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Agricultural anaerobic digestion power plants in Ireland and Germany: policy & practice: Agricultural AD in Ireland and Germany

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Agricultural anaerobic digestion power plants in Ireland and Germany: policy & practice

Running Title

Agricultural AD in Ireland and Germany

Authors

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Abstract

The process of anaerobic digestion (AD) is valued as a carbon-neutral energy source, while simultaneously treating organic waste, making it safer for disposal or use as a fertilizer on agricultural land. The AD process in many European nations, such as

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Germany, has grown from use of small, localized digesters to the operation of large-scale treatment facilities, which contribute significantly to national renewable energy quotas. However, these large AD plants are costly to run and demand intensive farming of energy crops for feedstock. Current policy in Germany has transitioned to support funding for smaller digesters, while also limiting the use of energy crops. AD within Ireland, as a new technology, is affected by ambiguous governmental policies concerning waste and energy. A clear governmental strategy supporting on-site AD processing of agricultural waste will significantly reduce Ireland's carbon footprint, improve the safety and bioavailability of agricultural waste, and provide an indigenous renewable energy source.

Keyword List

anaerobic digestion, biogas, energy, Ireland, renewable

Introduction

The industrialized process of anaerobic digestion (AD) is a chemical process mediated by microorganisms to break down organic material. In a controlled AD process, organic substrates from farms, landfills, industrial waste, or municipal sewage are converted to biogas (mostly methane, CH_4) and digestate.[1] The organic sources originating from agricultural biomass range from crops to slurry, as shown in Table 1.

There are several by-products produced during the AD process with useful applications. Firstly, the biogas can be used like natural gas to directly heat facilities on site and produce electricity via Combined Heat and Power (CHP).[2,3] Both the biomethane and electricity produced by CHP can be fed into local or national grids.[4] Alternatively, the biogas can be further purified to biomethane and replace natural gas as a fuel for transportation vehicles.[5] Finally, some of the liquid and solid digestate from the AD process can also be used as agricultural fertilizer and landspread.[6] These applications of biogas and digestate are the result of new technologies, which have been developed from refinement of the AD process over the last thousand years.

The History of AD

According to some sources, biogas was already used to heat water in Assyrian bathhouses over 1000 years BC.[7] Certainly, medieval alchemists knew of a flammable gas associated with putrefaction and intestinal digestion.[5] While Alessandro Volta was probably the first to isolate methane, subsequent work by other 19th century scientists such as Pasteur, Bechamp, Bunsen, Soehngen and Hoppe-Seyler identified the microorganisms and metabolic pathways involved in anaerobic digestion.[8].

In 1884, Pasteur proposed using the fermentation process as a fuel source for street lights in Exeter, England.[9] Around the same time, an anaerobic digestion plant for the treatment of sewage was built for lighting and electricity generation at a leper asylum in India.[10,11] Soon anaerobic digesters consisting chiefly of anaerobic ponds were being constructed in many parts of the world.[5]

Interest in biogas plants has been stimulated by global events. For instance, during periods of energy shortages such as WW2 or the 1970's oil crisis, AD was employed as an alternative for fuel generation, often utilizing agricultural waste material as an important AD feedstock.[12] More recently, dwindling supplies of fossil fuels, oil price volatility and concerns about anthropogenic climate change have again helped to boost the industry.[13,14] As the technology has advanced, in terms of both plant engineering and microbial community management, many governments and development organizations have started to actively encourage and support the installation of AD plants.[7]

AD Benefits and Biosafety

The perceived and realized benefits of agricultural AD are dependent on local conditions and requirements, even though the AD process remains fundamentally unchanged. For instance, in many developing countries, bioenergy production from household digesters serves primarily to provide energy to rural communities that are not served by conventional energy infrastructure.[10,15] These small-scale units replace highly polluting traditional solid fuels, such as firewood, cattle manure or crop residues and provide sought-after fertilizer.[7,16] In contrast, in many industrialized nations, application of AD is often driven by local environmental regulations and other policies governing land use and waste disposal.[14,17] Under these circumstances, a significant motivation for AD is the safe treatment and disposal of agricultural waste. More recently, however, the need for alternative energy sources has come into sharper focus, increasing the interest in biofuel energy crops, which are produced specifically as feedstock for biogas plants.

Regardless of scale, AD power plants are generally considered to have a positive environmental impact. Under optimum conditions, AD is a carbon neutral source of energy and helps to improve the biosafety of many waste materials.[18,19] With regard to agriculture, it serves to reduce methane gas emissions resulting from livestock farming and, by replacing synthetic inorganic fertilizer, reduces the overall cradle-to-gate emissions of agricultural products.[20] In comparison to untreated slurry or manure, AD digestate is arguably less malodorous, less prone to nutrient leakage and less likely to contain potential pathogens.[21-23] Agricultural AD processes operate at a range of temperatures spanning the mesophilic (30-42°C) and thermophilic (50-60°C).[24,25] Previous studies have shown that pathogen viability decreases faster with longer exposure to the higher thermophilic temperatures.[24,26] Thus, while the digestate resulting from the AD process is not necessarily pathogen-free, it is sure to contain fewer pathogens than sludge that is spread on land without prior treatment.[27,28]

AD in Germany

Within Europe, Germany has the highest production rate of biogas with approximately 8000 plants producing about 4 gigawatts of energy.[29] The first AD plant installations were commissioned in the early 1990s with a combined capacity of a few hundred megawatts; by 2006, capacity had reached 3 gigawatts.[30] While production of electricity from biogas is a valuable resource, the most common application of AD in Germany is CHP.[31] By using the heat output for heating or industrial applications, CHP plants are able to convert biogas into useable energy with 750-900 J kJ^{-1} efficiency.[11] Only 151 of German AD plants (1.7%) upgrade their biogas to biomethane.[3]

The growing energy production rate utilizing the AD process is a direct result of the German government's support for renewable energy. While AD plants produce about 23 J kJ^{-1} of the total energy in Germany, 230 J kJ^{-1} or 490 PJ of German energy comes from renewable sources.[3]

German bioenergy production has been spurred primarily by government feed-in tariffs, shown in Table 2, initiated in the year 2000 by the Erneuerbare Energien Gesetz

(EEG- *Renewable energy legislation*).[32] These feed-in tariffs guaranteed AD plant owners a consistent fee for 20 years and a priority connection to the grid, while also taking advantage of 'smart grid' technologies. These modern bi-directional power grids allow small and medium-sized operators to feed surplus energy into the public grid.[33] As a result, AD was considered a lucrative investment and up to 240 new plants were constructed each year.[3]

Since then, amendments to the legislation have stimulated the biogas industry even further. In 2004, the EEG was modified to provide a bonus for using energy crops as feedstock and for developing CHP.[34] This legislation led to an increase in the number of new plants going into commission to 450 per year.[3] In 2009, additional bonuses were included for use of manure, development of new technologies, and emission reduction, which increased the number of new AD plants even further to 1000 annually.[3,35]

Concurrently, and perhaps inadvertently, the EEG has encouraged building of large AD facilities that collect feedstock, not only from agricultural waste, such as manure, but also from energy crops. Currently, the most common substrates fed into German agricultural AD plants, sorted by fresh weight, are 410 g kg^{-1} maize silage, 310 g kg^{-1} liquid manure, 100 g kg^{-1} grass silage, 60 g kg^{-1} solid manure, 50 g kg^{-1} whole crop (barley and triticale) silage and 70 g kg^{-1} other feedstock derived primarily from cereal grain, forage rye and fodder.[25] Thus, while AD plants in Germany do utilize agricultural waste products for feedstock, such as manure, a significant percentage of the biomass comes from energy crops specifically grown to feed the digester, such as maize. The result is an increased demand for energy crops, the cultivation of which takes up one fifth of the arable land in Germany, or approximately 23 billion square meters.[3] This intensive cultivation is controversial, as utilization of crop acreage for energy generation now competes with land used for food production. Furthermore, energy crops, such as maize, are cultivated as monocultures and reduce biodiversity.[2] Additionally, while AD plants operate with the aim of being profitable, many would not be financially viable without government support. This is true in particular for large AD plants, which incur higher costs for the transportation of feedstock, since most of the substrate is not produced or generated on site.

In response to these and other factors, Germany modified the EEG in 2011 to discourage the production of large AD plants in favour of smaller ones.[36] For example, AD plants are now required to either: limit the use of energy crops to a maximum of 600 g kg^{-1} maize per year, make use of at least 600 J kJ^{-1} of the heat generated from the AD process, or transition to using at least 600 g kg^{-1} manure as feedstock. These and other new requirements on efficiency have helped to slow the number of new plants being built to 340 annually.[3]

Additional amendments in 2015 have further reduced the feed-in tariffs for new, large AD plants established since 2015.[37] Meanwhile, AD plants smaller than 75 kW that utilize manure substrates now receive higher subsidies compared to other AD plants. Also, AD plant operators will be charged for electricity produced that is used on-site. Finally, the increased energy production due to new AD plants will be limited to 100 MW per year. In sum, these changes seek to support smaller scale plants, drive the use of agricultural waste as feedstock for AD plants and decrease the cultivation of maize monocultures as energy crops on arable land.

AD in Ireland

Sustainable energy production within Ireland is a challenging but worthwhile goal, as Ireland remains highly dependent on imported energy (currently around 900 J kJ^{-1}).[38] In 2013, renewable energy contributed 33 J kJ^{-1} of the gross final energy demand, much less than Ireland's official 2020 target of 160 J kJ^{-1}.[39] Currently, the majority of the renewable energy is derived from wind energy, which contributes only 16 J kJ^{-1} of the gross final energy demand.[39] Energy produced from biomass (including electricity generated from solid biomass, landfill gas and biogas) accounted for just 11 J kJ^{-1} of the overall energy consumed in the country with the bulk of it arising from 24 landfill gas generators.[38,39]

In 2006, Ireland developed a Renewable Energy Feed in Tariff programme (REFIT 1-3) operated under the Department of Communications, Energy and Natural Resources, which aimed to provide support to renewable energy projects.[25,40] REFIT 3 in particular provides specific funding for AD plants for up to 15 years.[41] Under these schemes, the National Grid is obliged to purchase electricity from renewable energy producers at a set price. While the tariff offered to producers in Ireland is generally lower compared to other European countries, as shown in Table 2, other local factors besides tariffs also contribute to low utilization of AD. For example, in order to cover their costs, Irish AD plant operators charge waste producers gate fees ranging from €50 to 80 per 1000 kg of feedstock.[42] However these gate fees remain a significant deterrent for waste producers, such as farmers, who can simply landspread their untreated livestock waste for free. Furthermore, the gate fees are not regulated and their volatility discourages planning and investing in future AD plants.

As a result of these policies, there are just six biogas plants currently operating in Ireland, with several more being planned or under construction. The annual potential energy output from the operating plants totals approximately 0.25 megawatts of heat and 2.55 megawatts of electricity. The typical AD feedstock includes slurry and manure (mostly derived from cattle, pigs and chickens), other animal by-products, grease-trap, industrial sludge, food waste, grass/maize silage, tree cuttings and septic tank waste, all of which are subject to a gate fee charge (European Commission (http://ec.europa.eu/eurostat/data/database)).

Thus, even though the Irish livestock sector produces significant amounts of agricultural waste, the utilization of AD remains remarkably low.[38] With roughly 7 million cattle, 5.2 million sheep and 1.5 million pigs, together with waste arising from crop-farming, industry and households, there is certainly no shortage of potential indigenous AD feedstock that would provide a largely carbon neutral renewable source of energy, without requiring production of energy crops for feedstock.[43]

In addition to providing renewable energy, the health benefits associated with spreading AD digestate, as opposed to untreated waste, can serve to encourage the development of AD supportive legislation. As mentioned earlier, current Irish policy allows farmers to landspread their waste without prior treatment, which does little to prevent pathogen spread.

Therefore, in order to take advantage of AD benefits, Ireland’s governmental policy should carefully consider the appropriate levels for feed-in tariffs and gate fees. Optimally, the feed-in tariffs for AD plants should be set to provide a useful buffer for the agricultural industry against the volatility of the energy market, while also encouraging efficient use of the AD biogas generated. Also, the gate fees charged to waste producers should be in line with any other type of disposal fee assessed for that type of waste.

The experience of AD policy development within Ireland and Germany can also inform regulations in other countries seeking to incorporate sustainable AD. For instance, the European Union and the United States utilize agricultural subsidies to stimulate stable food crop production. Thus, additional legislation to promote AD development needs to ensure that subsidies for AD reactors do not compete with food crops, as experienced in Germany. Within Ireland, providing supportive tariffs to smaller AD plants would discourage construction of large digesters that drive demand for energy crops. Adopting measures such as these would encourage appropriate growth of the AD industry, while avoiding use of energy crops.

Conclusions

In summary, while the AD process remains a valuable component of carbon-neutral renewable energy sources, active utilization of productive AD plants depends on supportive governmental polices. The examples of AD in Germany and Ireland demonstrate how local circumstances and government policy can influence AD cost-effectiveness and national acceptance.

Within Germany, legislation stimulated the construction of large AD plants. However, these large plants drove demand for cultivation of energy crops, instead of utilizing waste feedstock, such as manure. Therefore, the German policy was amended to encourage a switch to waste feedstock, which requires smaller AD facilities located near the source of the waste generation. Hopefully, a successful transition to smaller AD plants will allow AD to remain an important component of renewable energy within Germany.

Likewise, with a high prevalence of low-intensity livestock farming throughout the country, Ireland is uniquely suited for developing a tight network of small-scale energy producers. Governmental policies are needed that recognize the national and global benefits of agricultural AD, both in relation to reducing the emission of greenhouse gases as well as enhancing the safety of agricultural waste. Such polices would be a significant benefit to both the economy and the environment, while simultaneously supporting the 'green image' of the Irish food industry.

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Table 1

Comparison of gas yield and methane concentration of agricultural substrates used in agricultural biogas reactors.[3]

AD Substrate	**Average Gas yield of fresh biomass at** 15 °C and 101.325 kPa **(m^3 kg^{-1})**	**Average CH_4 Methane concentration (m^3 dam^{-3})**
Grass silage	0.208	540
Whole crops (wheat, triticale)	0.214	520
Maize silage	0.185	520
Milk	0.163	560
Cow dung	0.090	550
Pig manure	0.074	600
Horse manure	0.063	550
Chicken dung	0.055	580
Beef cattle slurry	0.034	550
Dairy cattle slurry	0.020	550
Pig slurry	0.020	600

Table 2

Biogas production, plants, and feed-in tariffs from agricultural AD plants compared to average household electricity prices from several European nations.

Country	Biogas produced in 2013[44] (GJ)	Number of AD plants in 2014[*]	Subsidies in 2014[**] (Euro cents MJ^{-1})	Household electricity prices in 2014[**] (Euro cents MJ^{-1})
Austria	7310	293	3.59-6.53	5.61
Denmark	3115	72[†]	1.0-1.6[†]	8.45
France	4396	301	1.3-5.8	4.40
Finland	553	68	3.71	4.34
Germany	260220	8265	1.63-6.59	8.28
Ireland	**226**	**6**	**2.78-4.17**	**6.69**
Sweden	1830	78	0.56	5.46
The United Kingdom	0	285[‡]	3.17-4.56	5.33

[*]IEA Bioenergy (http://www.iea-biogas.net/country-reports.html)
[**]European Commission (http://ec.europa.eu/eurostat/data/database)
[†]2013
[‡]2015

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