigs and egg layers in England (based on 5x5 km data – Defra statistics, York)

The analysis was based on GIS data (Defra 2004) listing livestock population and number of holdings for all livestock categories and sub categories for 5km grid squares. To arrive at a cumulative estimate of the methane potential of slurries from the different livestock, dairy cattle and pigs were expressed as ‘cattle equivalent’ (CE), according to relative emissions of methane. Using this, a reasonable disaggregation of population density can be obtained by analysing 25km grid squares.

With this choice of grid squares the average distance to the CAD plant would be 10km. It should be noted that the distance that the poultry manure can be transported is considerably greater than that for either cattle or pig slurry. In our economic analysis (Section 4.3) we use 15 km as the 'road distance' travelled for the cattle and pig slurries, whereas that for egg layers is taken to be 60km.

Appendix 4 gives the methodology used to identify groups of CAD plants and their locations. Figure 5 shows dairy cattle and fattening pigs (expressed as cattle equivalent) by areas[2] of England, in a descending order.

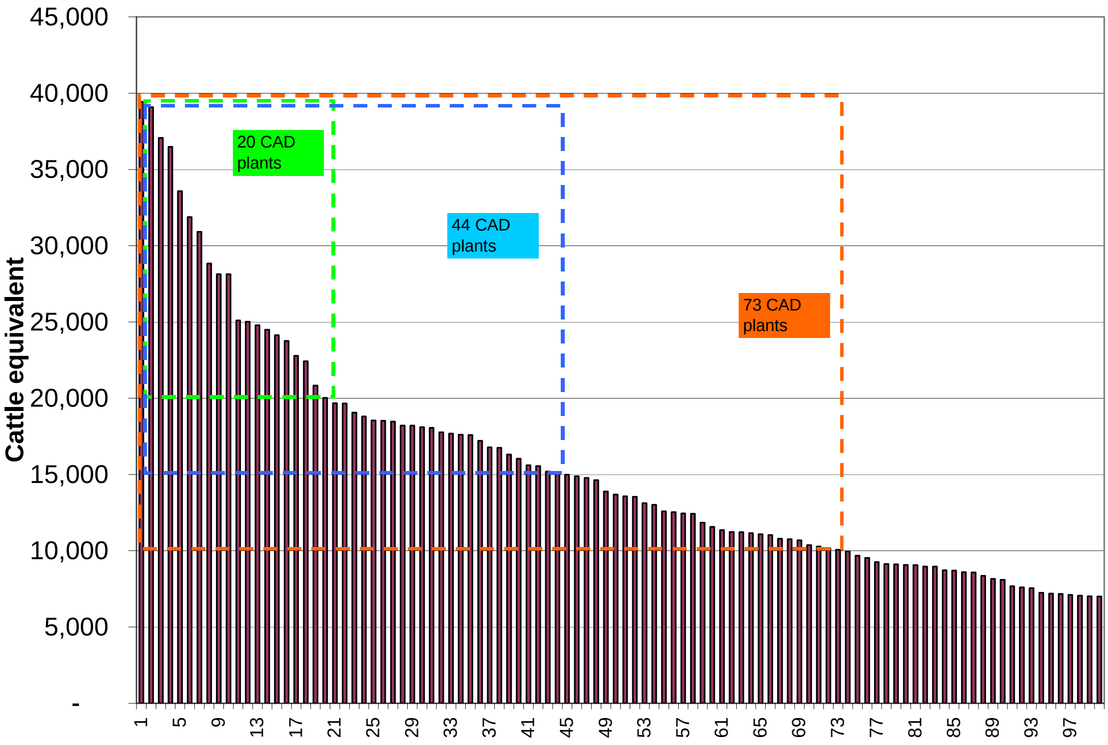

Figure 5: Dairy cattle and fattening pigs, expressed as cattle equivalent, as a function of 25km by 25km areas of England

The potential locations of the CAD plants are shown in Figure 6. The green dots correspond to the largest 20 CAD plants, yellow dots to the next 24 CAD plants and the blue dots to an additional 39 CAD plants. The options chosen, for analysis in the next sections, are as follows:

- CAD 20 option refers to the first 20 CAD plants, with CE value >20,000
- CAD 44 options refers to the first 20 and the next 24 CAD plants, with CE value of >15,000 and
- CAD 73 option refers to the above 44 as well as the next 39 plants, with CE value >10,000.

The livestock numbers and electrical generation capacity associated with the individual plants associated with these options are given in Table 6.

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[2] Total land area of England was split into 262 areas, of around 25km by 25km.

Table 6: Livestock associated with the CAD plants in the three categories

	Dairy cattle	Other cattle	Fattening pigs	Egg layers	CHP generation capacity
CAD 20 plant	12,658	4,202	11,350	421,277	3.6 MWe
CAD 44 plant	10,182	3,969	8,687	328,076	2.9 MWe
CAD 73 plant	8,656	3,700	7,395	301,191	2.6 MWe
Note: CHP generation capacity of the Holsworthy CAD plant is 2.1 MWe.					

CAD options chosen above would only address a proportion of the methane emissions. To explore greater coverage, on-farm AD plants were also considered but only for the larger size holdings as they provide a more economic solution than smaller holdings. We have considered seven options altogether as given in Table 7.

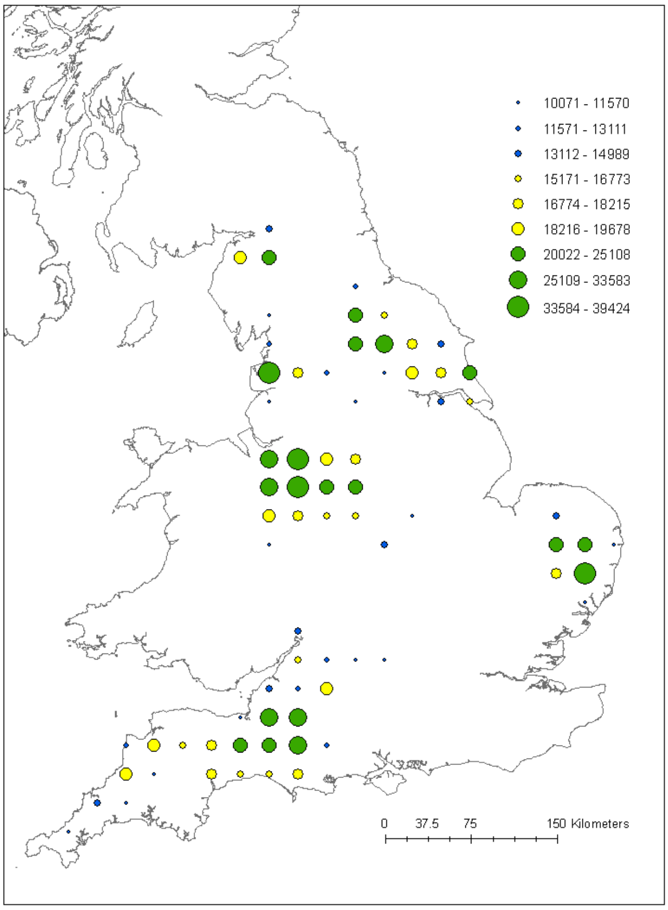

Figure 6: Potential locations of centralised AD plants in England (the key within the figure relates to dairy cattle and fattening pigs population, but expressed as cattle equivalent; see Appendix 3)

Table 7: Combination of OFAD and CAD comprising the methane mitigation options

Option	Farm/herd sizes included	Comments
Option 1:CAD-20	CAD plants	20 Centralised AD plants
Option 2: CAD-44	CAD Plants	44 Centralised AD plants
Option 3:CAD-73	CAD plants	73 Centralised AD plants
Option 4: CAD-20 and on-farm AD	CAD plants	20 Centralised AD plants
	100+ dairy cattle	On Farm AD Plants
	100+ other cattle	
	1000+ fattening pigs	
Option 5: CAD-44 and on-farm AD	CAD Plants	44 Centralised AD plants
	100+ dairy cattle	On Farm AD Plants
	100+ other cattle	
	1000+ fattening pigs	
Option 6: CAD-73 and on-farm AD	CAD plants	73 Centralised AD plants
	100+ dairy cattle	On Farm AD Plants
	100+ other cattle	
	1000+ fattening pigs	
Option 7: On farm AD	1-49 dairy cattle	On Farm AD Plants
	50-99 dairy cattle	
	100+ dairy cattle	
	1-49 other cattle	
	50-99 other cattle	
	100+ other cattle	
	<300 fattening pigs	
	300-999 fattening pigs	
	1000+ fattening pigs	

4.3 ECONOMIC & CO_2 EMISSION CALCULATIONS

The economic analysis is in two parts: the first looks at the costs and benefits of an AD plant for the project developer and the second looks at the broader costs and benefits of a policy to deliver the different AD options.

This section outlines the scope and key assumptions used in the economic and commercial evaluation that underpins the options evaluation and also the greenhouse gas emission reduction. As mentioned earlier, there are two models for farm waste AD. One is based on small on-farm AD plant and the other is for the waste of a number of farms to be taken to a large, centralised facility such as that developed at Holsworthy in Devon.

A number of assumptions are made to evaluate the feasibility of the AD options, as given in Appendix 4. The appendix also provides example calculations for three cases of on-farm AD and one case of CAD. Table 8 and Table 9 provide an overview of the economic and carbon balance for the projects.

The schematic of on-farm AD is given in Figure 7; whereas that for CAD is given in Figure 8.

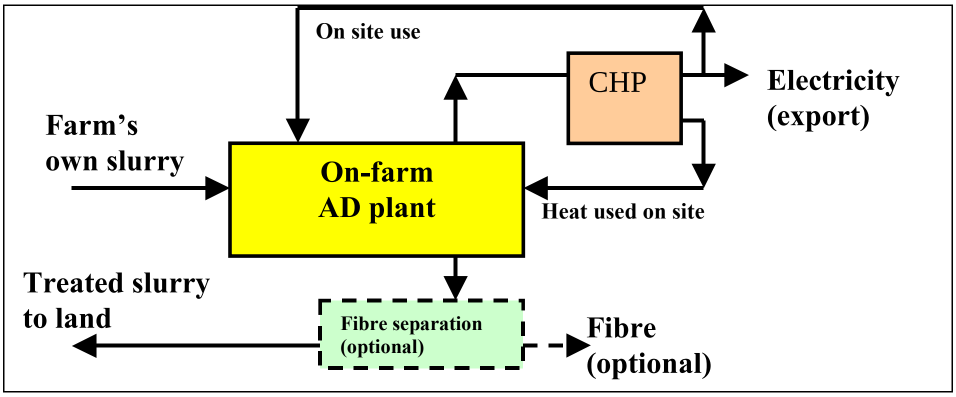

Figure 7: Schematic of On-farm AD plant

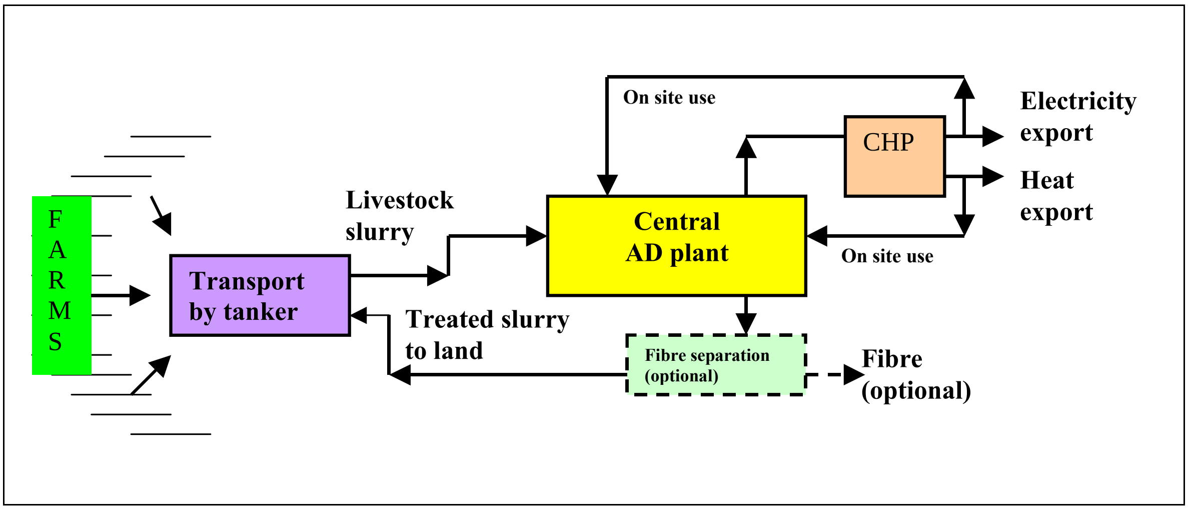

Figure 8: Schematic of Central AD plant, serving several livestock farms

Figure 9 shows the components of operating cost associated with a CAD plant, the basis of which is given in Table 8. Figure 10 shows the components of emissions, expressed as CO_2 equivalent, associated with a CAD plant. It should be noted that the CO_2 emissions related to biogas use are taken as 'biogenic', i.e. would be no more than if the waste decomposed naturally, and therefore taken as zero.

Table 8: Costs and income associated with the OFAD and CAD plants

Costs	Income
Capital cost of the AD	Income from electricity sales at base price
Capital cost of the CHP	Income from renewable obligation certificates (ROC)
Operation and maintenance (rates, insurance, maintenance, staff) costs	Income for avoided CCL (associated with issue of levy exemption certificates)
Slurry transport*	Income from the receipt of industrial waste (as gate fee)*
Poultry waste transport*	Any income from the sale of fibre – assumed none at this stage
	Any income from the (small) sale of digestate – assumed none at this stage
	Any capital grant or methane payment – assumed none at this stage (depending on policy option)
* Does not apply to the on farm AD plant	

Table 9: Carbon balance associated with the CAD plants

Savings	Emissions
Avoided carbon emissions from exported electricity	Transport of slurry (to/from) CAD*
Avoided carbon emissions from exported heat*	Transport of poultry manure to the plant*
	Leakage of methane from the AD plant
* Does not apply to the on farm AD plant	

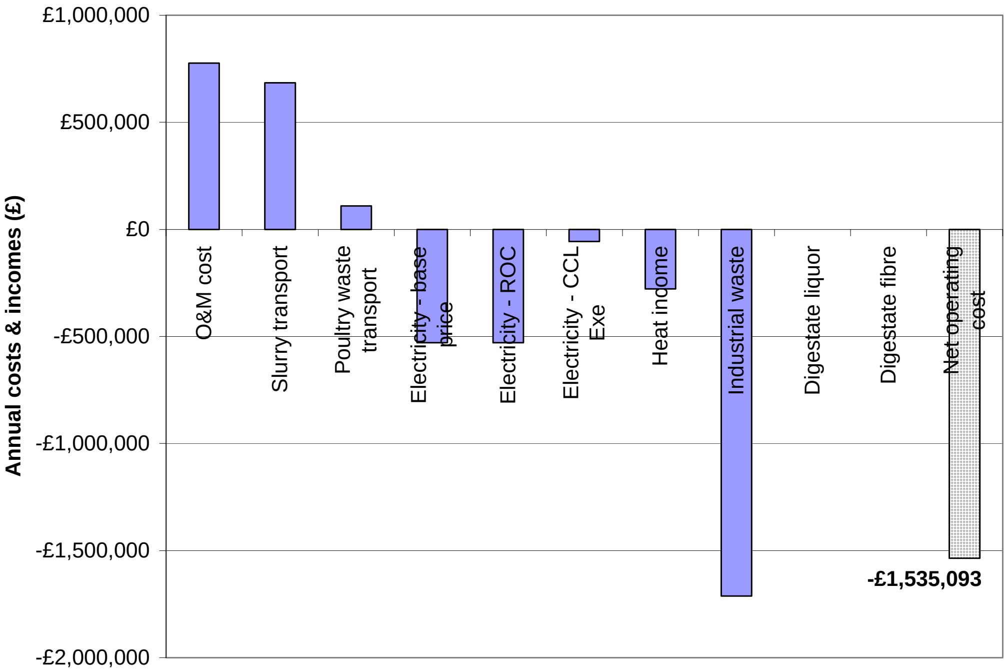

Figure 9: Components of operating cost associated with a CAD20 plant

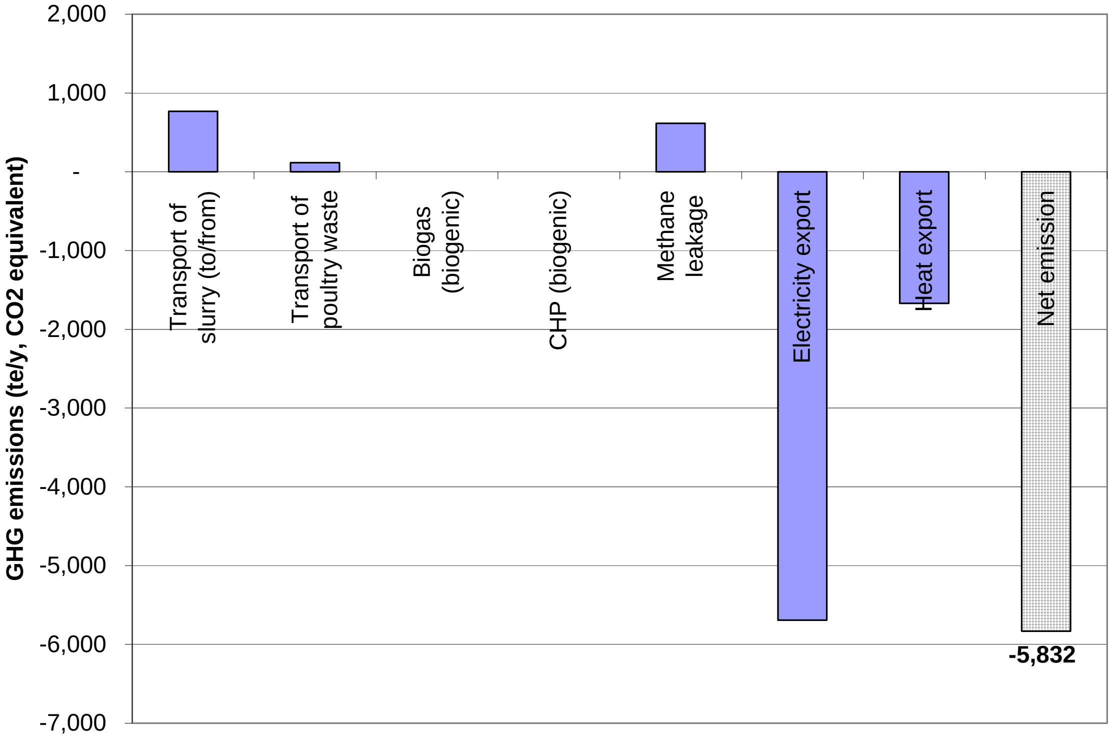

Figure 10: Components of GHG balance associated with a CAD20 plant

4.4 ANALYSIS OF PROJECT OPTIONS

There has been little development of AD in the UK to date, suggesting that it is uneconomic. In the economic analysis, we therefore included a policy option to provide additional support. As the main policy option, we assumed there would be a grant towards the capital cost of the plant. The level of the grant was set to the level necessary to achieve 15% return on a CAD project. For on-farm AD, the economics were such that 100% capital grants were assumed. As an alternative, we also analysed the costs of providing a subsidy based on the amount of methane produced (based on the assumption that this would be more easily measured than say the volume of waste treated). The lowest level of subsidy to make an on-farm option economic was selected (otherwise there would be a substantial deadweight in the policy). That value (£0.2/m^3 of methane) made on-farm AD economic for pigs but not the cattle options. It was assumed that the subsidy would not be offered in conjunction with grants for on-farm plants nor to methane in CAD.

The options studied are detailed in Table 10, which also provides the associated number of holdings and livestock population, the percentage of livestock covered by the options.

Table 11 shows total project costs for the options for England and the costs of the subsidy for the relevant plants. The IRR figures given are for individual projects before any grant support. Even for the larger CAD plants (Option 1), the IRR without capital grants is only 7% and a grant of 50% of capital cost would be required to make them economic (15% IRR). The proportion of capital needed as a grant increases slightly as the size of the CAD plant decreases. The economics for CAD plant become more favourable as size increases and it may be that a few very large plants would be economic in current market conditions. They would however cover a smaller proportion of methane emissions and would probably need a base load of other wastes in order to maintain operation throughout the year. On-farm AD for medium size dairy farms and other cattle farms are uneconomic even with 100% capital grants.

A large proportion of the operating income for CAD plants comes from gate fees for industrial waste and from the sale of electricity generated. The economics are thus quite sensitive to the assumptions made in these areas. If a guaranteed price level for electricity similar to that available in Germany were available, CAD would be very close to economic and on-farm pig AD plants would be financially attractive. In Denmark, levels of industrial waste up to 25% are treated in CAD. Input of this amount of industrial waste would make CAD (at the 20 plant size level) economic.

Table 10: Options versus livestock coverage in England

England		Total livestock	Average size of holding	No. of holdings	No. on slurry	Livestock covered by option	Total Livestock covered
Option 1 and 4: CAD-20 and on-farm AD	Dairy cattle		20 CAD plants: 383,580 DC from 3789 holdings** 466,861 OC from 8588 holdings** 694,791 FP from 2183 holdings**			28%	71% (DC) 66% (OC) 78% (FP)
	Other cattle					16%	
	Pigs					28%	
	100+ dairy cattle		160	3,687	2,433	43%	
	100+ other cattle		102	13,980	2,516	50%	
	1000+ fattening pigs		2,362	526	174	50%	
Option 2 and 5: CAD-44 and on-farm AD	Dairy cattle		44 CAD plants: 678,781 DC from 7134 holdings** 970,137 OC from 17600 holdings** 1,170,024 FP from 4004 holdings**			49%	79% (DC) 79% (OC) 84% (FP)
	Other cattle					34%	
	Fattening pigs					47%	
	100+ dairy cattle		157	2,639	1,742	30%	
	100+ other cattle		117	11,137	2,005	45%	
	1000+ fattening pigs		2,941	311	103	37%	
Option 3 and 6 CAD-73 and on-farm AD	Dairy cattle		73 CAD plants: 957,359 DC from 9886 holdings** 1,500,600 OC from 26893 holdings** 1,652,451 FP from 5875 holdings**			66%	86% (DC) 81% (OC) 89% (FP)
	Other cattle					52%	
	Fattening pigs					65%	
	100+ dairy cattle		154	1,777	1,173	20%	
	100+ other cattle		102	8,025	1,445	29%	
	1000+ fattening pigs		2,196	276	91	24%	
Option 7: On farm AD	1-49 dairy cattle	1,374,456	28	-	-	-	89% (DC)
	50-99 dairy cattle		78	5,220	3,445	29%	
	100+ dairy cattle		168	4,875	3,218	60%	
	1-49 other cattle	2,869,527	17	-	-	-	60% (OC)
	50-99 other cattle		47*	-	-	-	
	100+ other cattle		102	16,672	3,001	60%	
	<300 fattening pigs	2,502,351	27	-	-	-	95% (FP)
	300-999 fattening pigs		549	1,200	396	26%	
	1000+ fattening pigs		2,196	783	258	69%	

* Anomaly in data, caused by extrapolating UK holding data to that for England

** Out of these holdings, only those on slurry collection systems could participate in CAD plants

Table 11: Summary of plant economics and grant support by options for England

England		Capital cost (£m) (total for all plants within option)	Operating income (£m/y) Negative is cost	IRR, where appropriate)	Government grant support (£m)	CO_2 saving (t CO_2/y)
Option 1 CAD20	CAD = Dairy & other cattle & pigs	311	31	7%	145	116,642
Option 2: CAD44	CAD = Dairy & other cattle & pigs	582	53	6%	296	201,452
Option 3: CAD73	CAD = Dairy & other cattle & pigs	862	76	6%	450	296,011
Option 4: CAD-20 and OFAD	CAD = Dairy & other cattle & pigs	311	31	7%	145	116,642
	100+ dairy cattle	372	2	-	372	32,496
	100+ other cattle	346	-4	-	346	9,994
	1000+ fattening pigs	33	4	-	33	13,779
Option 5: CAD-44 and OFAD	CAD = Dairy & other cattle & pigs	582	53	6%	296	201,452
	100+ dairy cattle	266	2	-	266	22,823
	100+ other cattle	278	-3	-	278	9,132
	1000+ fattening pigs	21	3	-	21	10,144
Option 6: CAD-73 and OFAD	CAD = Dairy & other cattle & pigs	862	76	6%	450	296,011
	100+ dairy cattle	179	1	-	179	15,075
	100+ other cattle	199	-2	-	199	5,737
	1000+ fattening pigs	17	3	-	17	6,722
Option 7: OFAD	1-49 dairy cattle	No option**				
	50-99 dairy cattle	487	-3	-	487	22,429
	100+ dairy cattle	496	4	-	496	45,115
	1-49 other cattle	No option**				
	50-99 other cattle	No option**				
	100+ other cattle	413	-5	-	413	11,918
	<300 fattening pigs	No option**				
	300-999 fattening pigs	57	1	-	57	7,306
	1000+ fattening pigs	47.9	5	-	48	19,070

** The small farms would not be able to exploit AD, as the plant size will be too small for any economic returns from the investment. As such the suppliers also tend to exclude this in their range of supplies.

Table above continued:

England		Government grant support (£m)	Methane subsidy £M/y	CO_2 saving (te/y)
Option 4b: CAD-20 and OFAD	CAD = Dairy & other cattle & pigs	145		116,642
	1000+ fattening pigs		3	13,779
Option5b: CAD-44 and OFAD	CAD = Dairy & other cattle & pigs	296		201,452
	1000+ fattening pigs		2	10,144
Option 6b: CAD-73 and OFAD	CAD = Dairy & other cattle & pigs	450		296,011
	1000+ fattening pigs		2	6,722
Option 7b	1000+ fattening pigs		4	19,070

The larger CAD options are clearly the most cost effective but together cover a small proportion of the emissions. Table 12 provides emission saving by options, both as CO_2 equivalent and as CH_4 equivalent; in addition, Figure 11 illustrates the methane equivalent savings graphically. The largest proportion could be covered by up to 73 CADs supplemented by on-farm AD but this would involve large capital grants. To assess the wider costs and benefits of these options an analysis based on the Treasury Green Book guidelines[3] is presented below.

Table 12: Emissions from livestock wastes and savings associated with the options

	CO_2 equivalent, 000 te/y			CH_4 equivalent, 000 te/y		
	Direct	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
Current emission (England)	1580			75.2		
CAD-20 saving	315.7	85.7	401.4	15.0	4.1	19.1
CAD-44 saving	529.9	148.7	678.6	25.2	7.1	32.3
CAD-73 saving	714.0	215.7	929.7	34.0	10.3	44.3
CAD-20 & OFAD saving	797.3	142.0	939.3	38.0	6.8	44.7
CAD-44 & OFAD saving	886.2	190.8	1,077.0	42.2	9.1	51.3
CAD-73 & OFAD saving	948.6	243.3	1,191.8	45.2	11.6	56.8
OFAD saving	911.0	105.8	1,016.8	43.4	5.0	48.4

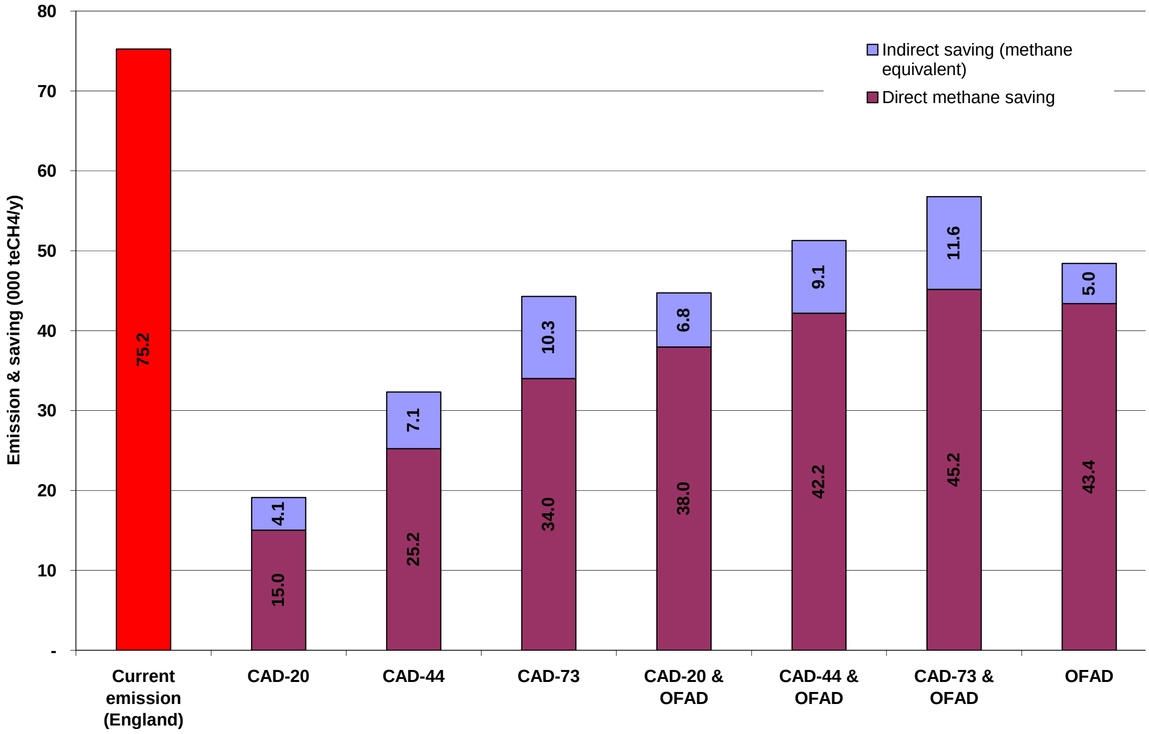

Figure 11 Current emissions and savings associated with different options, as methane equivalent

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[3] http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm

4.5 COST-BENEFIT ANALYSIS WITH RESPECT TO CARBON-SAVING

The detailed assumptions for the cost benefit analysis are detailed in Appendix 4. The net present value for the policy presented in Table 13 is based on capital (including Government grants) and operating costs and income from electricity sales and gate fees for industrial waste. On farm AD plants that are uneconomic even with 100% capital grants, are not included in the calculation. Income from ROCs and CCL (and resulting costs to consumers and Government) have not been included as they arise from existing policies. No ancillary impacts or costs to Government of implementing the policy (other than the grant or subsidy costs) have been quantified. The lifetime NPV and cost/benefit per tonne of carbon is presented in the table, with and without the social cost of carbon[4]. Figure 12 shows that when the social cost of carbon is included.

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[4] The social cost of carbon recognises the economic cost to society of climate change occurring.

Table 13 Appraisal of policy options for AD

Options	Appraisal: Impact on annual carbon in 2010 MtC	Appraisal: Impact on annual carbon in 2015 MtC	Appraisal: Impact on annual carbon in 2020 MtC	Appraisal: Lifetime NPV (Cost)/Benefit per te of carbon Without anci. impacts	Appraisal: Lifetime NPV (Cost)/Benefit per te of carbon With social cost of carbon	Appraisal: NPV (Cost)/Benefit to 2010 Without anci. impacts	Appraisal: NPV (Cost)/Benefit to 2010 With social cost of carbon	Appraisal: NPV lifetime (Cost)/Benefit Without ancillary impacts	Appraisal: NPV lifetime (Cost)/Benefit With ancillary impacts
1: 20 CAD	0.03	0.03	0.03	(60)	6	(240)	(231)	(38)	4
2: 44 CAD	0.05	0.05	0.05	(107)	(40)	(460)	(444)	(112)	(42)
3: 73 CAD	0.08	0.08	0.08	(115)	(48)	(687)	(662)	(192)	(81)
4: 20 CAD and on-farm AD	0.04	0.04	0.04	(558)	(491)	(652)	(644)	(470)	(414)
5: 44 CAD and on-farm AD	0.06	0.06	0.06	(331)	(264)	(752)	(732)	(416)	(332)
6: 73 CAD and on-farm AD	0.10	0.10	0.10	(189)	(123)	(886)	(853)	(398)	(258)
7: On farm AD	0.02	0.02	0.02	(1,561)	(1,493)	(609)	(601)	(626)	(599)
With methane subsidy:									
4b: 20 CAD + on farm pigs	0.03	0.03	0.03	(99)	(33)	(235)	(238)	(63)	(21)
5b: 44 CAD + on farm pigs	0.05	0.05	0.05	(146)	(80)	(465)	(456)	(154)	(84)
6b: 73 CAD + on farm pigs	0.08	0.08	0.08	(133)	(67)	(690)	(671)	(224)	(112)
7b: On farm (pigs only)	0.01	0.01	0.01	(723)	(656)	(40)	(57)	(83)	(75)

Options	Lifetime distributional impacts NPV (Cost)/Benefit Without ancillary impacts			Lifetime distributional impacts NPV (Cost)/Benefit With ancillary impacts		
	Exchequer	Firms	Consumers	Exchequer	Firms	Consumers
1: 20 CAD	(143)	105	0	(143)	105	42
2: 44 CAD	(293)	181	0	(293)	181	70
3: 73 CAD	(445)	253	0	(445)	253	111
4: 20 CAD and on-farm AD	(548)	85	0	(548)	85	50
5: 44 CAD and on-farm AD	(580)	164	0	(580)	164	84
6: 73 CAD and on-farm AD	(641)	243	0	(641)	243	140
7: On farm AD	(601)	(25)	0	(601)	(25)	27
With methane subsidy:						
4b: 20 CAD + on farm pigs	(186)	165	0	(186)	165	42
5b: 44 CAD + on farm pigs	(318)	189	0	(318)	189	70
6b: 73 CAD + on farm pigs	(467)	265	0	(467)	265	111
7b: On farm (pigs only)	(63)	41	0	(63)	41	8

All of the options have net costs over their lifetime. Options 1-3 save increasing amounts of carbon but also involve increasing costs to Government. The lowest costs to Government are for the methane subsidy for on-farm AD for pigs but this does not save has a high cost of carbon. Option 1 (20 CAD plants) looks to be the most attractive of these option, with annual carbon savings of 0.03MtC per year, a cost of carbon of £60/tC but a cost to the Exchequer of £143M. If the social cost of carbon is included there is a small net benefit. The option of 44 CAD plants does not provide significantly greater carbon savings, but does involve significantly higher cost to Government. Providing a methane subsidy results in higher costs to Government, but spread over a number of years.

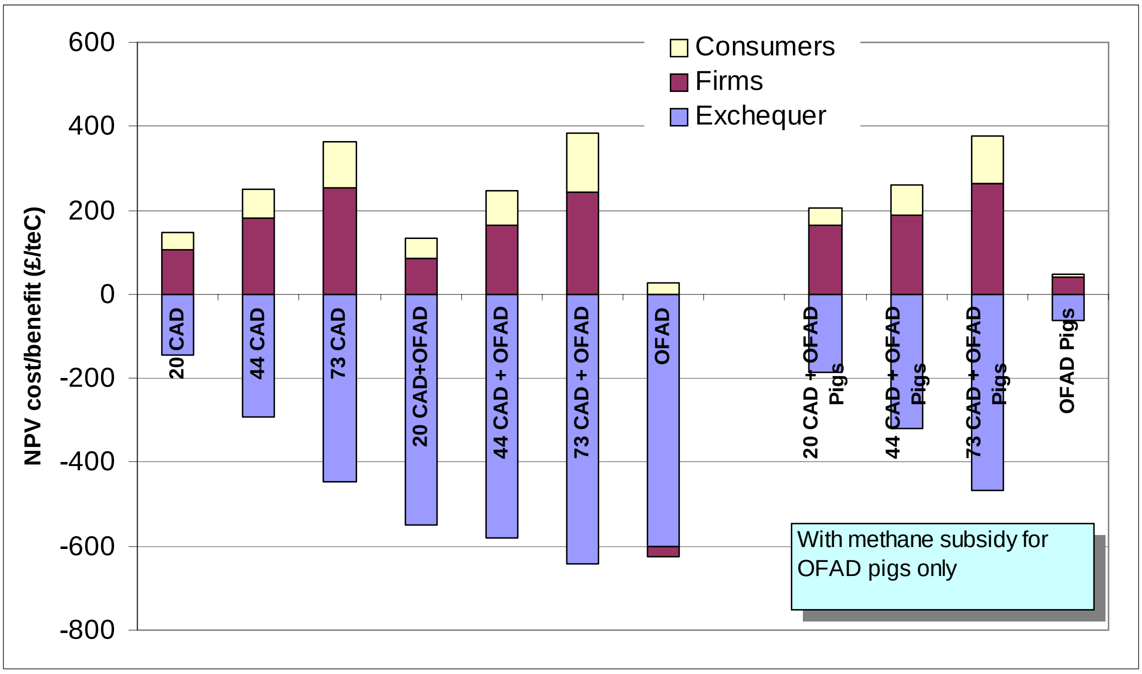

Figure 12: Lifetime distributional impacts, including ancillary impacts

4.6 SENSITIVITY ANALYSIS

The economic analysis given above is based on the parameters as given in Section 4.3 and Appendix 4. Four parameter values are explored further, with respect to their impact on the CAD plant associated with CAD 20 option; these are:

1. Proportion of industrial waste co-digested with livestock wastes (base case used 10%)
2. Electricity price associated with the electricity export (based case used 8.43 p/kWh)
3. Methane conversion efficiency (based case used 60%), and
4. Capital cost reduction.

Figure 13 shows the IRR sensitivity as a function of the changes in the above parameters. It shows that by increasing the proportion of industrial waste to ~17% or electricity price to ~19 p/kWh or capital cost reduction by ~36% would make these plants economic[5]. As for the methane conversion efficiency, increasing it from 60% to 85% will increase the IRR from ~7% to ~10%. As such can be seen there could be circumstances (e.g. access to a higher proportion of industrial waste) where the plant would not require capital grant.

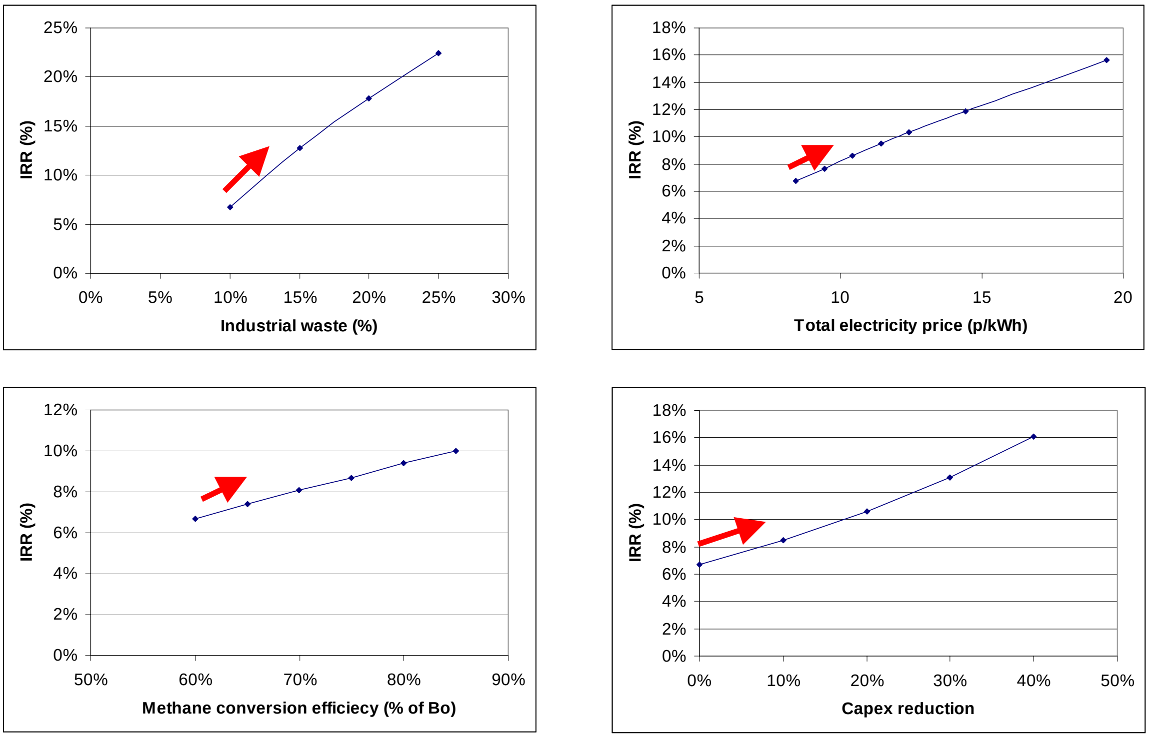

Figure 13: IRR sensitivity as a function of the proportion of industrial waste digested, electricity price increase, methane conversion efficiency and reduction in capital project cost

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[5] i.e. will lead to IRR=15%

5 Wider benefits and challenges for AD

5.1 MEETING WIDER ENVIRONMENTAL CHALLENGES

Agriculture covers over 70% of the land area of England and Wales[6] and many of the current agricultural practices are a major source of water and air pollution. This arises from

- Leaching from over-application of fertilisers and manures to surface and groundwater. Both nitrate and phosphate can enter water systems, which can cause considerable changes to the ecology;
- Faecal and other pathogens from livestock from overloaded or badly managed systems;
- Organic materials (slurries, silage liquor, surplus crops, sewage sludge and industrial wastes) that are poorly stored or disposed of by spreading on land.
- Manure, and includes ammonia and the greenhouse gas nitrous oxide which are also emitted from nitrogen related soil processes (ammonia and nitrous oxide are part of the UK National Emissions Inventory)

Current legislation regarding manure applications only applies to operations within designated Nitrate Vulnerable Zones, designed to protect potable ground water. In these areas limits are set on the amount of nitrogen that can be applied in the form of organic manure and the timing of such applications. Codes of Good Agricultural Practice exist which give guidance on application methods and timing designed to reduce the risk of pollution to water and air, but these are not enforceable.

AD can play a significant role in soil husbandry, for example CAD may be able to exploit excess manure from farms within nitrate vulnerable zones, although storage of digestate could be an issue.

AD Digestate
The AD process mineralises organic material to increase soluble nitrogen and phosphorus (ammonium and phosphate), that are more readily available to crops on land spreading and more easily converted to easily leached forms on porous or NVZ soils. The implications of AD process can be summarised below.

- ??Organic material imported into the farm increases the fertiliser value of the digestate and farmers need to take account of the increasing N, P and K content of the digestate that can reduce the emissions of nitrous oxide by removing the volatile solids that fuel denitrification.??
- Reduces the dry matter content of the digestate and this leads to less ammonia emissions on land spreading because the digestate that contains the ammonia is not retained on the surface by the dry matter, but can better infiltrate the soil.
- Reduces pathogen content in the digestate

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[6] http://www.defra.gov.uk/environment/water/quality/diffuse/agri/index.htm

During the AD process the dry matter solids are reduced to about 3%w/w/ a large part of this is fibrous material that are degraded to a point where the remaining fibres mainly comprise lignin like compounds that require an aerobic process for further degradation. This material can be applied directly, or composted prior to soil application. Composting can be based on the fibrous material alone, or in combination with other green wastes. In the latter case, the fibrous digestate is thought to add value to the process and aid green waste composting. Experience in Denmark shows that this can be managed effectively and with relative ease. Depending on the route chosen for the digestate, the value of this material can vary form zero to a few pounds per tonne. .

AD liquor

The AD process will not remove any of the inorganic compounds present in the feedstock although some ammonia and sulphur are present in the biogas. This means that the fertiliser value of the manures entering the process will be available in the liquor, as a low odour liquid amenable for applying back to the farmland on which the animals producing the feedstock manures were raised. This nutrient recycling should also be amenable to accreditation under organic farming schemes, unless additional feedstocks are introduced to the process that may contain inadmissible materials.

In large scale AD schemes, this liquor has the potential to be assayed for nutrient content and applied to land at an appropriate rate. This not only makes the application more amenable to control and thus less likely to lead to diffuse pollution, but also recognise the liquor as having a monetary value equal to commercial alternatives.

5.2 CHALLENGES TO AD

An overview of the challenges to AD and some possible actions to help overcome these are shown in Table 14. A more detailed discussion follows the table.

Table 14 Barriers to the development of AD in the UK

Barriers	Practical	Economic	Regulatory	Fiscal	Atti./awar's	CAD, OFAD or both	Priority	Method of assistance
Rare technology to agricultural sector	X	X			X	Both	High	Promotion of the technology through trade associations. Encourage and disseminate results of pioneer projects. Promote benefits to soil management and water pollution.
Negative perception of performance					X	Both	High	Disseminate results of pioneer projects and of experience in other countries.
Lack of expertise in operation and maintenance	X	X			X	Mainly OFAD	Low	Training schemes through trade associations. Establish an accreditation system and engage suppliers and installers.
Development of the supply chain	X	X	X		X	Mainly CAD	High	Government support (e.g. Defras energy crops scheme).
Lack of capital		X		X		Both	Medium	Grant support or favourable loan schemes.
High operating costs	X	X			X	Both	Low	Training schemes for operators. Share best practice. Encourage standardised equipment.
Lack of markets for products	X	X	X		X	Both	Low	Address regulatory uncertainty and define standards. Education to encourage use.
Volatility in the energy market		X	X		X	Both	Medium	Preferential electricity price for AD based on livestock wastes. For on-farm AD encourage consolidation of supply.
Grid connection issues	X	X				CAD	Low	Already being addressed for other forms of distributed generation.
Unreliable supply of feedstock	X	X		X		CAD	High	Use incentives to encourage disposal to CAD.
Lack of infrastructure for heat use	X	X				CAD	Low	Planning could be used to encourage developments including the infrastructure. The Community Energy Grant Scheme can also provide grants for heat infrastructure. Fiscal incentives to use renewable heat
Planning	X	X	X			CAD	Medium	Issue guidance to planners. Engage in dialogue with local communities
IPPC permitting	X	X	X			CAD	Low	Dialogue with regulators and trade associations
Ammonia emissions from digestate	X	X	X			Both	Medium	Ensure appropriate spreading practice through education of farmer
Storage of digestate	X	X	X			Mainly CAD	Low	Spread best practice
Biogas yield	X	X				CAD	Low	R&D Structure incentives to encourage high yield and low emissions to atmosphere

CHALLENGES FROM A DEVELOPING MARKET

As discussed previously the market for AD is immature in the UK. This brings its own challenges in terms of attitude and awareness of the benefits, development of infrastructure and lack of experience in the operation of AD. Potential strategies to address these are discussed below.

Development of market infrastructure

To promote the development of AD in the UK a series of partnerships will be required involving the technology suppliers, plant installers and maintainers, plant operators and financiers. However, history shows that markets for new technologies rarely form spontaneously and that some investment is required to either market or drive the opportunity forward. In the case of AD, we consider it highly unlikely that the methane emissions reductions that can be achieved by this technology will be delivered without some form of government intervention. This need not be through direct financial support but can be driven by a mixture of legislative and fiscal incentives within a framework of support to achieve a clear outcome.

In the case of the technology suppliers, they need to be willing to rise to the challenge of developing cost-effective AD solutions suitable for the UK market and to ensure that plant designs are standardised such that economies of scale can be achieved from the outset. This will also involve making sure that there is an installer network in place, either on a contract basis or as part of their supply offering. This network will also be required to offer maintenance support to the plant operators.

By setting out clear targets for the creation of a market for AD, this will form the basis for government to seek competitive tenders from technology suppliers to supply that market and the associated infrastructure support that will be required.

Having established a mechanism to supply cost effective technology, a means of operating the AD systems will be required. These could through a series of plant owners/operators, or the use of specialist operators working under contract to the plant owners. One model for implementation could be based on involving the water companies and their associated service suppliers to build own and operate such plant. This is because they are already completely conversant with the use of AD to treat sewage and would be ideally placed to operate AD plant in the agricultural sector. Indeed, there is potential benefit from the use of this industry to treat agricultural materials as in the rural sector; many sewage treatment plants are little more than collection facilities, with sewage being tankered to larger facilities for treatment. Having more local treatment works would reduce the need for this transport.

As with technology suppliers, we see the potential for the government to invite the water industry to tender to operate (and even own) larger AD plant within a well defined market framework.

Early steps to deliver this strategy can include more traditional approaches. This could include part aided demonstration plants, strategically placed throughout the country. This would be an excellent way to raise awareness of the technology demonstrating wider benefits locally, including:

- Creation of skilled, local green jobs in commissioning, maintenance, etc.
- Transport of wastes and wider 'waste management organisation'.
- Opportunities around the supply and demand of soil conditioner (from digestate) into a range of markets.
- Generation of local wealth, through small business creation; for instance, in local waste management system, managing waste from local businesses to reduce waste costs in the locality.
- Mitigation of odours from livestock slurry
- Sustainable method of generating local heat and electricity supply, from a renewable source.
- Use of existing agricultural knowledge transfer groups

General Education and Advocacy

As has been mentioned, AD can help comply with a wide variety of regulations and meet the environmental challenges. However, to guarantee that stakeholders (farmers, local authorities, environmental agencies, etc) can make an informed decision about AD, they must be made aware of the benefits and shortcomings of the technology. This awareness raising could include:

- Presentations to key stakeholders
- Workshops
- Website
- Newsletters

In addition to the general awareness-raising programme, an active campaign of advocacy of the AD plants would be required. Targeted meetings and joint events with key players-manufacturers, buyers, specifiers and trade associations.

Pioneer Projects

Many experts recognise that the success of the AD schemes in Germany is due to a large amount of preparatory and pioneering work done by early players in the eighties, before the large scale propagation of AD has come about. Depending on the route that might be chosen by the UK, there is a strong need to encourage the implementation to be undertaken by some 'early players'.

PRACTICAL AND FINANCIAL CHALLENGES TO PROJECT DEVELOPMENT

Development of the Supply Chain

The success of a CAD plant will depend on a steady source of feedstock. This will require the development of local infrastructures and supply chains, with further equipment supply opportunities around issues such as vehicle cleaning, disinfection and fibre processing. In the same way as for energy crops, grants may need to be offered to set up the supply side from farmers. For other wastes, the supply chain is probably less of an issue and factors such as the Landfill Directive will put pressures on all organic waste although AD would need to be cost competitive with other forms of disposal. It is expected that the overall cost of landfilling will continue to rise and industrial waste as well as organic fraction of municipal waste would need outlets such as AD plants.

Market for Digestate/Liquor
While the bulk of the treated slurry would be sent back to the livestock farmers, a revenue stream around the sale of digestate or liquor (as fertiliser) would be beneficial. Although the digestate has several useful applications, there is uncertainty of the regulations surrounding the definition of the digestate or any soil conditioners that can be marketed as a product.

At present the Composting Association is the body that has undertaken the role of setting and 'informally regulating' compost standards for market development in the UK. The standards are set by means of product specifications that define composts suitable for use in any application. These standards assume that application or use of the composts is made in accordance with relevant codes of practice and statutory regulations, including:

- Code of Good Agricultural Practice for the Protection of Water (1998)
- Code of Good Agricultural Practice for the Protection of Soil (1998)

There is a clear need to provide simple, clear baseline specification for compost so that producers understand what their end users require from the products[7].

Electricity and heat sales
Market economics in the UK favours the use of biogas for electricity generation. This is because AD is included in the Renewables Obligation as an 'advanced conversion technique' and thus the electricity generated by it is eligible for Renewable Obligation Certificates (ROC's). Currently the market for ROCs is undersupplied and so the values that they attract in the market can be over 5p/kWh. This, plus the wholesale value of the electricity makes every kWh of electricity from an AD plant potentially worth over 8p/kWh. This, combined with the relative ease with which electricity can be transported compared to gas, makes the electricity market very attractive. The use of the heat produced by an AD scheme can only add to the economic performance of the project if it is of local value, i.e. by displacing fossil fuel use.

The current energy market is highly volatile and although prices are likely to remain high, the perceived risk in this market is high. However provided a steady supply of waste is available, AD has an advantage in being a 'base load' generator. It has the capacity to add to security of energy supply and also to add to local grid stability in rural areas where this has been a traditional problem. For distributed generation as a whole, there can be technical problems and costs associated with grid connection and these are being addressed by Government and the regulator.

The issue of market volatility and grid connection are likely to be more significant to on-farm AD, especially as costs will vary widely on a case-by-case basis.

Where there is a local use for the heat from the electricity generation process, this may attract additional income. Typically, heat values are a lot lower than electricity at around 2p/kWh and the cost of transporting heat can be high. Therefore, in most instances the value of the heat will be zero, although it can be used for beneficial on-site use such as to warm the process to speed it up and thus reduce the size of the digestion tank and the capital cost required. Ian addition, heat can be used within the plant for pasteurisation, drying, etc. Wider

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[7] http://www.wrap.org.uk/materials/organics/

use of heat from CAD would depend on the development of infrastructure to deliver the heat to where it is needed. The availability of such infrastructure in Denmark has made CAD successful there. In the UK, the Community Energy programme offers grants to develop district heating schemes. Incentives for the use of renewable heat in the same way as renewable electricity would also increase the likelihood of the development of a market for heat.

Research Challenges

There are three potential areas of interest. First by developing a more intensive thermophilic process more feedstock can be digested with the HRT changing from 20-30 days to 3-5 days resulting in less capital cost necessary for capital purchase. Second by optimising the blend of feedstock to produce more biogas. Third, optimise the parameters of the digester to produce more biogas that approaches the theoretical amount.

Implementation of these advances, that would include some form of computer and sensor control, would fall in line with the AD system becoming a self regulating system or 'black box' that could be monitored.

Challenges would be reduced and there would be benefits to the farmer, given the current financial circumstances, by minimising AD plant maintenance/optimisation.

REGULATORY CHALLENGES

PPC Permit to operate

The centralised anaerobic digestion schemes would be subject to the Pollution Prevention and Control (PPC) Regulations. These will serve as the 'umbrella regulations' and will bring several other legislative and regulatory requirements into one, through the requirement of a PPC permit to operate. By way of the permit, the regulator (EA) will set a number of operational conditions. These conditions will be based on the use of Best Available Techniques. The permit condition will also require steps to ensure that energy is used efficiently, avoid or minimise waste, prevent accidents and limit their consequences. AD plants should be seen as BAT, although each plant will have to be judged individually and within the context of the local environment.

Planning Consent

As with any industrial plant, the CAD plants will have to acquire the site development planning consent according to the Town and Country Planning Regulations. Given the rather 'novel' nature of the scheme, with likely 'emotive' issues such as frequency of vehicle movement to and from the plant, bio-hazards and odour the developers will be required to provide detailed justification that the CAD schemes are suitable in the vicinity.

The Local Authority Planning Department will determine the application and some pro-active education and awareness aimed at planning officers would be beneficial. The Kelly Review[8] is examining the case for making the planning system more effective towards delivery expansion of the waste management facilities. Some representation to this review would be worthwhile.

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[8] Pre-budget report, 5 December 2005

The Animal By-Product Order (ABPO)
The EU Animal By-Products Regulation has tightened the regulations that govern the processing and disposal of animal by-products. These regulations favour biological treatment schemes but with stringent controls on the process, including time-temperature profile requirements, strict segregation of clean and dirty sides of the process and facilities for vehicle washing. Regulation EC 1774/2002 (the 'EU Animal By-Products Regulation') has applied since 1 May 2003. It permits AD plants to treat catering waste as well as low risk animal by-products as long as they are treated to at least 70°C for 1 hour in a closed system.

ENVIRONMENTAL CHALLENGES

The increased available nitrogen content of livestock slurry, due to breakdown of the more complex organic compounds in AD leads to an increased potential for ammonia emissions, both during the storage of the digestate (which should therefore ideally be covered) and following application to land. Although if the digestate has a lower dry matter then the higher digestate soil infiltration rates will reduce the ammonia emissions from surface spreading. There is also the potential for increases in nitrous oxide emission and nitrate leaching. However, with the lower carbon content present to fuel nitrous oxide formation, emissions are also likely to be lower on application to land. It is important therefore that application appropriate application methods, timing and rates are used when applying digestate. Slurry should be applied using band spreading or shallow injection technology to minimise ammonia emissions, and the rates and time of application should be matched to the needs of the crop receiving the manure.

Centralised AD plants, are likely to receive other agro-industrial residues, which after co-digestion with livestock slurries will increase both the volume and nutrient content of the digestate available for application to land. This may have implications in high livestock density areas within Nitrate Vulnerable Zones, where insufficient land may be available locally to accommodate the nutrient loading. Even in areas where nutrient-loading ceilings would not be an issue, the increased volumes of digestate to be spread by farmers would likely mean an increase in on-farm storage capacity to ensure that application rates and timings are agronomically sensible and that pollution risks are minimised. A further consideration for centralised AD plants is that all materials are pasteurised prior to the digestion process to minimise the risk of pathogen transfers between sites, although AD has been identified as a means of reducing pathogens. A current project involving Greenfinch Ltd in SW Scotland is using AD to reduce pathogens in the local beaches. AD therefore can have implications for the EU Bath Water Directive.

5.3 FINANCING OPTIONS

All AD plants require relatively significant capital expenditure, as appropriately designed and engineered systems are needed, whether on-farm or at a large central facility. The paybacks are generally long and any financing scheme will be adapted to this type of investment. Private investors are unlikely to be interested in significant investment in AD under current circumstances.

The Government already provide incentives that contribute to improving the economics of AD including:

- The Renewable Obligation
- CCL exemption
- Landfill Tax

The Enhanced Capital Allowance scheme is currently operated for water and energy technologies. The Chancellor[9] has announced the UK Government's commitment to support cleanest biofuels plants to stimulate the development of alterative fuels. Anaerobic digestion fits this category and there is an urgent need to encourage suppliers of AD plants to include their equipments and systems on the Technology List so that food industry, possibly with large food manufacturing sites, can invest in plants that would cater for their wastes. There is a natural synergy with the management of organic fraction of municipal waste and industrial wastes, as they carry a large 'gate fee', which is a strong driver to investing in AD plants. Individual on-farm AD plants appear uneconomic. It is possible that farmers with adjoining farms or in a small co-operative, could join forces with several farms to apply AD more cost-effectively. Further analysis would be required to identify ranges of parameters (e.g. slurry from a minimum number of cattle or their equivalent; together with availability of other wastes that could be treated within the plant) that would ensure viability of such plants.

There is a natural synergy between dairy farms and industrial dairy sites that process milk or milk products. In such circumstances, possibilities should exist where industrial food sites, with significant waste disposal costs, would prefer to invest in plants at farm locations. This would be highly suitable for dairy cattle farms, as it would guarantee much needed feedstockduring the summer months when the cattle graze on open fields.

The key to encouraging investment in AD is to reduce the risks to the project either through long term guarantees of income streams or by reducing the cost of capital through grants or loans with favourable conditions.

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[9] In his pre-budget report, on 5 December 2005

6 Conclusions and Recommendations

6.1 PRINCIPAL CONCLUSIONS

We have estimated methane emissions associated with the current livestock management practices for England and UK as a whole. Using this information for England we have outlined and analysed four options based on combinations of CAD and on-farm AD plants that address greenhouse gas mitigation through methane. Subsequently, we assessed the environmental, economic and social benefits associated with each of the options to be able to present information to Defrato aid the discussions on the best course of any future actions.

The principal conclusions, based on the analysis, show that:

1. 40% of the UK livestock farms have slurry based systems, yet they contribute around three quarters of the methane emissions from livestock manues and slurries.

2. The most common system for methane recovery from slurries is anaerobic digestion (AD) in an engineered system that can help to deliver efficient and effective management of manures. The technology lends itself to the development of an environmental sustainable economy within a locality as well as deliver UK's international obligations on reducing GHG emissions.

3. The technical potential for methane recovery is high. Assuming collectable materials are treated by anaerobic digestion, it could help to generate about 5 TWh of electricity, which is around 15% of the current renewables obligation, set for 2010.

4. AD technology is widely applied in Europe, where there is a great deal experience. However, in the UK less than 0.1% of the livestock manures are treated by AD plants.

5. Economic returns are poor from the on-farm AD plants, due to lack of scale economy for the technology. Where it has been applied the farmers have faced numerous operational difficulties.

6. Examination of the economics of options, based on a combination of centralised and on farm AD plants, shows that:
   - All AD plants are uneconomic without some extra Government support
   - A small number of larger CAD could become economic if the local and market conditions can combine positively.
   - A large proportion of the operating income for CAD plants comes from gate fees for industrial waste and from ROCs for the electricity generated. The economics are thus quite sensitive to the assumptions made in these areas.

7. Of the options analysed, they all have net costs over their lifetime. The option based on 20 CAD plants is the most attractive, with a cost of carbon of £60/tC and that to the Exchequer of around £130M. This could help to save up to 0.03MtC. All on-farm AD would need capital grants of 100%, unless particularly large farms could be found.

8. Sensitivity analysis shows that by increasing the proportion of industrial waste from 10% to ~17% or electricity price from 8.43 to ~19 p/kWh or capital cost reduction by ~36% would make these plants economic. As such there could be circumstances (e.g. access to a higher proportion of industrial waste) where some of the centralised AD plants would not require capital grant.

9. There are still the barriers associated with acceptance of the technology and economics by farmers and the public and these will need to be addressed in any methane mitigation or recovery strategy.

10. The commercial exploitation of AD would be more attractive if:
    - Reliable supply of feedstock, including from poultry, could be ensured. The growth of biomass on farms should be considered.
    - Stable and guaranteed prices are associated with the sale of electricity through the ROC mechanism;
    - Technology could be introduced to make the AD system was more hands free and produce more energy
    - Accesses to markets, for by-products derived from the digestate, could be made easier
    - Closer links could be established with the disposal of industrial and/or municipal waste[10], thereby providing a 'gate fee' income, which is absent and unlikely from the intake of livestock slurries.
    - Access were provided to possible heat supply market

11. Additional areas of support include promotion of the technology to trade associations; dissemination of good stories and training to those likely to be involved in the supply of waste and utilising treated wastes.

6.2 KEY RECOMMENDATIONS

Based on the information presented in this report, Defra would be able to choose the general direction of approach so as to formulate a more focused methane mitigation strategy. Towards the next step and prior to any consideration of the forward strategy, we strongly recommend that discussions be held on the best way forward that ensures buy-in from stakeholders into the potential schemes and ensures a higher degree of sustainability of the AD schemes.

We expect that 'security of feedstock outlet' is important for both groups of feedstock providers: livestock farmers and industrial waste producers. Consequently, the need to reduce risks to the feedstock flows (i.e. in the chain ranging from generation and supply to final disposal), combined with the need to run a clean, efficient and effective treatment plant, is of paramount importance. These considerations would bring insights to help move towards an effective livestock manure management strategy.

Once a broad form of strategy is agreed, we suggest

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[10] Defra is currently reviewing its Waste Strategy and the beneficial link with livestock wastes should be highlighted.

1. Developing guidance to allow decisions makers to evaluate CAD and OFAD proposals. This could comprise range of parameters that allow economic plants to come forth, with little or no government assistance.

2. Identifying prime locations of CAD plants and providing a more detailed assessment of the techno-economic and commercial evaluations.

3. Predicting an uptake based on practical and policy based scenarios

4. Undertaking environmental impact appraisal of CAD implementation, with specific reference to candidate sites, in England/UK. These would include impacts due to transport of slurries and any waste, emissions from AD plants, as well as positive impacts due to generation of energy in the form of biogas and its contribution in the displacement of fossil fuels.

5. Demonstrate and consider better utilisation of the AD plants by improving technology and reducing on-site maintenance.

7 Glossary, References & Appendices

7.1 GLOSSARY OF TERMS

AD = anaerobic digestion
Bo = Methane producing potential of the manure, expressed as cubic metres (m^3) of methane per kg of VS. Also referred to as the maximum methane-producing capacity for the manure. It varies by animal species and diet.
BOD = Biochemical oxygen demand (expressed as mg/l)
CCL = Climate Change Levy
COD = Chemical oxygen demand (expressed as mg/l)
CH_4 = methane (gas*)
CO_2 = carbon dioxide (gas*)
d = days
DF = Discount factor
DCF = Discounted cash flow
EF = Emission factor
FYM = Farmyard manure
g = gram(s)
GWh = Giga watt-hours
IRR = Internal Rate of Return
kg = kilogram(s)
kJ = kilo joule(s)
kW = kilo watt(s)
kWh = kilo watt-hour(s)
MWh = Mega watt-hours
m^3 = cubic metres of gas*
MCF = methane conversion factors for each manure management system
Mesophilic = temperatures of AD between 35^oC and 40^oC
MJ = Mega Joule(s)
GJ = Giga Joules
MSW = municipal solid waste
NFFO = Non Fossil Fuel Obligation
RO = Renewables Obligation
Thermophilic = temperatures of AD above ~55^oC

TWh = Terra watt-hours
VFA = Volatile fatty acids (intermediate compounds in the breakdown of organics by AD)
VS = Volatile solids; i.e. degradable organic material in livestock manure.
y = year

* All gas volumes are quoted at ~20^oC and 1 atmosphere.

All costs should be read as those as at June 2005.

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Appendices

Appendix 1	Methane to Markets Questionnaire
Appendix 2	Manure and Methane Production Data
Appendix 3	Basis of Options for England
Appendix 4	Economics and Greenhouse Gas Balance of AD

Appendix 1: Methane to Market Questionnaire

(Template for country profiles for Animal Waste Management)

(Supplied separately)

Appendix 2: Manure and Methane Production by Livestock in the UK

Table 2.1 shows the livestock population in the UK, as taken from Defra's June 2004 census of livestock. Total manure production from housed livestock in the UK, based on 2004 livestock numbers, amounts to approximately 88 million tonnes (Figure 2.1 and Table 2.2). Of this total, just under one third is as liquid slurry and just over two-thirds as solid farmyard manure (FYM) or poultry litter. Cattle are by far the greatest contributors to the total, with dairy cattle predominantly housed on slurry-based systems and beef cattle mostly housed on straw-based systems producing FYM. Pig production in the UK is also a mixture of slurry- and straw-based housing systems.

Table A2.1 Livestock population in the UK (Defra, June 2004 census)

Livestock type	UK numbers 2004		Livestock type	UK numbers 2004
	'000s			'000s
Dairy			Poultry	
Dairy cattle & heifers	2,131		Laying hens	29,662
Dairy heifers in calf	460		Broilers	119,912
Dairy replacements >2 yrs	203		Pullets	8,156
Dairy replacements 1-2 yrs	203		Breeding Hens	8,201
Dairy bulls > 2 yrs	44		Turkeys (m)	3,648
Dairy bulls 1-2 yrs	13		Turkeys (f)	3,648
Dairy calves	216		Ducks	2,911
Beef			Sheep, goat, deer etc.	
Beef cattle & heifers	1,739		Ewes - lowland	9,587
Beef heifers in calf	230		Ewes - upland	9,028
Bulls >2 yrs	33		Lambs - lowland	8,897
Bulls 1-2 yrs	10		Lambs - upland	8,378
Beef > 2 yrs	631		Goats	92
Beef 1-2 yrs	2,064		Stags	1
Calves (<1yr)	2,625		Hinds	17
			deer calves	15
Pigs				
Dry sows	489			
Sows plus litters	98			
Boars	21			
Fatteners 20-130 kg	3,105			
Weaners (<20 kg)	1,446			

Manure production totals as given in Table 2.1 were derived by combining livestock numbers from the 2004 June census (Defra), which include sub-categories for each livestock type (e.g. dairy cattle and heifers, dairy heifers in calf, dairy replacements > 2 years old, dairy replacements 1-2 years old, etc.), with literature values for daily excretal output per livestock type (Smith et al., 2000b; Smith and Frost, 2000). Account was taken of the proportion of the year for which the livestock were housed and the proportion housed in slurry- or straw-based systems (Defra Reference Booklet 209; Defra Farm Practices Surveys 2004 and 2005; Sheppard, 2002; Smith et al., 2000a; Smith et al., 2001).

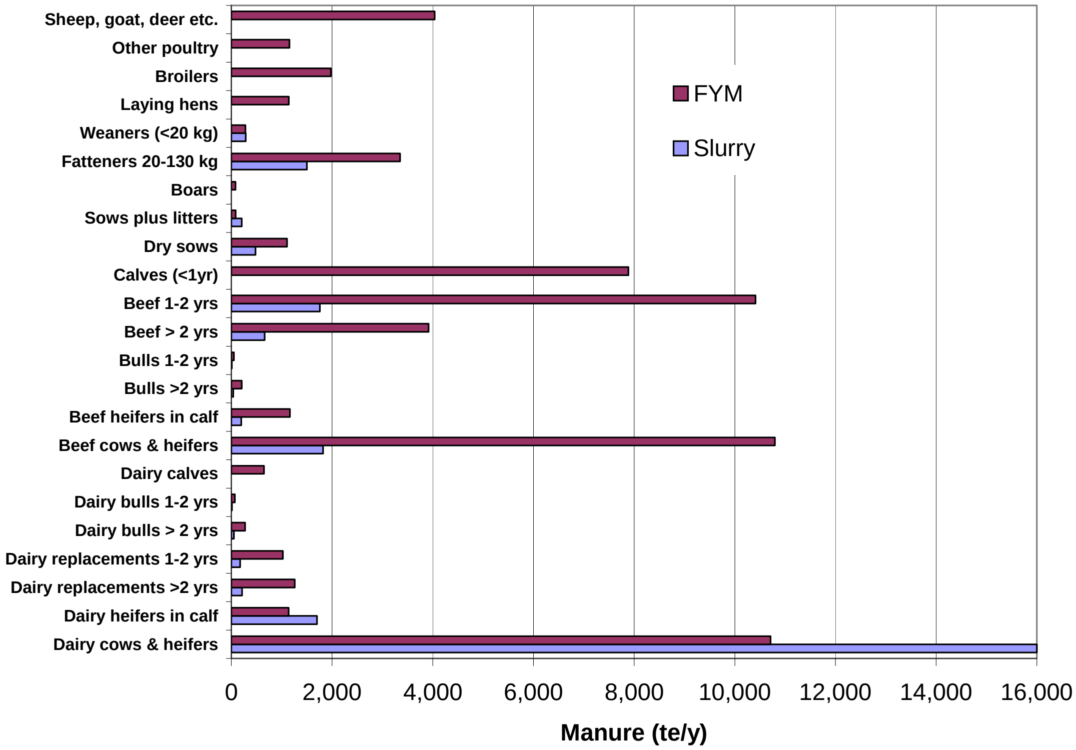

Figure A2.1: Slurry and FYM in the UK, by sub-categories of livestock

Table A2.2 Manure productions by UK livestock (millions tonnes)

	Slurry	Solid manure (FYM/litter)	Total
Dairy cattle	18.1	15.1	
Beef cattle	4.5	34.4	
Pigs	2.5	4.9	
Poultry	0	4.3	
Sheep	0	4.0	
TOTAL	25.1	62.8	87.9

Manure density maps were produced for England by combining livestock numbers disaggregated to a 5 km grid square level with the excretal output values. These maps highlight both the potential areas and proportions of manure for which centralised anaerobic digestion might be appropriate.

Current manure management systems

For the purposes of estimating methane production from manure management, a number of animal waste management systems have been defined (IPCC, 1997). The proportion of manure from different livestock types managed within each system has been estimated for the UK (Table 2.2), based largely on the same surveys and literature sources as mentioned above. Each management system is associated with a methane conversion factor (IPCC, 2000), which expresses the percentage of the theoretical maximum methane emission which might be expected to arise under each particular management system. 'Liquid systems' (i.e. slurry) are associated with the highest emission factor as more methane will be generated within the anaerobic storage conditions of a slurry pit or lagoon. 'Daily spread' represents systems (slurry or solid manure), which have little or no manure storage (generally regarded as 1 month or less) and therefore a low potential for methane emissions. Straw-based cattle, pig and sheep housing systems are represented by the 'solid storage and drylot' category, associated with a low methane conversion factor reflecting the more aerobic nature of this manure storage. 'Pasture range and paddock' represents excretal returns directly to land by grazing (or free-range) animals. This manure is not stored and is also not included in the manure production statistics given in Table 2.1. Poultry manure, which tends to be drier than pig, cattle and sheep FYM, is categorised as 'other' and associated with a slightly higher methane conversion factor than FYM. A proportion of poultry litter is incinerated for energy production and this is associated with a zero methane conversion factor.

Table A2.3 Proportion of manure (%) managed under different systems together with methane conversion factor (%) for each system

	Liquid system	**Daily spread**	**Solid storage and drylot**	**Pasture range and paddock**	**Other**	**Incinerated**
Dairy cattle	31	14	10	36		
Other cattle (excl. calves)	6	23	20	51		
Calves	0	23	22	55		
Dry sows	31	6	55	7		
Sows plus litters	36	7	28	29		
Fatteners (>20 kg)	29	6	64	1		
Weaners (<20 kg)	38	8	46	8		
Poultry	0	0	0	5	77	18
Sheep	0	0	2	98		
Methane Conversion Factor	39.0	0.1	1.0	1.0	1.5	0

Current Methane Emissions

Methane emissions from the current manure management practices in the UK were derived using a Tier 2 IPCC methodology (IPCC, 1997). An annual emission factor (*EF*, kg a^{-1}) was derived for each livestock type based on an estimation of the daily volatile solids excreted (*VS*, kg d^{-1}), the maximum methane producing capacity for the manure type (B_o, m^3 kg^{-1} VS) and the sum of the products of the proportion of manure managed (*MS*, %) and the methane conversion factor (*MCF*, %) associated with each system:

$$EF = VS \times 365 \times B_o \times 0.67 \times \sum {}^{MCF}\!/_{100} \times {}^{MS}\!/_{100}$$

where 0.67 is the conversion factor for methane from m^3 to kg. Default values for B_o for each livestock manure type have been used (IPCC, 1997). For dairy cattle, UK-specific estimates for *VS* were derived from data on milk production, live weight, feed intake and digestibility.

For all other livestock types default values for *VS* were used (IPCC, 1997) together with UK-specific data on animal waste management system breakdown (Table 2.2).
Mean emission factors for each livestock type, together with an estimate of total annual methane emission from manure management (based on 2004 livestock numbers) are given in Table 2.3. No account has been taken of any methane recovery systems in current use on UK farms. This is partly because reliable statistics on the proportion of manure used in this way are difficult to collate, but the assumption is that this would apply to a very minor proportion of the total UK manure produced. The AD-NETT report (2000) estimated that there were 31 on-farm AD plants in the UK (but gave no indication of total biogas production) and anecdotal evidence would suggest that this number has not significantly increased. The estimated total methane emissions from manure management of approximately 130 kt may differ slightly from that to be reported by the UK for 2004 (yet to be submitted) because the official UK inventory uses a Tier 1 approach (default emission factors per animal) for livestock types other than cattle (L Cardenas, IGER, personal communication). A Tier 2 approach was used in this exercise because it was important to be able to differentiate between the different manure management systems. Cattle manure is by far the greatest contributor to total emissions, with pig manure the second greatest. Emissions from slurry management systems account for the majority of total emissions because of the much greater methane conversion factor. Pig manure has a greater potential for methane production than cattle manure as is evident from the higher B_o value (Table 2.3).

In terms of mitigating methane emissions from manure management, applying methane recovery systems, such as AD, to slurry management systems offers the greatest potential. Methane recovery from solid manures would do little to mitigate current emissions from manure management, but could play an important part in renewable energy, offsetting greenhouse gas emissions from current energy production from fossil fuels. Methane recovery technologies from solid manure systems should therefore not be ignored. The VS, B_o and emission factor data per livestock type for the slurry systems will enable assessment of both on-farm and centralised AD systems in terms of their potential to mitigate methane emissions from manure management and recover energy.

Table A2.4 Methane emission factors (kg CH_4 head^{-1} a^{-1}) and total annual emission (kt) from manure management of UK livestock

			All manure management systems		**Slurry systems (excl. daily spread)**		**Solid manure systems (excl. daily spread)**	
	VS (kg head^{-1} d^{-1})	B_o (m^3 CH_4 kg^{-1} VS)	EF (kg CH_4 head^{-1} a^{-1})	Total emission (kt CH_4)	EF (kg CH_4 head^{-1} a^{-1})	Total emission (kt CH_4)	EF (kg CH_4 head^{-1} a^{-1})	Total emission (kt CH_4)
Dairy cattle	3.48	0.24	25.5	54.4	79.7	52.0	2.0	0.4
Other cattle (excl. calves)	2.70	0.17	3.4	19.4	43.8	14.8	1.1	1.3
Calves	1.46	0.17	0.5	1.4			0.6	0.4
Total cattle				75.2		66.7		2.1
Dry sows	0.63	0.45	8.9	4.6	27.1	4.3	0.7	0.2
Sows plus litters	0.63	0.45	10.0	1.0	27.1	0.9	0.7	0.0
Fatteners (>20kg)	0.49	0.45	6.5	20.1	21.0	19.0	0.5	1.1
Weaners (<20kg)	0.24	0.45	4.0	5.8	10.1	5.6	0.3	0.2
Total pigs				31.5		29.9		1.5
Poultry	0.10	0.32	0.1	16.9			0.1	10.8
Sheep	0.4	0.19	0.2	6.7			0.2	0.1
TOTAL				130.3		96.7		14.5

Appendix 3: Basis of Options for England

In this section we show how the examination of the number of livestock in more details provided the potential number and location of CAD plants.

This analysis was based on GIS data (Defra 2004) in 5km grid squares, which listed livestock population and number of holdings for all livestock categories and sub categories. A reasonable dis-aggregation of population density could be obtained by analysing 25km grid squares. This was done by expressing dairy cattle and fattening pigs as ‘cattle equivalent (CE)’, according to the definition in Table 1.

With this choice of grid squares the average distance to the CAD plant would be 10 km. It should be noted that the distance that the poultry waste can be transported considerably greater distance than this. In our economic analysis, presented in the report, we use 15 km as the ‘road distance’ travelled for the cattle and pig slurries; whereas that for egg layers’ waste is taken to be 60km.

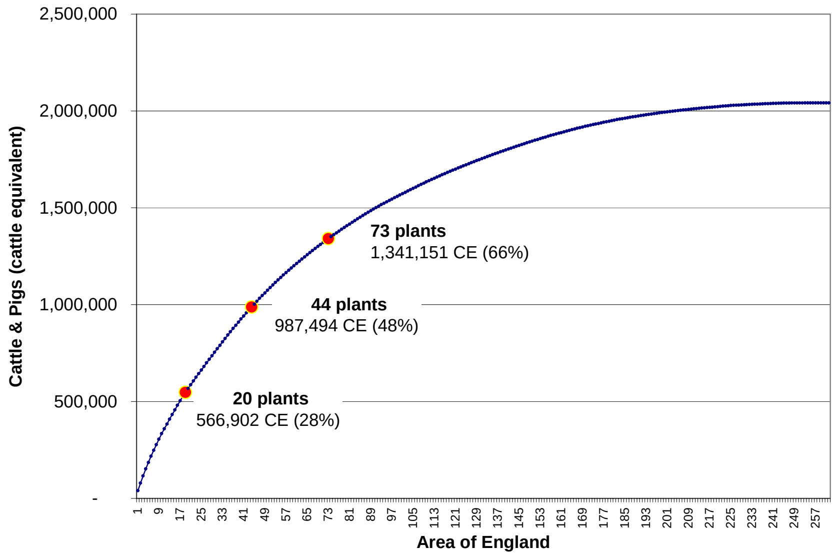

Figure 1: Cumulative dairy cattle and fattening pigs, expressed as cattle equivalent, as a function of (25km by 25km) areas of England

Table 1: Parameters used to calculate energy production and derivation of 'cattle equivalent'

	Excretal output	Bo	VS	Methane potential	Cattle equivalent
	kg/hd/d	$m^3CH_4/kgVS$	kg/hd/day	m^3 CH_4/d	
Dairy cattle	53	0.24	3.48	0.84	1.00
Other cattle	29.1	0.17	2.70	0.46	0.55
Fattening pigs (>20 kg)	4.5	0.45	0.49	0.22	0.26
Poultry – layers only	0.115	0.32	0.10	0.03	0.04

An analysis of cumulative CE values versus respective grid areas, provided a gross relationship between the number of CAD plants and the percentage (of total cattle) covered. We chose the following three bands, to define the number of CAD plants in our options analysis:

- CE > 20000
- 15,000 < CE < 20,000
- 10,000 < CE < 15,000

This grid square falling within those bands also pointed to potential locations of the CAD plants. Size band 1 corresponded to 20 CAD plants, size band 2 corresponded to additional 24 CAD plants; and size band 3 with additional 39 CAD plants. The livestock numbers associated with these three options (i.e. the first 20 CAD plants, the first 44 plants altogether and the 73 plants altogether) are given in Table 2.

Table 2: Livestock and holding statistics associated with the CAD options

	Dairy cattle		Other cattle		Fattening pigs	
	number	holdings	number	holdings	number	holdings
CAD 20 plant	19,179	189	23,343	429	34,740	109
CAD 44 plant	15,427	162	22,049	401	26,591	91
CAD 73 plant	13,115	141	20,556	378	22,636	83

In assessing the CAD options it soon became apparent that the CAD options alone would not provide the kind of coverage required for an effective methane mitigation strategy. For instance, by choosing the first 20 CAD plants, the coverage of farms amounted to some 28% of dairy cattle and 28% of fattening pigs. By going to 73 CAD plants the coverage was around 66% for dairy cattle and 65% for fattening pigs. The first range provides CAD plants of much greater size than the other ranges and with likely variations in the economic and commercial attractiveness. As such all three options were chosen for evaluation. To ensure a higher degree of coverage of area, on-farm AD plants were also considered for the larger size farms.

Appendix 4: Economics and GHG Balance of AD

The following assumptions are made in the derivation of the material and energy balances, economic evaluation of the AD plants and cost-benefit analysis around the four options.

Technical

- A continuous operation is represented by 365 days.
- The quantity of livestock slurry is calculated using the IPCC parameters given earlier.
- For centralised AD, 10% of the total waste feed by mass was industrial waste, taken in on a gate fee paying basis (i.e. income), which has the VS content of 10%.
- The quantity of egg layers' (poultry) waste considered within 85 km x 85km grid; i.e. average straight line distance of 40km, which was taken as 60km road distance.
- Methane generation factors (m^3/kgVS) are based on IPCC values as shown in Table 4.b.
- Methane leakage is assumed as follows:
  - For OFAD 3% of that generated
  - For CAD 1% of that generated
- Energy value of CH_4 is 36.80 MJ/m^3, at 20°C.
- Electricity generation is via CHP (irrespective of the quantity of methane), with electrical generation efficiency of 35% and heat generation efficiency of 50% (i.e. 85% efficiency overall). 20% of electricity generation is used on plant and 80% is exported. For the OFAD it is assumed that all heat is utilised on the site, but for the CAD half of the heat is used on plant with the other half exported.
- Size of digester (in m^3) is taken as 20 times the daily volume of waste, plus 25% excess capacity.

Economic Assumptions

- No land cost is taken into account.
- Capital cost of AD plants are based on the following:
  - For OFAD: Interpolations between the capital costs supplied from the SEERAD study, but reduced by 25% as there would a price decrease if a wide spread OFAD strategy was to be adopted. The cost of a given volume of digester is same - whether treating cattle or pig slurries.
  - For CAD: Correlation based on the classical 'total plant cost estimation correlation', using m^3 of digester as the key size parameter. The basis: 8000 m^3 digester capacity plant costs £5.5 million.
- O&M cost is taken as 2% and 5% of the total capital cost, for OFAD and CAD plants, respectively.
- Income from the sale of electricity:
  - Base price for the electricity exported to the grid is taken to be 4 p/kWh

  - ROC price for the electricity exported to the grid is taken to be 4 p/kWh. (This is around 5 p/kWh, but 20% of this is assumed to go to the distributor/supplier, leaving 4 p/kWh for the producer.)
  - Income from the CCL Exemption Certificates is based on 0.43 p/kWh.
- Heat sale income is based on 2.5 p/kWh. This assumes access to heat supply network and price is based on 2p/kWh gas fuel and 80% conversion efficiency. This waste heat could be attractive to nearby industrial sites, as it would help them to meet their CCA targets with ease!
- Income from industrial waste at the plant gate is taken to be £48 per tonne. This is because the plant operator will keep a degree of parity with LF charges in the area. As such it is made up of £18/te LF tax and £30/te disposal fee.
- Income from digestate liquor is taken as zero, just as for the fibre. This assumes that cost of fibre separation matches that which can be earned from its sale!

Other

- The cost-benefit analysis of the options is based on the Treasury Greenbook Analysis.
- CO_2 emission in the biogas or that emitted through its combustion are biogenic and therefore regarded as neutral, as they do not add to the emissions, over alternative, non-AD options; i.e. the emissions would be no more than if the waste was to decompose naturally.
- CO_2 credit for electricity export is taken as 0.43 $kgCO_2/kWh$. However, this could be slightly higher if calculated on fuel consumption basis!
- The global warming potential of methane (CH_4) is 21 times that of CO_2 on equivalent mass basis.

We provide example calculations associated with on farm and CAD plants. Table 3 provides that three on-farm plants associated with dairy cattle (168 cattle); other cattle (102 cattle) and fattening pigs (2196 pigs).

Table 3: On Farm Anaerobic Digestion Plant

On-Farm AD model	Any assumed parameter	On-farm	On-farm	On-farm
Waste from farms		Dairy cattle	Other cattle	Fatt'g Pig
Cattle		168	102	
Pigs				2196
Cattle housed (% in year)		59%	50%	90%
Quantity of waste (kg/d)		8,904	2,964	9,882
Quantity of waste (average kg/d)		5,245	1,482	8,894
Quantity of VS (kgVS/d)		585	275	1,074
Quantity of VS (average kgVS/d)		344	138	967
Total quantity of waste (kg/d)		5,245	1,482	8,894
Total quantity of waste (kgVS/d)		344	138	967
Quantity of waste (kg/y)		1,914,360	540,999	3,246,237
Quantity of VS		125,698	50,261	352,852
Project lifetime (years)	20	20	20	20
Utilisation	100%	100%	100%	100%

Size of digester, m^3,		131	37	222
Recovery efficiency	60%	60%	60%	60%
Methane generation factor (m^3/kgVS)		0.24	0.17	0.45
Methane produced from digester (m^3)		18,100	5,127	95,270
Methane leakage (overall fugitive), %	3.0%	3%	3%	3%
Methane leakage (m^3)		543	154	2,858
Net methane produced (m^3)		17,557	4,973	92,412
Net methane produced (GJ)		646	183	3,401
Electricity produced (GJ)	35%	226	64	1,190
Electricity produced (kWh)		62,823	17,793	330,663
(kW)		7	2	38
Generator size		12	4	42
Heat produced (GJ)	50%	323	92	1,701
Electricity used on plant (kWh)	20%	12,565	3,559	66,133
Electricity exported (kWh)		50,258	14,235	264,530
PLANT COSTS				
Capital cost of AD plant		£144,144	£133,280	£154,681
Capital cost of CHP scheme		£9,998	£4,301	£30,863
Total capital cost		£154,142	£137,581	£185,544
Annual O&M cost (purchased services)	2.0%	£3,083	£2,752	£3,711
Farm district storage tanks		N/A	N/A	N/A
Financing costs	0%	£0	£0	£0
Average slurry transport cost		N/A	N/A	N/A
Annual operating costs		£3,083	£2,752	£3,711
INCOME STREAMS				
Energy income - Electricity base price (£/kWh)	0.0400	£2,010	£569	£10,581
Energy income – Electricity ROC (£/kWh)	0.0400	£2,010	£569	£10,581
Energy income – CCL (£/kWh)	0.0043	£216	£61	£1,137
Energy income - Heat (£/kWh)		£0	£0	£0
Income from industrial waste		£0	£0	£0
Income from digestate liquor		£0	£0	£0
Income from fibre		£0	£0	£0
Income		£4,237	£1,200	£22,300
Net income		£1,154	-£1,552	£18,589
Grant required (% of total capex)		100%	100%	100%
Pay back time (years)		0.0075	-0.0113	0.1002
IRR		N/A	N/A	N/A
England Summary calculations				
Total number of farms in category		4875	8025	783
% on slurry based system		66%	18%	33%
No. of on-farm AD installations		3218	1445	258
Potential grant reduction (% of capital)		1%	-2%	20%
Cost to Government @100% capital grants		495,953,31	198,735,304	47,942,616
GHG Balance (te/y)				
CO_2 emission - Transport of slurry (to/from)		0.0	0.0	0.0

CO_2 emission - transport of poultry waste		0.0	0.0	0.0
CO_2 in the biogas (biogenic)		0.0	0.0	0.0
CO_2 emissions from CHP (biogenic)		0.0	0.0	0.0
Methane leakage (te/y)	0.67	0.361	0.102	1.902
Methane leakage – equivalent CO_2 saving	21	7.6	2.1	39.9
CO_2 credit for electricity export	0.43	-21.6	-6.1	-113.7
CO_2 credit for waste heat export	0.15	0.0	0.0	0.0
Net CO_2 emission/farm		-14	-4	-74
Total CO_2 emission/England per category		-45,115	-5,737	-19,070

For centralised AD plants, livestock numbers are used to calculate the feed characteristics in the feed as shown in the table below. These parameters are then used to characterise the centralised AD plant, carry out materials and energy balances and assess economic and commercial viability. The grant support for CAD is the amount needed by private developer to meet 15% return on their investment.

Table 4a: Livestock and quantity of waste based on CAD 20 plant

	Livestock number in area	**Max proportion for AD**	**Those on slurry system**	**Effective livestock numbers**	**Excretal output (kg excreta/hd/d)**	**Quantity of waste (kg/d)**
Dairy cattle	19,179	100%	66%	12,658	53.0	670,881
Other cattle	23,343	100%	18%	4,202	29.1	122,113
Fattening pigs	34,740	99%	33%	11,350	4.50	51,073
Poultry layers	421,277	73%		307,532	0.115	35,366
Total						879,434

Table 4b: Livestock and their waste characteristics based on CAD 20 plant

	VS kg/hd/day	**Quantity of VS (kg/d)**	**Annual average quantities (kg/d)**	**Bo (m^3CH_4/kg VS)**	**Weighted, Bo**	**% year housed**	**Quantity of VS (kg/d)**
Dairy cattle	3.48	44050	395,820	0.24	10,572	59%	25,990
Other cattle	2.7	11345	61,057	0.17	1,929	50%	5,672
Fattening pigs	0.49	5551	51,073	0.45	2,498	100%	5,551
Poultry layers	0.10	30753	35,366	0.32	9,841	100%	30,753
Total		91700	543,316	0.27			67,967

Table 4c: Centralised AD plant based on CAD20 option

Calculation order	Any assumed parameter	Value
Quantity of waste (kg/d)		879,434
Industrial (kg/d)		97715
Industrial (kgVS/d)		9,771
Total quantity fed to digester (kg/d)		977,149
Total VS fed to digester (kg/d)		91,700

Quantity slurry transported (te/y)		171,139
Quantity poultry transported (te/y)		12,909
Total quantity per year (te/y)		184,047
Total VS per year (te/y)		27,049
Project lifetime (years)	20	20
Plant availability	95%	95%
Utilisation	100%	100%
Operation hours/y		8,322
Size of digester, m^3, (@20 day retention time, +20%)		24,429
Recovery efficiency		60%
Methane generation factor (m^3/kgVS)		0.27
Methane produced from digester (m^3)		4,396,323
Methane leakage, overall fugitive (%)	1.0%	43,963
Net methane produced (m^3)		4,352,360
Net methane produced (GJ)		160,183
Electricity produced (GJ)	35%	56,064
Electricity produced (kWh)		15,573,364
Electricity produced (kW)		1,778
Generator size (kW)		3,626
Heat produced (GJ)	50%	80,092
Heat produced (kWh)		22,247,663
Electricity used on plant (kWh)	15%	2,336,005
Electricity exported (kWh)	85%	13,237,359
Heat for export @50% of generation (kWh)	50%	11,123,831
CAPITAL COSTS		
Capital cost of AD plant (Total)		£13,434,183
Capital cost of CHP scheme	correlation	£2,097,776
Total capital cost		£15,531,959
ANNUAL COSTS/INCOMES		
O&M cost	5.0%	£776,598
Slurry transport		£684,555
Poultry waste transport		£109,724
Electricity - base price	0.04	-£529,494
Electricity – ROC	0.04	-£529,494
Electricity - CCL Exe	0.0043	-£56,921
Heat income	0.025	-£278,096
Industrial waste	£48	-£1,711,965
Digestate liquor	Sent to farms	£0
Digestate fibre	No income	£0
Net operating cost		-£1,535,093
Pay back time, with grant (years)		10.1
IRR		6.74%
GHG Balance (te/y)		
Transport of slurry (to/from)		769
Transport of poultry waste		116
Biogas (biogenic)		-
CHP (biogenic)		-
Methane leakage from AD plant/infrastructure (te/y)	0.67	29
Methane leakage	21	614
Electricity export	0.43	- 5,692

Heat export	0.15	- 1,669
Net emission		- 5,832
DISCOUNTED CASH FLOW		
Plant throughput (te/y)	50	184,047
Capital cost (£)		£15,531,959
Construction and commissioing time (y)		2
Plant's operating life (y)		20
Net operating cost (£)		-£1,535,093
IRR		6.74%

Cost benefit analysis of options

The cost benefit analysis is based on the Treasury Green Book and the appraisal guidance for the climate change programme review.

All costs are in 2005 prices and are discounted using the social discount rate of 3.5%. A 20 year lifetime is assumed with the on-farm AD plants built and operating by the end of year 1 and CAD by the end of year 2. Costs to Government are the capital grants given in Table 11 and it is assumed that these are all allocated in the first two years. In practice, the grants would be spread over a number of years but we have not included this at this stage. Costs to firms are the operating and transport costs (see Table 2c). ROCs and CCL exemption are not included in the appraisal as they are the result of an existing Government policy. Income to the firms is from electricity sales and from the gate fee for industrial waste. The basis for the amount is the project analysis discussed above.

The social cost of carbon is included in the calculation and the benefits assigned to consumers. No other ancillary benefits have been quantified.