Anaerobic Digestion:
Benefits for Waste Management, Agriculture, Energy, and the Environment

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Introduction

Anaerobic digestion is a proven technology that extracts energy in the form of biogas from organic waste. The process provides several environmental benefits. Digestion of agricultural slurries yields a substance that has lower pollution potential and is more suitable than raw slurries for plant uptake. Global warming dividends arise because electricity generated from biogas displaces fossil fuel generated electricity and thus reduces carbon dioxide emissions to the environment.

There are, at present, three major national environmental policy objectives in which anaerobic digestion could play a significant role. The policy objectives relate to the Kyoto Protocol/global warming, renewable energy, and the Nitrates Directive/water pollution. This paper re-examines the feasibility of anaerobic digestion in the context of these national environmental policy objectives, appraising the scope for anaerobic digestion across the country, its energy potential and cost.

The Policy Context

Ireland's greenhouse gas emissions in 2003 were 24.9% above 1990 levels but Ireland is committed under the Kyoto Protocol to reduce emissions to 13% above 1990 levels between 2008-2012. The agriculture sector accounted for the largest share of national greenhouse gas emissions in 2003 at 28.1% and as such will increasingly be the focus of efforts to reduce greenhouse gas emissions. A moderate reduction in emissions from the agricultural sector with a corresponding reduction from the fossil fuel energy sector will make a significant contribution to achieving our Kyoto obligations.

Renewable energy is being promoted in the electricity market to reduce both reliance on imports and exposure to international markets, as well as reduce damaging emissions to the atmosphere. In addition, under EU Directive 2001/77/EC Ireland must increase electricity produced from renewable energy sources from a level of 3.6% in 1997 to greater than 13.2% by 2010. This Directive has created clear market opportunities for renewable energy sources. Wind energy is generally the most economic renewable energy source for electricity generation and while the Commission for Energy Regulation (CER) has ended the moratorium pertaining to wind farm connections to the national grid, the market share for wind energy will always be tempered by the inherent intermittence of wind. Therefore, considerable scope exists for biomass energy sources.

In implementing the Nitrates Directive (91/676/EEC) Ireland is committed to reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. The Nitrates Action Programme, submitted to the EU on 29th October 2004, included implementation measures relating to land application of fertilisers and livestock manure storage requirements. Proposed slurry storage requirements vary by region between 16 and 20 weeks,[1] which will require substantial investment in slurry storage capacity on many farms. Research undertaken

[1] Ireland's National Action Programme, under the Nitrates Directive

on behalf of the IFA[2] estimated that 85% of dairy and specialist beef farms have a slurry storage deficit, with the majority of farms having a 50-75% deficit. New storage to remove this deficit could be built that also facilitates the development of anaerobic digestion.

The bacteriological contamination of groundwater and compliance with drinking water regulations are also significant policy concerns. Compliance with drinking water regulations is relatively high but non-compliance is a problem in some areas and an issue of extreme concern to consumers affected.[3] The deficiency in the quality of drinking water supplies is acknowledged by a Government commitment of €644 million in the National Development Plan to tackle the issue. Anaerobic digestion, which both reduces the pollution potential of organic waste and can assist with nutrient management, will complement measures undertaken elsewhere to provide high quality drinking water supplies.

Anaerobic Digestion

Anaerobic digestion (AD) is a natural process of decomposition and decay that takes place in the absence of oxygen and by which organic mater is broken down to its simpler chemical components. The AD process can be used to turn residues from livestock farming, food processing industries, waste water treatment sludge, water treatment plant sludge among other organic wastes into biogas. The biogas can be used to generate heat and/or electricity; fibre, which can be used as a soil conditioner; and liquor, which can be used as a liquid fertiliser. The post-AD combination of fibre and liquor is termed digestate. The biogas produced in AD plants is comprised largely of methane (60-80%) and carbon dioxide (20-40%) but also usually contains a small amount of hydrogen sulphide (H_2S) and ammonia (NH_3), as well as traces of other gases.[4]

While anaerobic digestion is a natural process, the efficient management of an anaerobic digestion plant, yielding maximum biogas and proper breakdown of organic feed material, is a complex process. For instance, water content of raw material must be monitored because digestion of material with total solid content lower than 5% is usually not economically viable. Temperature must be maintained relatively constant to sustain gas production. The acid-alkaline chemical balance must be controlled for efficient digestion. Similarly the ratio of carbon to nitrogen must also be closely managed. The implication is that the efficient management of a large-scale anaerobic digestion plant requires trained full-time staff.

Energy Potential of Agricultural Slurries

Some 132 million wet tonnes of agricultural slurries, wastewaters, effluent and sludge are generated in Ireland annually, [5] while the primary food processing and catering sectors also generate substantial waste flows. At present the majority of these wastes are either spread on land, rendered, or disposed to landfill but with additional processing these waste flows can be more beneficially exploited.

[2] O'Sullivan, 2004
[3] The compliance rate for total coliforms in 'public' group water schemes was 86.3% in 2003 and 54.7% in 'private' group water schemes. Page, *et al.*, 2004
[4] British Biogen, 2000; Monnet, 2003; FEC Services Ltd, 2003; Al Seadi, 2001
[5] Brogan, *et al*., 2001

Indicative figures of the energy potential of agricultural slurries from anaerobic digestion are presented in Table 1. Poultry waste has the highest per tonne energy potential at roughly 0.131 MWh of electricity per tonne but cattle, with a population of almost 7 million, have the greatest potential for energy generation in the agricultural sector.[6] Food-processing wastes, in particular from abattoirs, have a high energy potential, as shown in Table 2. The energy potential of cattle, pig and poultry waste is estimated at some 2.759 million MWh of electricity per annum. This represents approximately 11% of the total electricity supplied in the Irish economy in 2001[7] but if sludge from wastewater treatment plants, creameries, breweries, and organic wastes from other industry were processed by AD this figure could be substantially higher. For instance, the food, beverage and tobacco sectors generated some 67,000 tonnes (dry weight) of sludge in 2001 that could be used as inputs into the AD process.[8] Electricity generated from processed organic wastes displaces electricity from fossil fuels. Such a displacement has significant beneficial implications. First, it reduces the economy's over-reliance on gas, coal and oil and secondly, it reduces the level of carbon dioxide emissions.

Table 1: Indicative Energy Potential from Livestock Slurries[9]

Livestock	Population June 2003 (thousands)	Wet Tonnes/year (millions)	Potential Biogas m^3/year (millions)	Potential Electricity MWh/year	Electricity MWh/tonne waste
Cattle	6,967	84.763	1,441.0	2,641,772	0.031
Pigs	1,713	2.274	35.2	64,493	0.028
Poultry	12,738	0.404	28.8	52,810	0.131
Total		87.441	1,505.0	2,759,075	

Table 2: Biogas from Agriculture and Abattoir Wastes

	Biogas (m^3) per tonne organic waste	Energy equivalence in heating oil (litres)
Cattle slurry	22	13
Pig slurry	22	14
Poultry manure	50-100	33-65
Abattoir gastro-intestinal waste	40-60	26-39
Abattoir fatty waste	>100	>65

Source: Birkmose, 2000

A key issue in determining whether potential energy from agricultural and food sector wastes can be realised depends on availability of sufficient volumes of wastes in close proximity to an anaerobic digester. Regardless of proximity to an anaerobic digester, a considerable proportion of cattle slurries will not be available for digestion. If on average cattle spend 16-20 weeks indoors during the winter some 30-40% of cattle slurry is stored and therefore potentially available for anaerobic digestion. The

[6] 1 MWh = 1 Megawatt hours = 1 thousand kilowatts (kWh)
[7] DCMNR/SEI, 2004
[8] Meaney, *et al.*, 2003
[9] The calculations are based on total estimated cattle, pig and poultry wastes not the proportion stored and managed, while energy potential calculations are based on simple average yields across cattle, pig and poultry populations.

availability and spatial distribution of agricultural wastes are investigated later in the paper, while the following two sections look at other aspects of anaerobic digestion.

Other benefits of Anaerobic Digestion

In addition to the benefits of energy recovery and displacement of greenhouse gas emissions from fossil fuels, anaerobic digestion produces several additional beneficial outcomes.

- AD destroys a wide range of pathogenic and faecal micro-organisms. Under the EU animal by-products regulation (1774/2002) biogas plants must be fitted with pasteurisation/hygienisation units of minimum treatment of 70°C for one hour. Such treatment will kill all pathogens and seeds, thereby eliminating cross-farm contamination of pathogens or weeds.
- AD substantially reduces odours associated with animal slurries by as much as 80%.[10] Compounds associated with offensive odours, including volatile fatty acids and molecules of mercaptans, are degraded into methane and carbon dioxide by the anaerobic bacteria.[11]
- AD reduces the organic pollution potential of animal slurries. Tests of animal slurries from pilot and farm scale digesters show a reduction of 55% of BOD_5 for cattle slurry, 75% for pigs and 80% for poultry slurries.[12]
- An appreciable portion of the geology of the country is of a karst limestone composition, which makes groundwater particularly vulnerable to pollution. The lower pollution potential of AD processed slurries will provide additional protection to groundwater.
- AD increases the proportion of nutrients immediately available for uptake by plants. During the digestion process nutrients are mineralised, which allows improved plant uptake. For instance, digestate has 25% more accessible inorganic nitrogen (NH_4-N) and a higher pH value than untreated liquid manure,[13] though some research suggests that in excess of 80% of the nitrogen in digestate can be available to plants.[14] Table 3 shows some typical analytic numbers for untreated cattle and pig slurry, and a digested compound of equal parts cattle and pig slurry. Total N, P, and K content in the digested compound remain unchanged compared to the constituent slurries but dry matter is considerably reduced making slurry thinner, while ammonium (NH_4-N) content and pH rises.
- Depending on the mixture of slurries (e.g. cattle, pig, poultry, etc) the nutrient balance of digestate may be more balanced for agricultural application. AD transforms organic bound nutrients to a mineral form, which is readily available for crops. With a better nutrient balance and more accessible nutrients the requirement for artificial fertilisers may be lessened, which results in a cost saving to farmers.

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[10] Monnet, 2003
[11] FEC Services Ltd, 2003
[12] FEC Services Ltd, 2003; Hobson and Robertson, 1977
[13] Monnet, 2003; http://www.landbrugsraadet.dk/view.asp?ID=2281
[14] Heslop, 2004

Table 3: Analysis of Cattle and Pig Slurry and 50/50 Cattle/Pig Digested Slurry

	Dry Matter, %	Total N kg/tonne	NH_4-N k/tonne	P kg/tonne	K kg/tonne	pH factor
Cattle slurry	6.0	5.0	2.8	0.8	3.5	6.5
Pig slurry	4.0	5.0	3.8	1.0	2.0	7.0
Digested slurry	2.8	5.0	4.0	0.9	2.8	7.5

Source: Birkmose, 2000

Disadvantages of Anaerobic Digestion

There are several potentially significant obstacles to the development of centralised anaerobic digestion.

- An AD plant has significant capital and operating costs. Several assessments have concluded that AD as a source of renewable energy is not a financially viable stand-alone project. The viability of an AD plant depends on it being part of an integrated waste management system generating several income streams.
- Though anaerobic digestion itself is a natural process, the running of an AD plant is a relatively complicated process, which in the case of a centralised plant involving multiple waste sources needs to be managed by specialists.
- AD, like animal slurries, produces emissions that can be harmful to the environment and human health (e.g. methane, ammonia and hydrogen sulphide). Proper management requires that these risks be controlled.
- A centralised AD plant will create traffic movements transporting wastes to the plant and waste residues away from the plant. Site placement for an AD plant can minimise the traffic impact on adjacent communities, as well as minimise transport costs. Financial viability may be dependent on securing a market for heat energy generated. Ideal site placement requires proximity to waste sources (i.e. farms and organic wastes from industry), customers for the heat (i.e. close to population centres) and the electricity grid.
- AD plants have a visual impact and also generate noise (from pumps, compressors, etc.). AD plants would require both planning approval and an EPA operating licence. Similar to other waste management and energy facilities, AD developers are likely to experience a certain level of local opposition, however, visual and other impacts can be minimised in the design and construction stages.

Feasibility of Centralised Anaerobic Digestion

There are several anaerobic digestion plants in Ireland with at least 3 on-farm plants but the technology is also used outside the agricultural sector for the treatment of industrial organic wastes.[15] Two Irish studies have considered in detail the feasibility of centralised anaerobic digestion as a component of a waste management plan for agricultural wastes.[16] Both studies questioned the financial feasibility of AD, though highlighted the large environmental benefits of AD that are not normally considered in the financial analysis. As the environmental benefits accrue to society at large,

[15] Mahony, *et al.*, 2002
[16] Gannon, *et al.*, 1994; Mahony, *et al.*, 2002

rather than to particular individuals, there is a compelling case for public support for the development of AD. The return on public investment in AD would include improved water quality, groundwater protection, reduced carbon dioxide emissions, and an increase in indigenous renewable energy. The government has already several international commitments with respect to these issues including the Kyoto Protocol, the Renewable Energy Directive, and the Nitrates Directive.

The remainder of the paper examines in greater detail the energy potential from agricultural wastes in Ireland, the spatial distribution of agricultural wastes, and considers the possibilities for a network of centralised anaerobic digesters in Ireland

Spatial Distribution of Agricultural Slurries in Ireland

Table 1 reported statistics on the national energy potential of agricultural wastes but storage of agricultural wastes and spatial distribution are critical elements for the development of centralised AD plants. Only stored agricultural wastes are potentially available for AD and as the financial viability of AD is dependant on sufficient waste volumes in close proximity, the spatial distribution of agricultural wastes is critical.

The concentration of farms plays an important role in the viability of centralised AD, as a sufficient volume of waste in relatively close proximity to a centralised AD plant is required. Table 4 presents estimates of stored agricultural wastes by county, which reflects the relative intensity of agriculture. Cork has over 14,000 farms generating on a daily basis some 14,000 tonnes of stored slurries, whereas Galway has almost as many farms but generates on a daily basis roughly 5,000 tonnes of stored slurries. Limerick generates a similar amount of stored waste as Galway but from roughly half the number of farms. The feasibility of centralised AD in specific locations depends on the participation of sufficient farms, preferably within a 5-8 mile radius of a proposed AD site. The data in Table 4 suggests that there is sufficient stored agriculture waste to supply many centralised AD plants around the country.

To more easily identify the localities where the highest concentrations of organic material exist and therefore where centralised AD is most likely to succeed, data from Table 4 is mapped at District Electoral Division (DED) level in Figure 1. The map in Figure 1 contains estimated stored cattle slurry and the location of EPA licensed sites engaged in intensive agriculture and food/beverage processing, which potentially could supply organic wastes and sludge to AD plants.[17] The map shows that there are numerous areas around the country with high concentrations of cattle slurry in close proximity to sources of other organic material (e.g. food processing, rendering plants, etc.). Cavan and Monaghan have a particularly high concentration of EPA licensed sites surrounded by relatively high concentrations of cattle slurry. Other counties with potential for multiple AD plants are Meath, Waterford, Cork, Limerick, Tipperary, Offaly and Laois. The potential for centralised AD in other counties may not be as high, however nearly all counties have districts containing both high cattle slurry concentrations and nearby factories producing by-product organic wastes, for example, Donegal, Mayo, Galway, Kerry, Wexford and Wicklow.

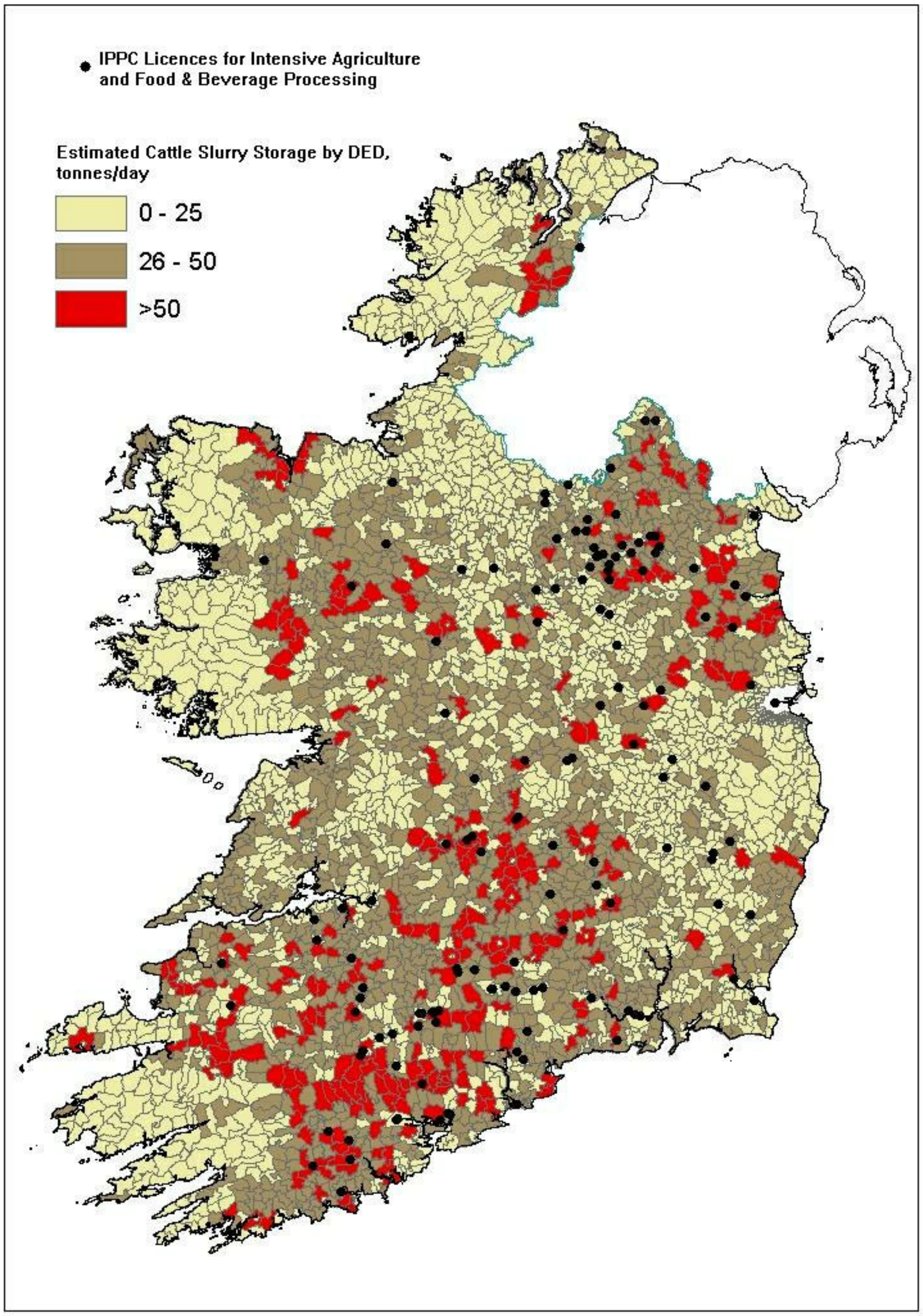
[17] Census of Agriculture data for pig and poultry production was not available at District Electoral Division level.

Table 4: Spatial Distribution of Stored Agricultural Slurries and Farms*

	Thousands Wet tonnes (annual)			Combined Slurries	Hundreds farms		
	CATTLE	PIGS	POULTRY	Tonnes/day	CATTLE	PIGS	POULTRY
Carlow	386	51	0.8	1,200	14.7	0.2	1.7
Dublin	133	0	0.7	366	5.1	0.0	0.6
Kildare	553	67	4.1	1,711	20.2	0.3	2.5
Kilkenny	1,352	149	0.7	4,113	33.6	0.4	3.5
Laois	933	106	0.8	2,849	30.3	0.4	3.6
Longford	512	41	1.1	1,517	26.1	0.2	1.7
Louth	364	44	10.5	1,145	13.3	0.2	1.0
Meath	1,298	93	13.8	3,848	38.4	0.4	3.0
Offaly	882	309	0.3	3,265	32.1	0.4	2.7
Westmeath	824	104	1.5	2,548	31.5	0.4	2.8
Wexford	1,107	165	5.5	3,498	34.5	0.8	3.9
Wicklow	531	65	1.7	1,638	18.3	0.3	2.3
Clare	1,286	37	0.5	3,626	63.8	0.4	6.0
Cork	4,341	895	35.8	14,441	127.5	2.5	10.0
Kerry	1,571	124	7.3	4,663	75.0	0.6	5.5
Limerick	1,723	136	70.8	5,289	58.6	0.6	5.3
Tipperary NR	1,222	112	0.6	3,655	35.5	0.2	3.1
Tipperary SR	1,345	239	0.4	4,340	35.3	0.6	3.1
Waterford	1,034	219	34.2	3,526	24.4	0.4	2.0
Galway	1,853	19	7.1	5,149	124.9	0.4	10.5
Leitrim	454	18	1.2	1,295	34.0	0.2	1.8
Mayo	1,282	62	12.4	3,718	108.8	0.4	9.6
Roscommon	882	60	0.2	2,582	59.3	0.2	3.2
Sligo	549	8	0.4	1,528	40.8	0.1	3.5
Cavan	1,282	922	27.4	6,114	51.3	1.2	3.5
Donegal	762	97	1.9	2,359	61.4	0.6	6.5
Monaghan	1,110	99	218.9	3,911	42.5	0.6	4.0
Ireland	29,568	4,243	461	93,895	1,241.1	12.8	106.5

Source: Based on CSO's Census of Agriculture 2000. * Calculations assume 16 weeks of stored cattle slurry in Leitrim, Cavan and Monaghan and 20 weeks elsewhere. It was assumed that all pig and poultry slurry is managed (stored), therefore potentially available for AD. Combined slurries measured in tonnes/day is calculated as the sum of stored cattle, pig and poultry slurry divided by 365.

Figure 1: Cattle Slurry and EPA licensed Agriculture and Food Processing Sites



Centralised AD Plant Technology, Size, Transportation and Storage Capacity

This paper does not purport to prescribe infrastructural requirements for AD plants and there is no single standard anaerobic plant size or process technology. The characteristics and composition of the waste determine the infrastructure and processes used within an AD plant. Several publications provide information on technologies and infrastructure of existing AD plants that can be used for indicative purposes.[18] Denmark has a 20-year history of centralised AD plants and has over 20 separate operating AD plants. A summary of the characteristics of Danish AD plants is presented in Table 5.

Danish AD plants vary in size and profitability but the scale of operation is not the critical element for profitability.[19] AD plants with the strongest economic performance include small, medium and large plants and operate under both mesophilic (20-45º) and thermophilic (50-65º) conditions.

All the Danish centralised AD plants listed in Table 5 use multiple waste sources, which has two important implications. The first is that co-digesting agricultural wastes with non-agricultural wastes improves biogas production. The majority of plants digest abattoir wastes, which as shown in Table 2 has a relatively high biogas yield. The importance of co-digestion of wastes as well as achieving a balanced waste intake is reflected in the biogas yields of the Thorsø and Studsgaard plants in Table 5, both of which have an intake of roughly 263 tonnes/day but the latter plant has twice the biogas yield. The second implication of taking non-agricultural wastes is the significant revenue it generates.

[18] See for example, Al Seadi, 2000; Mahony, *et al.*, 2002.

[19] Hjort-Gregersen, 1999, reports details on the economic performance of AD plants.

Table 5: Details of Danish Centralised Anaerobic Digestion Plants

Plant	Animal Manure	Other Biomass	Biogas	Digester Capacity	Vacuum tanker capacity	Average farm-plant distance	No. Farms supply waste	Waste Intake				
	tonnes/ day	tonnes/ day	Nm^3/ year	m^3	m^3	km	No.	cattle	pig	abattoir	food	other
Vester Hjermistslev	41	13	1.0	1500	15	1.5	5	✓	✓		✓	✓
Vegger	42	17	2.1	920	20	5	5	✓		✓	✓	
Davinde	25	3	0.3	750	14	5.7	6	✓	✓		✓	
Sinding - Ørre	117	18	2.4	2250	26	5	34	✓	✓	✓	✓	✓
Fangel	124	19	2.2	3750	20	6.5	26	✓	✓	✓	✓	✓
Ribe	352	68	4.8	5235	70	11	69	✓	✓	✓	✓	✓
Lintrup	410	137	5.7	7200	60	7.5	66	✓	✓	✓	✓	✓
Lemvig	362	75	5.4	7600	74	7.5	80	✓	✓		✓	✓
Hodsager	42	6	0.7	880	16	3	6	✓	✓	✓	✓	
Hashøj	100	38	3.0	3000	20	4	16	✓	✓	✓	✓	✓
Thorsø	230	31	2.9	4650	60	7.5	75	✓	✓	✓	✓	✓
Århus Nord	346	46	3.8	8500	60	5.5	70	✓	✓	✓	✓	✓
Filskov	61	18	1.3	880	20	4	11	✓	✓	✓	✓	
Studsgaard	230	36	5.7	6000	*	5	49	✓	✓		✓	✓
Blåbjerg	222	87	3.1	5000	40	5	49	✓	✓		✓	✓
Snertinge	66	42	1.6	3000	20	5	11	✓	✓	✓	✓	✓
Blåhøj	70	17	1.4	1320	20	5	14	✓	✓	✓	✓	
Nysted	180	31	2.6	5000	36	7	36	✓	✓	✓	✓	✓

Source: Al Seadi, 2000. * 5 farms supply the Studsgaard plant by pipeline.

Transport costs are generally a significant proportion (25-35%) of AD plant operating costs.[20] Consequently the location of an AD plant is critical for its viability. The average farm to AD plant distance for the majority of AD plants in Denmark is in the 5-8km range with up to 80 farms supplying animal slurries.[21]

Distance to an AD plant's customers is also critical. Piping biogas to off-site customers is generally not economic, therefore, biogas is used onsite to generate electricity. Access to supply electricity to the national grid affects AD site location. In addition to electricity sales, many of the Danish AD plants rely on income from heat sales either to district heating networks or large heat consumers. District heating networks generally do not exist in Ireland and therefore Irish AD plants cannot rely on such a revenue stream.[22] However, heat sales to poultry producers, factories, greenhouses, swimming pools, leisure centres or other large buildings are possible if an AD plant is suitably located.

[20] FEC Services Ltd, 2003
[21] Information on the most distant farms is not available but it is reasonable to assume that the majority of supplying farms are within a 16km/10 mile radius of the AD plant.
[22] WS Atkins Consultants Ltd., 2002 assess the options for deployment of district heating in Ireland.

Except for smaller AD plants, specialist vacuum tankers are required to transport slurries and digestate. Danish AD plants' vacuum tankers have a $20m^3$ average capacity; with the larger plants (i.e. >100 tonnes/day agricultural waste) operating one $20m^3$ tanker per 100 tonnes daily intake of agricultural slurry. Transport of non-agricultural wastes to the plant is generally the responsibility of the waste generators.

The infrastructure requirements for a centralised AD plant include on-site facilities (e.g. digester, gas storage, odour and safety technology, waste and digestate storage) and off-site storage. On site storage for both pre-digested and post-digested waste is relatively small. The majority of post-digestion waste is stored off site. Two off site storage options are usual. The first is on-farm from where animal slurries originated. The second is in shared storage tanks adjacent to land blocks where the disgestate will be land-spread. Slurry and digestate are not usually mixed but stored separately. Consequently, centralised AD plants will require development of new slurry storage capacity. The Nitrates Directive Implementation Plan requires many farms to increase their slurry storage capacity, therefore, the opportunity exists to encourage the development of storage capacity consistent with the requirements of both the Nitrates Directive Action Plan and centralised AD.

The anaerobic digestion process does not significantly reduce the volume of wastes. Therefore AD is not an alternative to storage capacity. In fact when non-agricultural wastes are combined with agricultural slurries in the AD process additional capacity is required to store the digestate.

Outputs of Anaerobic Digestion

An AD plant produces two outputs, biogas and digestate, but both can be further processed or utilised to produce secondary outputs.

Biogas can be used as a natural gas substitute but is predominantly used to generate electricity. If a combined heat and power (CHP) system is used to generate electricity the heat recovered can be used to maintain temperature levels within the anaerobic digester and surplus heat sold. CHP systems cover a range of technologies but indicative energy outputs per m^3 of biogas are 1.7 kWh electricity and 2.5kWh heat.[23] The combined production of electricity and heat is highly desirable if it displaces fossil fuel energy demand elsewhere and therefore reduces the amount of carbon dioxide released into the atmosphere.

Digestate can be further processed to produce liquor and a fibrous material. The fibre, which can be processed into compost, is a bulky material with low levels of nutrients and can be used as a soil conditioner or a low level fertiliser. A high proportion of the nutrients remain in the liquor, which can be used as a liquid fertiliser.

Digestate Use Options

Land spreading is likely to be the most practical and economical use of the digestate. There are several characteristics of digestate that make it more suitable for land spreading than raw animal slurries. It has a much lower pollution potential,[24]

[23] Mahony, *et al.*, 2002 and assumes $20MJ/m^3$ of biogas.
[24] FEC Services Ltd, 2003; Hobson and Robertson, 1977

nutrients are more amenable to plant uptake and thus avoid leaching into soils, [25] the nutrient mix is more balanced, and odours are significantly reduced.[26]

Land spreading itself is restricted by the Nitrates Directive, which imposes a limit on the amount of organic fertiliser applied to land per year. The limit is the amount of organic fertiliser containing 170 kg of nitrogen per hectare per year.[27] The limits in the Nitrates Directive still apply with AD.

Other disposal options include the processing of the digestate's dry matter into compost. This compost could be marketed to the horticultural or gardening sectors. At present the majority of gardening compost is from peat and our peatlands are a finite natural resource, whereas AD produced compost would be a much more sustainable source. For example, Silver Hill Farms in Emyvale, Co. Monaghan, a large duck farming enterprise generating over 63,000 tonnes of slurry per annum, traditionally spread its slurry on farmland but at present is developing a new waste management system incorporating anaerobic digestion. The new system will involve dewatering the slurry to produce a dry fertiliser and treatment of the liquid fraction by AD to a standard suitable for discharge to a local river. Heat from the combustion of biogas will dry the dewatered slurry in the creation of the fertiliser.[28]

Constructed wetlands have been mooted as a treatment system for agricultural wastes. Guidelines are currently being developed on appropriate use and capacity of such systems. In general constructed wetlands are considered only suitable for treatment of agricultural wastewaters (e.g. dairy wash waters) and not for the treatment of animal slurries. In any event the rotation of nutrients back to land is the best use of the nutrients and displaces artificial fertiliser use.

Financing a Centralised Anaerobic Digester

The most critical factor facing the development of centralised anaerobic digesters is securing adequate financial return. Previous research on the feasibility of centralised AD in Ireland concluded that an AD plant's anticipated operating profit would be insufficient to repay the invested capital.[29] Unlike that previous research a central element of this paper's proposal is to source suitable non-agricultural wastes for co-digestion with agricultural slurries. Other aspects that significantly change the economic climate for centralised AD include the Nitrates Directive and Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources.

Data on the operating costs presented here are adapted from relatively detailed statistics on various size and type of AD plants built in Denmark over the past 20 years.[30] Hypothetical figures are presented for three plant sizes with intakes of 150, 250 and 400 tonnes per day of agricultural waste and an additional 25% of non-agricultural biomass waste per day, i.e. assumed 80:20 ratio of agricultural and non-agricultural wastes. Non-agricultural waste intake varied between 11% and 39% in

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[25] Monnet, 2003; http://www.landbrugsraadet.dk/view.asp?ID=2281
[26] Monnet, 2003
[27] Possibly subject to a derogation of 250 kg N/ha/yr.
[28] http://www.silverhillfoodslife-env.com/html/proposed.asp
[29] Mahony, *et al.*, 2002
[30] Hjort-Gregersen, 1999

Danish plants and varied across a wide range of wastes including abattoir, fish processing, food processing, sugar industry, and brewery wastes.

For the purpose of animal disease control, land spreading of abattoir wastes is prohibited in Ireland.[31] A case for exempting AD processed abattoir wastes could be made on the basis that AD plants must comply with the EU animal by-products regulation,[32] which requires that biogas plants be fitted with pasteurisation/ hygienisation units of minimum treatment of 70°C for one hour, hence removing animal disease control concerns. The animal by-products regulation places strict guidelines on the operation and management of facilities processing animal wastes, including AD or biogas plants.

In the analysis presented below biogas production yield was conservatively assumed to be 40m^3 per tonne.[33] Biogas yield is largely dependent on the waste inputs and in particular the mixture of non-agricultural wastes that are mixed with the animal slurries. Table 2 earlier indicated that some non-agricultural wastes, in particular fatty abattoir wastes, have substantially higher biogas yields compared to animal slurries.

The price secured for AD electricity sales is subject to negotiation and electricity market rules as overseen by the Commission for Energy Regulation. Renewable energy development is supported through the Alternative Energy Requirement (AER) competitions, where successful bidders are awarded 15 year Power Purchase Agreements with the ESB.[34] In the most recent competition the price cap offered in the market to biomass generators was €0.07/kWh compared to a 'best new entrant' price of €0.0479/kWh in 2004.[35] For the purpose of this analysis an electricity supply price of €0.08/kWh was assumed.[36] Internationally, price premia are also used to promote renewable electricity. Premia are achieved through 'green electricity certificate' schemes in Australia, Belgium, Italy, The Netherlands and the UK, while Germany, for example, has legislated for special feed-in tariffs, which for biomass was €0.15/kWh in 2004.[37]

Fees for the intake of non-agricultural wastes are important for the financial viability of centralised AD plants. The current cost facing industry for disposal of organic

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[31] S.I. No. 551 of 2002, Diseases of animals act 1966 (transmissible spongiform encephalopathies) (meat and bone meal and poultry offal) order 2002.

[32] Regulation (EC) 1774/2002 of the European Parliament and of the council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption.

[33] Based on Danish AD plants the average is 43m^3/tonne and ranges from 27m^3/tonne to 98m^3/tonne. The sensitivity of 40m^3/t assumption on the economic outcome is that for each 1m^3/tonne change in biogas yield, revenue from electricity sales changes by roughly €0.15/tonne based on an electricity sale price of €0.08/kWh.

[34] The Department of Communications, Marine and Natural Resources runs the Alternative Energy Requirement competitions.

[35] DCMNR/SEI, 2004. The €0.07/kWh price was 46% above the 2004 'best new entrant' price, which is the price for the most efficient generation technology; combined cycle gas turbine. The 'best new entrant price' for 2005 is €0.0536/kWh (Commission for Energy Regulation, 2004).

[36] The sensitivity of the €0.08/kWh price assumption for a biogas yield of 40m^3/t is that for each €0.01/kWh change in the price of electricity, electricity sales revenue changes by €0.73/tonne. Or alternatively a change in annual revenue of €50,000, €84,000, €134,000 for AD plants with daily intake of 187.5, 312.5 and 500 tonnes respectively

[37] http://www.jxj.com/magsandj/rew/news/2004_01_03.html, Renewable Energy World, January-February 2004.

wastes will determine the level of fees that an AD plant can competitively charge. Fees at rendering plants will determine the upper limit chargeable for accepting abattoir waste. Landfill fees will determine the upper limit chargeable for accepting wastes previously disposed in landfills. In the analysis presented below a fee of €65/tonne on non-agricultural wastes was assumed.

It is difficult to accurately estimate operating and infrastructure costs without specifying in detail the infrastructure employed, which may vary by location depending on waste composition and local circumstances. The average operating cost in Danish agri-food AD plants in 1998 was roughly €8/tonne with the most costly plant operating at €15/tonne.[38] Allowing that Irish operating costs are possibly higher than the Danish average due to higher wage costs, etc., and also allowing for approximately 50% industrial wage inflation in Ireland since 1998, operating costs were estimated at €15/tonne.[39]

The capital cost of the two most recently constructed Danish AD plants for which data is available were used to estimate an indicative capital cost for similar plant in Ireland. One plant is mesophilic with a daily intake of 211 tonnes and the other is thermophilic with a daily intake of 87 tonnes. The analysis presented excludes organic municipal waste, for which there are higher capital and operating costs to facilitate pre-sorting and processing of non-homogenous wastes.

Based on the assumptions outlined above, financial outcomes for three hypothetical AD plants are presented in Table 6. The bottom line financial analysis, based on the assumptions presented, is that AD is feasible with co-digestion of non-agricultural wastes and market supports to the renewable electricity sector. Assuming a 5% interest rate and a 15-year investment horizon the Net Present Value (NPV) of investment in centralised anaerobic digestion is negative. In normal business circumstances when the present value of future income streams is less than the initial investment (i.e. negative NPV), an investment is deemed unprofitable. However, as mentioned previously, financial analyses of AD disregard environmental benefits, even those of substantial value. AD investors cannot charge a fee for the provision of environmental benefits because the benefits are freely available for everybody's enjoyment. To ensure that the environmental benefits of AD are secured for the benefit of society the public should pay for the environmental benefits by means of a subsidy to AD. Based on the scenarios in Table 6 a subsidy in the form of initial grant aid of 50% of the capital cost would make centralised AD an attractive proposition to the private sector (i.e. NPV becoming positive).

The *Irish Farmers' Journal* recently published an article about on-farm anaerobic digestion,[40] the economics of which is substantially different than centralised AD plants due to the relative difference in plant sizes. The on-farm plant described in the article has capacity for 15,000 tonnes/year compared to the centralised AD plants outlined in Table 6 that have an annual capacity of 68-183,000 tonnes and which are

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[38] Hjort-Gregersen, 1999

[39] Operating costs will have both a fixed and variable element but insufficient information was available to estimate separately. For a €1/tonne change in operating costs annual operating cost in the analysis undertaken changes by €68,000, €114,000, and €183,000 respectively for AD plants with daily intake of 187.5, 312.5 and 500 tonnes.

[40] Doyle and Kennedy, 2005

supplied animal waste by multiple farms. The *Journal* article, which is based on a workshop provided by a company involved in the establishment of AD units, is buoyant on the economic viability of AD but the analysis is based on some generous assumptions. The article's assumption of $26m^3$ of biogas/tonne of pig slurry is feasible but on the higher side of plausible ranges, as average pig slurry biogas yield is approximately $15m^3/t$ (see Monnet, 2003). The assumption of $40m^3$ biogas per tonne of organic waste outlined earlier in this paper presumes waste composed of animal slurries and higher energy yielding food-processing wastes. The *Journal*'s article also assumes that the energy content of the biogas is $23MJ/m^3$ compared to $20\text{-}22MJ/m^3$ used in this paper and elsewhere, and the analysis also assumes approximately 39% conversion efficiency to electric energy compared to 30% in this paper and elsewhere. The veracity of assumptions underlying the analysis in the *Journal*, this paper and elsewhere depends on the AD technology employed and the composition of the wastes digested, however, the *Journal's* conclusion that €0.06/kWh for electricity sales is the breakeven point is quite optimistic.

Table 6: Economic Analysis of Hypothetical Centralised AD Plants

AD Plant	Unit	A	B	C
Wastes Intake	tonnes/day	187.5	312.5	500.0
- Agricultural (80%)	tonnes/day	150.0	250.0	400.0
- Non-agricultural (20%)	tonnes/day	37.5	62.5	100.0
Gas Production	million m^3	2.74	4.56	7.30
Electricity Generation	Gigawatts	5.02	8.36	13.38
Non-Agricultural waste intake fees	€m	0.89	1.48	2.37
Electricity Revenue	€m	0.40	0.67	1.07
Operating costs	€m	1.03	1.71	2.74
Plant Infrastructure Cost	€m	3.38	5.63	9.00
Tanker & Storage Cost	€m	0.56	0.94	1.50
Net Present Value (NPV)	€m	-1.80	-3.01	-4.81
NPV (incl. 50% grant on plant and storage)	€m	0.53	0.88	1.41

Grant aid required for specific AD plants will depend on individual circumstances. The existing Farm Waste Management Scheme currently provides for grant aid on farm waste management expenditure, amounting to €20 million in 2003, which could easily incorporate centralised AD and in particular off-site AD storage for digestate. The current scheme provides grant aid up to a maximum of 40% of cost, while the Brosnan report calls for a 60% state contribution for storage systems.[41] The greater environmental benefit from centralised AD versus standard slurry storage is reason in itself to increase both the level and coverage of the Farm Waste Management Scheme.

Internationally, three types of policy initiatives have been used to support renewable energy development. Several countries, including Ireland, use a competitive bidding system (i.e., the AER competition) to allocate a quota of fixed term purchase

[41] Brosnan, 2004

contracts. Feed-in tariffs have been used elsewhere that oblige utilities to purchase renewable electricity at a fixed price. This approach has been very successful in developing wind farm capacity in Germany, Denmark and Spain. A third approach obliges utilities to demonstrate that a certain proportion of their electricity comes from renewable sources, which in essence places an additional value on renewable energy sources. The renewable electricity suppliers recoup this premium by means of a trading system in 'green electricity' certificates. This approach has been followed in the UK, Netherlands, Belgium, Italy, and more recently Denmark has switched from feed-in tariffs to green certificates.[42] Expansion of a renewable electricity price premium scheme in Ireland is an alternative to grant aid for the promotion of renewable energy and specifically centralised AD. A €0.08/kWh premium above the 'best new entrant' price[43] over 15 years is roughly equivalent to the 50% capital grant requirement outlined earlier.

Environmental Benefits

The AD option affords greater water quality benefits than standard slurry storage because AD digestate has lower pollution potential,[44] and its nutrients are more amenable to plant uptake and thus avoid leaching into the soil.[45] AD also provides additional benefits in terms of meeting our targets under the Kyoto Protocol and EU Directive 2001/77/EC on electricity from renewable energy sources.

EU funded research concluded that the external cost, in terms of global warming, public health, occupation health, and material damage related to coal sourced electricity production is €0.06-0.08/kWh.[46] In the case of the 500 tonne/day AD plant scenario in Table 6, external costs averted would amount to some €600,000 per annum. If this single environmental benefit materialised as an actual annual income stream it almost matches the 50% grant aid requirement.

Conclusion

AD has the potential to deliver multiple environmental benefits, including reduced water pollution potential, lower greenhouse gas emissions, and reduced odours from agricultural slurries. In places that have high concentrations of animal waste threatening water quality centralised AD can play a significant role in managing the problem. AD is also unique among policy instruments as it can deliver positive outcomes for multiple policy objectives with respect to global warming, renewable energy and water pollution.

The major stumbling block for AD is that its financial return is insufficient to repay the investment outlay but usual financial analyses ignore the environmental benefits. Government support for centralised AD can be justified on the basis of its environmental benefits, which without government support would not be realised.

[42] Ó Gallachóir, *et al.*, 2002; Meyer, 2004
[43] The 'best new entrant price' is €0.0536/kWh for 2005 (Commission for Energy Regulation, 2004).
[44] FEC Services Ltd, 2003; Hobson and Robertson, 1977
[45] Monnet, 2003; http://www.landbrugsraadet.dk/view.asp?ID=2281
[46] Directorate-General for Research, 2003

As mentioned previously, the government has stated policy objectives and commitments with respect to the Kyoto Protocol, renewable energy and the Nitrates Directive. Accordingly, the government is invariably committed to spending resources, either directly through funding or indirectly through tax incentives, etc, to achieve these separate targets. Another reason for government support for AD is that a single measure supporting AD can deliver progress in all three areas mentioned and thus prove to be a highly efficient use of public funds. For example, grant aid for AD storage compared to standard slurry storage under the present Farm Waste Management Scheme provides additional environmental benefits at negligible additional cost.

The construction of additional storage infrastructure to comply with the Nitrates Action Plan, which has been estimated to cost in excess of €1 billion, can be easily adapted to facilitate development of AD.[47] Therefore, through the Farm Waste Management Scheme, under which the Brosnan Report has advocated 60% grant aid for farm slurry storage, the government is potentially committed to a substantial expenditure to achieve compliance with the Nitrates Directive. Accordingly, the implementation of the Nitrates Action Plan provides a useful opportunity to actively promote AD in Ireland.

Besides grant aid there are other measures such as Public Private Partnerships (PPP) that the government could undertake to promote the development of AD in Ireland. PPP arrangements have been proposed to deliver on national waste management policy objectives, in particular projects that incorporate either materials reuse and recycling (including biological treatment), energy recovery, or environmentally sound disposal of residual wastes,[48] as well as projects dealing with alternative energy.[49]

The fact that it is cheaper to produce electricity from fossil fuels than from renewable energy sources is a significant economic disincentive for the growth of renewable energy electricity. With Directive 2001/77/EC requiring increased electricity generation from renewable energy sources, countries have introduced specific measures to improve the economics of renewable electricity. Ireland predominantly uses a quota system, through the AER competition, to promote renewable energy, as does Sweden, Italy and the UK. Other countries such as Germany, Denmark and France have measures that directly support the renewable electricity price for all producers. A more extensive support system either through green electricity certificates or feed-in price tariffs would benefit AD and other renewable energies and would obviate the need for a capital grant.

As outlined in the discussion above, centralised AD, with suitable support measures, is a viable policy option to address national commitments in the areas of global warming, renewable energy and water pollution. Concerted action is required from the various stakeholders if a network of centralised anaerobic digesters across the country is to be reality. In that context we wish to use this paper to initiate a

[47] O'Sullivan, 2004, estimates that the cost of compliance with the Nitrates Directive by dairy and commercial dry-stock farms will range from €498 million for earthen banks/lagoons or €990 million for concrete structures. Lenehan and Drennan, 2003, and Ryan, 2003, provide estimates of the cost of individual farm buildings, including storage.
[48] Department of Environment and Local Government, 2003
[49] See http://www.ppp.gov.ie

discussion between the Agri-food sector, government and other interested parties on the merits of developing a network of centralised anaerobic digesters.

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