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Integration of Anaerobic Digestion into Farming Systems

in Australia, Canada, Italy, and the UK

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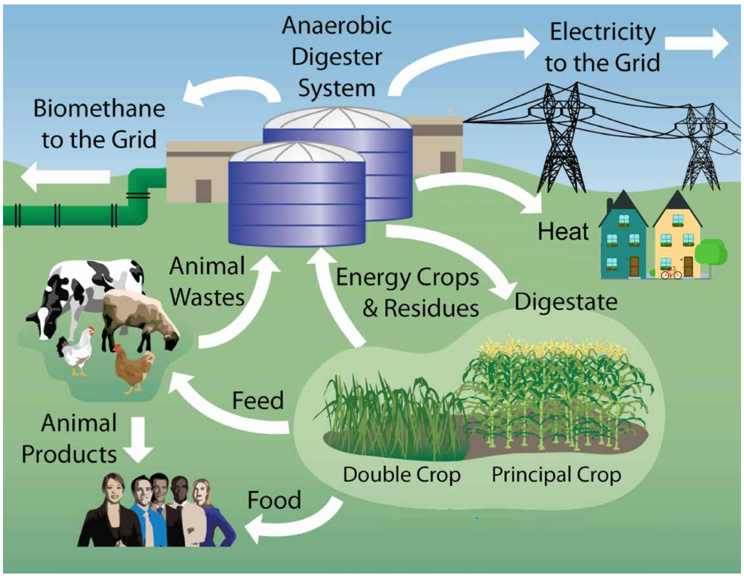

Integration of Anaerobic Digestion into Farming Systems
in Australia, Canada, Italy, and the UK

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Cover graphic: The Biogasdoneright[R] concept (from: Dale, et al., (2020). The potential for expanding sustainable biogas production and some possible impacts in specific countries DOI: 10.1002/bbb.2134; *Biofuels. Bioprod. Bioref.*)

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Preface page

This multi-country report describes how anaerobic digestion has been integrated into farming systems in Australia, Canada, Italy, and the United Kingdom. As much as possible, consistent terminology has been used to improve readability. Some terms have been maintained such as biomethane and renewable natural gas, as EU readers are more used to biomethane while North American audiences employ the term renewable natural gas or RNG to describe upgraded biogas.

Currency

Authors in the report refer to prices, costs and investments using their own country's currency. To assist the reader, approximate currency values are provided in the following table using the US currency as a standard. The four countries in this report have a floating monitory policy and thus the exact exchange rate fluctuates every day.

Country	Currency	Value in Country Currency	US Dollar Value (range)
Australia	Dollar (AUD)	$1	$0.65 to 0.70
Canada	Dollar (CAD)	$1	$0.70 to 0.75
Italy	Euro	1	$1.09 to 1.14
UK	Pound Sterling	1	$1.22 to 1.28

Executive Summary

The four countries – Australia, Canada, Italy, and United Kingdom - differ with respect to their size, climate, and type of agricultural production. Canada and Australia have the largest landmass but vastly different climates. Anaerobic digestion and biogas production in the agriculture sector is highest in Italy, followed by the UK, Australia, and Canada.

The adoption of anaerobic digestion (AD) has grown in all four of these countries over the last decades, albeit at different rates. In all cases, energy and climate change policies have been the dominant drivers that have enabled growth. In Canada, energy, waste management and environment policies are mostly under provincial jurisdiction, and thus AD development is discussed by province.

The environmental sustainability of agriculture has many facets. In this section of the report, each country description provides a different lens on sustainability and the role of anaerobic digestion. In Australia, AD is used primarily to reduce the environmental impact of wastewaters from red meat processing and piggeries. The section by Canada describes the regulatory framework for AD in agriculture in the different provinces. Italy has seen widespread adoption of the Biogasdoneright[R] concept – a set of innovations that includes AD as a core technology. In the UK, AD of manure along with improved crop production technologies, including precision agriculture, are reducing the environmental footprint of agriculture. Other environmental benefits such as the destruction of pathogens and weed seeds are also noted. Agriculture is a source of GHG emissions but has the capacity to remove CO_2 from the atmosphere and sequester carbon in the soil. Anaerobic digestion and the production of biogas can reduce the GHG emissions from manure management and offset more GHG-intensive forms of energy; together with increased photosynthesis associated with catch crops and increased soil organic content associated with no till, this can result in negative emissions in the circular economy system. The GHG impact of AD depends on the availability (collectability) of feedstock and the GHG intensity of the country's energy system. In Australia, there are significant amounts of collectible manure and adoption of AD could reduce both manure emissions and energy related GHG emissions from the broader economy. In Canada, the potential varies significantly by province, depending on the amount of collectible manure, the percentage of hydroelectricity in a province's energy system, and renewable natural gas (RNG) policies and incentives. Upgrading biogas to RNG provides greater emission reductions but is only financially viable for large AD systems. In Italy, the adoption of the Biogasdoneright^R (or BDR) concept can significantly increase carbon sequestration in the soil, reduce farm GHG emissions to close to zero and offset GHG emissions from the energy system. AD is a core technology in this concept that is complemented by the production and use of catch crops (fast growing crop grown between successive planting of main crop) and greater digestate production. Similarly, in the UK, emissions reductions in farming involves precision farming, AD and the appropriate use of digestate – part of the trend to more sustainable agriculture.

The adoption of AD at Australian piggeries and direct on-site use of biogas energy is financially profitable with pay back periods under 10 years. Off-setting on-farm energy costs (electricity, diesel, LPG) and selling surplus energy to the grid are critical to the financial bottom line and are more reliable than revenue from carbon credits that can disappear with a change in government. In Canada, investment in on-farm AD systems has required a long-term feed-in-tariff (FIT) contract and revenue from tipping fees for off-farm material. Most FIT programs have ended, and two Canadian Provinces are now offering premiums for RNG production that could offer opportunities for larger AD systems. In Italy, the incentive for producing energy from biogas has continued to decline since 2008. With the adoption of Biogasdoneright^R, farmers are expected to increase their revenue and reduce biomethane production costs by extracting more value from digestate nutrients, use less expensive second crop harvest (in place of first crops), and achieve greater first crop yields. In the UK, farm adoption of AD can change crop selection as well as the farm's business model. There are several different ways for a farm to finance new AD systems, ranging from being strictly a feedstock supplier to 100 % ownership.

In all four countries there are opportunities to increase the production of biogas and renewable energy from on-farm AD systems. In both Italy and the United Kingdom, energy from biogas is explicitly recognized as a mitigation measure in the respective countries' renewable energy and climate change policies, and AD is well integrated into crop production. The policy signals and financial incentives are significantly weaker in Australia and Canada and would need to be strengthened to encourage new investment that would achieve the growth potential for agricultural AD projects in these countries. Apart from the use of digestate on agricultural soils, here AD has not yet been integrated into crop production and the broader concept of sustainable agriculture.

In the last section of the report, on-farm AD success stories are described by Australia, Canada, and the United Kingdom. Italy uses a case study of a hypothetical farm in Northern Italy to illustrate, in quantitative terms, the potential GHG emissions reduction and carbon balance that could be achieved with the adoption of the BDR concept.

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Section 1
Introduction to Countries and Respective Biogas Industries

The four countries - Australia, Canada, Italy, and United Kingdom - differ with respect to their size, climate, and type of agricultural production. Canada and Australia have the largest landmass but vastly different climates. Anaerobic digestion and biogas production in the agriculture sector is highest in Italy, followed by the UK, Australia, and Canada.

1.1 AUSTRALIA

Australia is the largest country in Oceania and the world's sixth largest country by total area. The population of 26 million is highly urbanised and heavily concentrated on the eastern seaboard. While Australia is the driest inhabited continent in the world (70 % classed as arid or semi-arid), it exhibits a wide range of climatic zones (Figure 1-1).

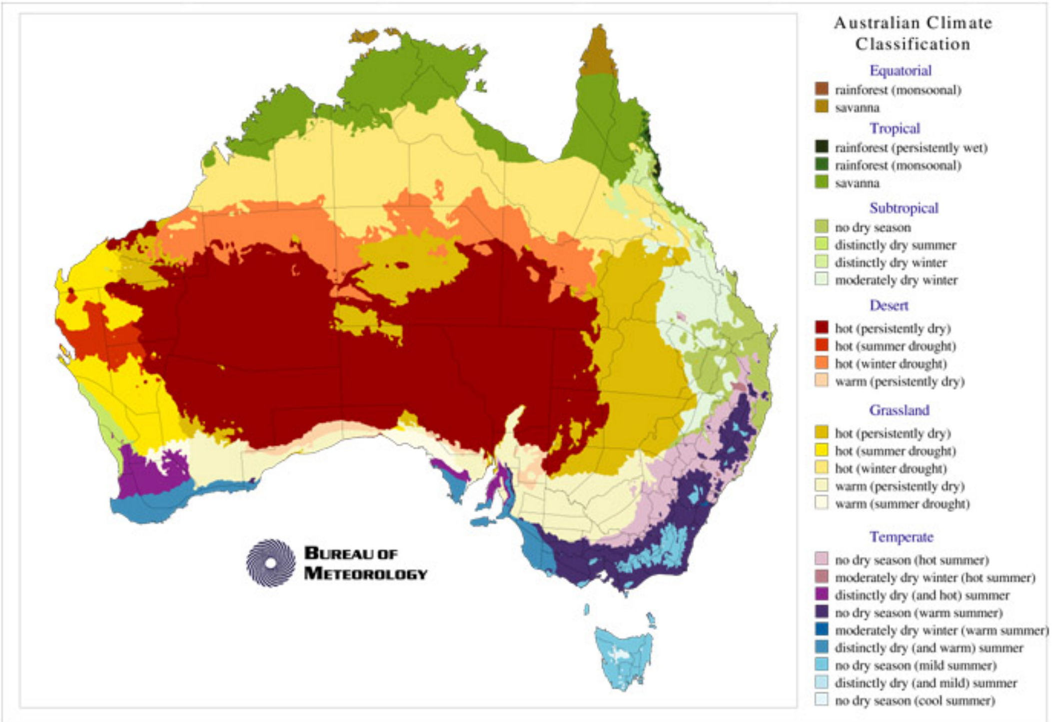


Figure 1-1: Map of Australia with Climatic Zones (Bureau of Meterology, 2001)

The areas of interest for cropping and livestock are focussed on the temperate and grassland regions in the northern interior, east, south-east, south and south-west of the country with some agricultural land use in tropical and subtropical areas. Australia's climate is highly variable, with lower mean rainfall and higher rainfall variability than most other nations. As a result, Australian agriculture is subject to more revenue volatility than almost any other country in the world. While Australian farmers are well-accustomed to climate variability, the emergence of climate change is presenting some new challenges. Climate models predict large changes in future rainfall including lower rainfall in southern Australia and more severe droughts and floods. Over the last 20 years, large changes in Australian climate have been observed, including reductions in average winter rainfall in southern Australia and general increases in temperature (Bureau of Meteorology, 2018).

Agriculture has a total land area of 769 million hectares (ha) of which 373 million ha are used for agricultural production. Cropping and improved pasture account for 31 and 36 million ha respectively, while the remaining 305 million ha are considered non-specific grazing land. Cropping and meat production in Australia is diverse, producing a range of products. The country's temperate and sub-tropical climate is suitable for a wide range of fruits, grapes, vegetables, and nuts. Its livestock population comprises 24 million head of beef, 2.6 million head of dairy cattle, 71 million head of sheep and 3 million head of pigs (Australian Bureau of Statistics, 2018, 2019a, 2019b 2019c).

The Australian biogas industry is emerging. In 2016-17, electricity generation from biogas was about 1,200 GWh (4.32 PJ), or 0.5 per cent of the national electricity generation. As of September 2019, biogas contributed 0.51% of Australian electricity generation, equivalent to 4.74 PJ of a total 930 PJ (Australian Government, 2019).

The total number of biogas plants, including landfills, is estimated to be 242 (Table 1-1). A map of anaerobic digestion (AD) plant locations is available at the link: https://biogas.usq.edu.au/#/map. Embedded into each AD location is nameplate data on the installation (University of Southern Queensland 2017). Most biogas production is associated with municipal wastewater treatment plants (WWTP) and landfill gas power units. WWTP use various technologies for the mono digestion of sewage sludge.

Table 1-1: Australian biogas plants and capacity

Substrate/Plant type	Estimated number of plants	Potential production (GWh/yr)*
Landfill	129**	1,075
Wastewater treatment plant	52	381
Industrial	34	44
Agriculture	22	24
Biowaste	5	63
Total	**242**	**1,587**

* Calculated from the installed capacity of the survey respondents.

**2006 Sustainable Power Plant Register, Australian Business Council for Sustainable Energy

Most of the agricultural AD facilities are in the east and southeast coastal areas of Australia. Agricultural AD plants treat waste manure from piggeries (20 systems) and two previously commissioned digesters treat manure slurry from dairies and poultry. Feedlot manure is not converted into biogas but is stockpiled and used as a solid fertilizer on agricultural land; its contamination with soil renders the manure unsuitable for use in AD facilities (MLA, 2017).

Over one half, (approximately 18) of the industrial AD plants process wastewater from red meat processing and rendering plants as feedstock for biogas production. Although several different technologies are used, covered anaerobic lagoons are widely employed to treat agricultural and industrial waste. In the cooler areas of Australia, biogas production from unheated covered anaerobic lagoons diminishes throughout winter as temperatures approach freezing.

There has been recent interest in the feasibility of using co-digestion (e.g. using trucked organic waste, other waste streams and glycerol) at WWTP, intensive agriculture industries and red meat processing plants. Australia neither uses energy crops for biogas production nor has any upgrading facilities to produce biomethane for grid injection or vehicle use. While there is significant feedstock availability for biogas production in the Australian farming sector, AD of crop residues is not currently practiced on Australian farms, and adoption of AD by the livestock sectors is limited (IEA Bioenergy Country Report, 2019).

1.2 CANADA

Canada is a North-American country that surpasses almost all other countries in the world in size (9,984,670 km^2, of which ~9% is water), but has at the same time one of the lowest population densities (3.92 people km^{-2}, totalling 37,797,496 people in 2019) that is concentrated in the southern parts of most provinces. The Canadian climate regions, shown in Figure 1-2, are dominated by temperature and precipitation gradients. The arctic North is dominated by very cold winters (av. -34°C to 0°C) and short, cool summers (-10°C to +10°C). Temperature increases going south, with summers lengthening and warming, but with tremendous differences in water supply.

In the West, the Rocky Mountains Cordillera, which extents north to south throughout most of British Columbia (brown zone, Figure 1-2) stops most of the incoming precipitation from the Pacific Ocean, resulting in a temperate climate without much frost and precipitation of over 1,000 mm per year at the coast, while the inland valleys are semi-arid. This semi-arid zone extends into the continental climate of the Canadian prairies (orange area, Figure 1-2) (most prominently in the Palliser triangle between southern Alberta and Saskatchewan), where precipitation ranges from 250 mm per year in the very south to 500 mm in the centre of the provinces and going east into Manitoba. The provinces with the highest population (Ontario and Quebec) have a large forest cover in the north (beige area, Figure 1-2) and agriculture (light orange area, Figure 1-2) is based in the southern parts of these provinces. Here the weather is temperate thanks to the Great Lakes and St. Lawrence Seaway with sufficient moisture (>800 mm per year). The four Atlantic Provinces in the East include New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland/ Labrador (purple area, Figure 1-2) have a maritime climate.

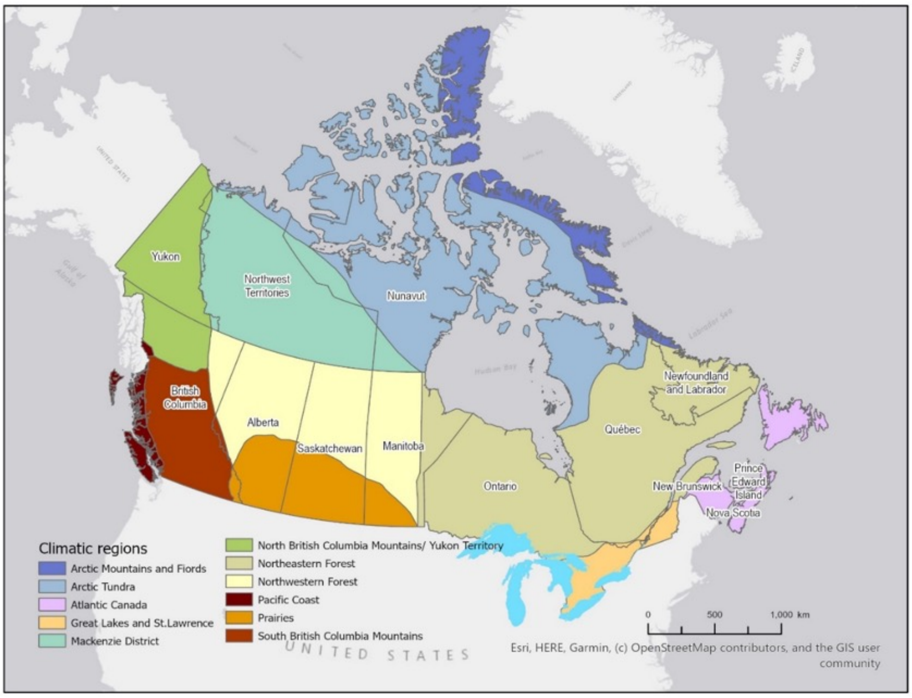


Figure 1-2: Canadian Provinces and Territories and Climatic Regions

Canada's total agricultural land area is 64.2 million hectares with 31.8 million hectares defined as cropland. In Canada's central provinces, agricultural production focusses on corn, soy, winter wheat, horticulture, and some annual staple crops, as well as intensive dairy, pork, and poultry production to satisfy the demand of major urban centres of Toronto, Montreal and Ottawa. The prairie region, with ~80 % of Canada's agricultural cropland base, but only 60 % of farm cash receipts, is dominated by export-oriented agriculture on millions of hectares, with its major annual crops being wheat and canola. Furthermore, large grassland areas provide the backbone of the Canadian beef industry which culminates in Alberta's grain and silage feedlot operations. Southern British Columbia (B.C.) has fruit production such as cherries, apples, grapes, and peaches, while the highly intensive Fraser River valley in the south west portion of B.C. is characterized by dairy, poultry, and pork operations for Vancouver. Extensive beef production is situated throughout the province.

In 2017, renewable energy technologies provided 2,120 PJ of energy, or 17 % of Canada's total primary energy supply or 67 % of its electricity production. Energy from biogas contributed 1.2 % of the total renewable energy. The Canadian Biogas Association estimates that biogas production capacity is at least 195 MW of electricity and 111 GWh/yr (400,000 GJ) of renewable natural gas (RNG) (Canadian Biogas Association, 2020). These numbers are conservative as they do not include all biogas-generating facilities. Over half of the generated biogas is converted into electrical energy alone, with the remainder going to heat and electricity (25 %); heat only (10 %); RNG (4 %); and electricity and RNG (1 %) (Jain, 2019). The total number of landfills, with gas capture and energy use, and operating anaerobic digestion (AD) facilities is estimated to be around 150 with 6 to 10 facilities under construction. The types of AD facilities include wastewater treatment plants (WWTP) treating biosolids, digesters treating source separated organics, industrial AD systems treating wastewater in agri-food processing plants and pulp mills, and on-farm digesters. As shown in Figure 1-3, they are distributed across the country with the highest concentration of facilities in the Province of Ontario.

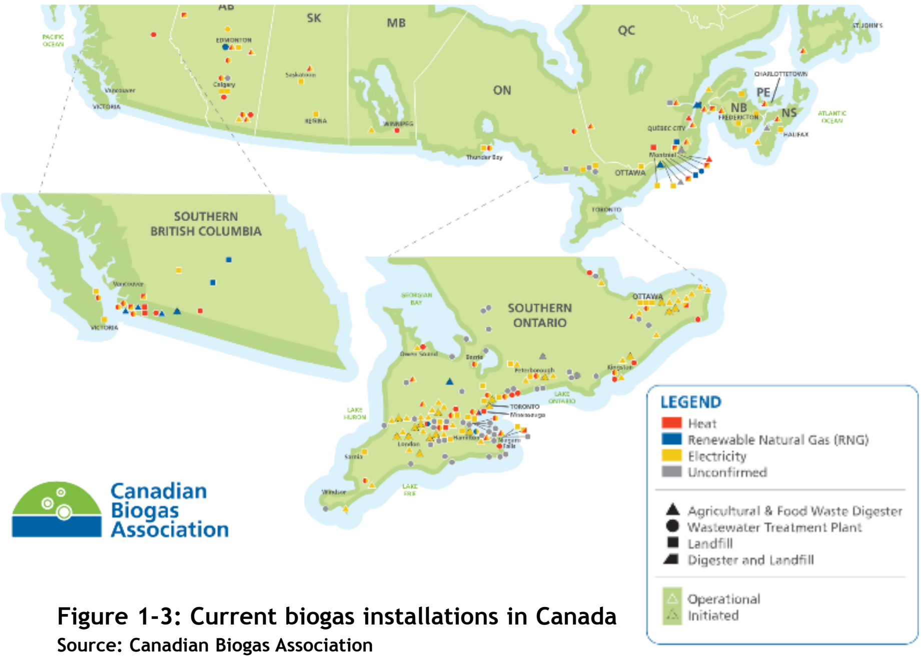


Figure 1-3: Current biogas installations in Canada
Source: Canadian Biogas Association

As of April 2020, it is estimated that there are 44 on-farm digesters in Canada, and 23 digesters operating in the food and beverage industry (Figure 1-3). Most of the on-farm digesters (42) produce electricity and heat, and two facilities in B.C. upgrade their biogas to RNG. Most facilities are located on dairy farms in the Province of Ontario, and all facilities co-digest manure with other organic materials. Biogas produced by the food and beverage industry is used internally to generate process heat, thereby offsetting natural gas use.

Virtually no bioenergy crops are grown for biogas production at this time, though crop residues, wasted feed and horticulture residues are being used to balance digester inputs. In 2018, livestock manure and food processing wastes were converted into more than 25 MW (electrical) and 13 MW (thermal) energy and 36 GWh/yr (130,000 GJ/yr) of RNG.

1.3 ITALY

Italy, located in southern Europe, has a land area of 301,349 km² and a population of 60 million people. Its population is concentrated in cities throughout the country. Italy is included in the range of mesothermal climates; however, due to its extension in latitude, its orography and the action of the sea surrounding it on three sides, it has a considerable variety of local climates, which can be grouped into three basic types - mountain, continental and Mediterranean climates. The continental climate, typical of the Po Valley in the northern part of Italy (Figure 1-4), is characterized by an average annual temperature of about 20°C which plays a major role in sustaining year-round agriculture. It has

Figure 1-4: Map of Italy

two maximum precipitation periods (spring and autumn) and two minimum (summer and winter). The Po region is characterized by high relative humidity because of the intense summer evapotranspiration due to the abundance of surface water from lakes, rivers and canals and accentuated by the type of cultivation (rice, horticulture) practiced in northern Italy (Piedmont, Lombardy, and Veneto regions) where water is relatively abundant. The continental character of the climate of the Po Valley varies according to the distance from the sea; therefore, it is more pronounced in the west and less so in the east, approaching the Adriatic Sea. Central and Southern Italy are much dryer and hotter with a Mediterranean summer climate and mild wet winters.

Italy's climate is particularly favorable to the development of crops that occupy about 12 million hectares of which the prevalent crops are fodder for livestock and cereals. As shown in Table 1-2, 70 % of the agricultural land is used for these two types of crops (Osservatori, undated). Crops are grown throughout the country; however, the Po Valley in northern Italy represents the largest area available for agriculture. The average farm size in Italy is about 10 hectares (Istat, 2015) and typically includes orchards and high value horticultural crops including grapes; farms with field crops and livestock are larger.

Table 1-2: Land use by type of agricultural production in Italy
(Source: Osservatori, undated)

Type of Production	Percentage of Agricultural Land Area
Fodder crops	45.4%
Cereals	25.7%
Oliviculture	9.7%
Viticulture	5.4%
Fruit and citrus fruits	4.9%
Industrial cultivations such as hemp & energy crops	4.0%
Vegetables	4.4%
Potatoes	0.5%

Farm practices in Italy's agricultural production systems are based on a balance between livestock and crop outputs to meet consumer needs. When crop and animal production systems are well integrated, good conditions are created for biogas production from anaerobic digestion as evidenced by a significant development of biogas production in the last 10 years from manure, crop residues and agricultural co-products.

Electricity produced from biogas accounts for about 2.8 % of Italy's energy demand and 3 % of net national energy production. On an energy basis, biomethane derived from biogas currently accounts for 4.5 % of the national natural gas consumption. As of December 31st, 2018 (Table 1-3), there were 2,136 digesters operating in Italy producing electricity and biomethane. Livestock manure together with biomass from agricultural and forestry activities represent the substrates for 77 % of the total number of digesters or 69 % of the total installed biogas electrical capacity and 82 % of the total electricity production. The average size of plants based on manure as the principal feedstock is 388 kW, while those also fed with energy crops, residues and by-products have an average size of 731 kW (Terna, 2018). To date, biogas plants are mostly located in the Northern part of Italy.

Table 1-3: Number of biogas plants, electrical capacity, and production (Source: Terna, 2018)

Source of feedstock (Substrate)	Anaerobic Digesters	Total installed power	Average plant capacity	Electricity production
	(number)	(MW_e)	(MW_e)	(GWh)
Manure	615	238.47	0.388	1,237
Agricultural and forestry activities	1,039	760.03	0.731	5,555
Municipal solid waste	403	405.37	1.006	1,382
Wastewater treatment	79	44.14	0.559	126
TOTAL	**2,136**	**1,448**		**8,300**

In 2018, anaerobic digestion of municipal sources of biomass accounted for 23 % of Italy's digesters. As shown in Table 1-4, the contribution of biogas from municipal waste and sludge digestion is slightly more than 30 % of total installed power capacity, but accounts for less than 20 % of the total electricity production.

Table 1-4: Biogas plants and energy production by feedstock type (CIB elaboration on Terna data for 2018)

Source of feedstock (substrate)	Percentage of Digesters	Percentage of Installed Electrical Capacity	Percentage of Electricity Production
Manure	29 %	16 %	15 %
Agricultural and forestry activities	49 %	52 %	67 %
Sub total	*77%*	*69%*	*82 %*
Municipal solid waste	19 %	28 %	17 %
Wastewater treatment	**4 %**	**3 %**	**2 %**
Sub total	***23 %***	***31 %***	***18 %***
	100 %	**100 %**	**100 %**

1.4 UNITED KINGDOM

The United Kingdom (UK) extends over 10 degrees of latitude, a distance of 1,200 kilometres from the northern tip of the Shetland Islands off the north coast of Scotland to the Isles of Scilly situated over 60 kilometres into the Atlantic Ocean off the coast of Cornwall in South West England. Figure 1-5 shows how the land area lies under the influence of five different air masses.

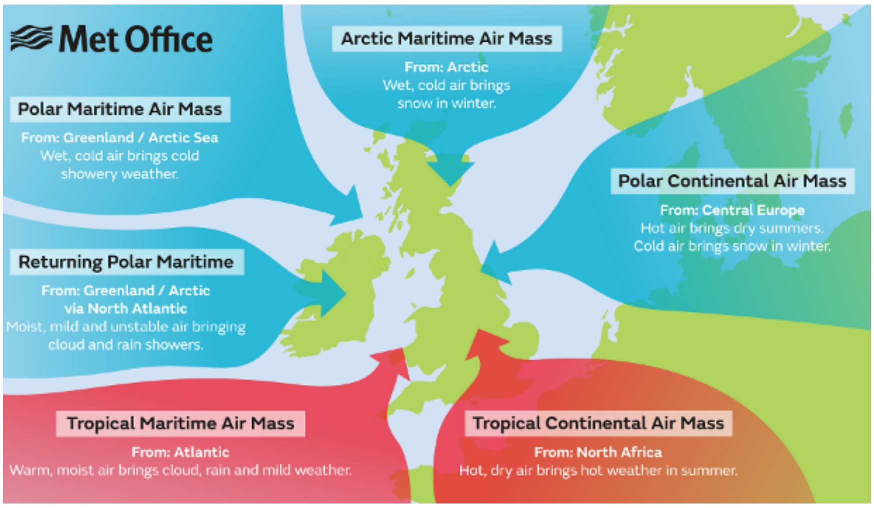


Figure 1-5: Air masses which contribute to UK weather conditions
(© British Crown Copyright Met Office)

While the UK is classed as a cool temperate climate, the interaction of these air masses creates variable weather patterns which from time to time lead to prolonged heat waves or cold spells, flood or drought according to which is dominant at the time.

There is virtually a north east to south west divide extending from the mountainous or hilly areas from Scotland southward through the centre of England to South West England where the moisture laden winds from across the Atlantic are forced to rise over the high ground.

As a result of the mountainous range (Figure 1-6), very high orographic rainfall occurs in those areas west of the mountains and hills, and leads to warmer temperatures and drier conditions in the south and east areas of the north east – south west divide. The regional weather characteristics which arise from these air masses have implications for land use decisions and for the choice of farming systems in the various parts of the country as well as for the feasibility in the adoption of anaerobic digesters on the farms.

Figure 1-6: Mountain Divide in Great Britain
(© British Crown Copyright Ordnance Survey)

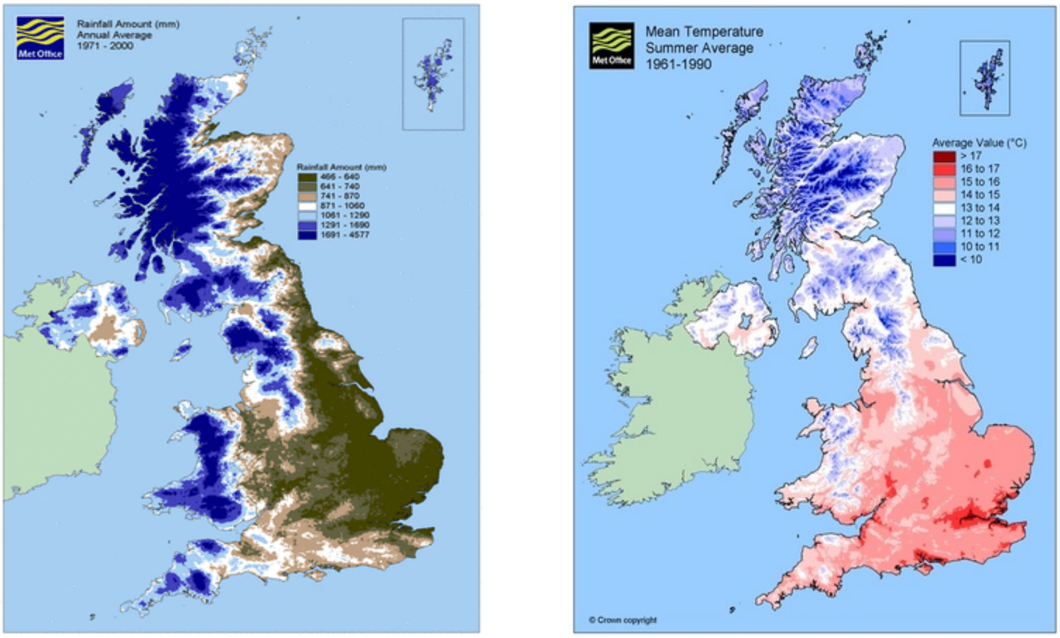


Figure 1-7: (Left) Distribution of mean annual rainfall (Right) Average temperatures
(© British Crown Copyright Met Office)

Figure 1-8 illustrates predominant land use patterns, with crop production concentrated in the east and livestock production in the southern and western regions of the UK. The total agricultural land area is 17.2 million hectares with 6.2 million hectares (36 %) designated as arable land. Twenty percent of all farms in the UK have holdings over 100 ha in size, and this class of large farms accounts for 75 % of the country's farmed area.

In 2018 there were 660 AD plants operating in the UK of which 51 % are classed as agricultural. Other sectors such as mixed agricultural, industrial, and municipal waste treatment accounted for 60 % of facilities. Energy production from all biogas plants in the UK amounted to 2,809 kilo tonnes of oil equivalent (kTOE) energy or 117 PJ. In 2019 natural gas consumption in the UK was in the range 78.8 billion m^3 (c. 2994PJ); as such energy in produced biogas equates to c. 3.9 % of energy in natural gas. This is in close agreement with (Scarlat et al, 2018) who stated that the UK in 2015 had a 3.7 % biogas share in natural gas use.

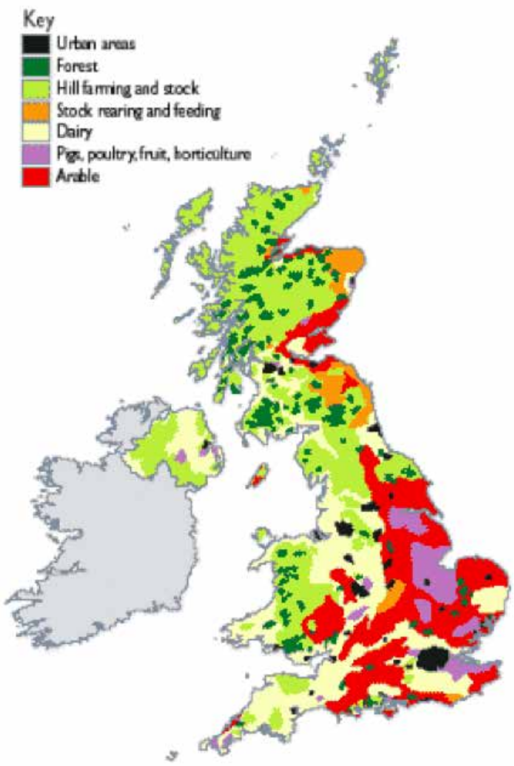


Figure 1-8: Predominant Land Use Patterns in the UK determined by Rainfall and Temperature from: Environmental Health: Seasonal Allergies in the British isles
Sourced from: http://environment.aurametrix.com

Section 2
Development of Anaerobic Digestion in Each Country

The adoption of anaerobic digestion has grown in all four of these countries over the last decades, albeit at different rates. In all cases, energy and climate change policies have been the dominant drivers that have enabled growth. In Canada, energy, waste management and environment policies are mostly under provincial jurisdiction, and thus AD development is discussed by province.

2.1 AUSTRALIA

Australia's Renewable Energy Target (RET) scheme has been operating since 2001 and while scaled back to 33,000 GWh in 2015, the scheme enables projects to acquire large-scale generation certificates (LGCs) or small-scale technology certificates (STCs) until 2030. The Carbon Farming Initiative (CFI) was a voluntary carbon abatement scheme that ran between 2011 and 2014 when it was integrated with the Emissions Reduction Fund (ERF) and was a key tool to develop the biogas sector in the early years of project development, particularly for piggeries. A carbon pricing scheme was introduced in 2012 and was intended to control emissions in the country, as well as support the growth of the economy through the development of clean energy technologies. Although it did achieve a reduction in the country's greenhouse gas (GHG) emissions, the initiative faced significant challenges and was finally repealed in 2014. However, it was a driver for Australia's landfill, wastewater industry and red meat processing sector to review waste management. The Paris Agreement entered into force in Australia in December 2016. The Agreement created a vision and target for GHG reductions by 26 % of its 2005 level by 2030 and serves as a mechanism to develop instruments to incentivize the development of bioenergy going forward.

The Clean Energy Finance Corporation (CEFC) committed up to AUD 100M to the Australian Bioenergy Fund which invests in energy from agricultural waste, AD of sustainably sourced biomass, and landfill gas capture through loan provisions. In addition to national programs, each state can have additional policies to support the development of the sector.

At the farm level, the introduction of biogas was driven by the need to manage nutrients and farm odour issues in addition to increasing energy and fertilizer costs. These factors incentivized farmers to install digesters - large manure slurry lagoons that are covered to capture biogas - to generate electricity for farm use, utilize heat captured in the process and apply sludge to land. A Feed-in-Tariff program is used to encourage the sale of electricity to the grid and provides a mechanism to incentivize projects, however, excess electricity sold to the grid represents only a modest income for farmers.

Table 2-1: Australian biogas consumption from 2014-2018. [a] Australian Government (2016); [b] Australian Government (2017); [c] Australian Government (2019); [d] Australian Government (2018).

Category	2014-15[a]	2015-16[b]	2016-17[c]	2017-18[d]
Biogas consumption (PJ)	19.1	17.5	15	16.1
Landfill gas (PJ)	ND	ND	12.2	12
Other biogas (PJ)	ND	ND	2.8	4.1

Despite Australia being a net energy exporter of many fuel types; the development of the bioenergy sector is nevertheless based on the need for cleaner fuel to meet national targets. The bioenergy industry remains a minor component of the Australian energy landscape at 3.51 % or 216.4 PJ of the 6,172 PJ consumed in 2017-18 (July to June). Within the bioenergy segment produced in Australia in 2017-18, biogas makes up only 7.44 % or 16.1 PJ. The share of biogas is split between landfill gas at 12 PJ or 74.5 % of biogas, and 'other' biogas at 4.1 PJ or 25.5 % of biogas consumption. Bioenergy from non-landfill sites, including agricultural AD, has increased from 2.8 to 4.1 PJ in one year and is indicative of the emergence and relevance of anaerobic digestion on the national stage (Table 2-1). Data by category for biogas origins have only been differentiated in the national energy update reports since 2016.

National electricity generation for the period 2017-18 was 261,140 GWh (940 PJ), and of this, bioenergy produced 3,518 GWh (12.6 PJ) or 1.3 % of total electricity generated. Furthermore, while electricity production from wind and solar energy generation in Australia has grown considerably since 2010, driving renewable electricity generation in Australia to 17.1 %, the growth of electricity generation from bioenergy has stagnated (Figure 2-1). Within the electricity from bioenergy category, combustion of sugarcane bagasse contributed the majority at 40.5 % (Table 2-2). Biogas contributed a total of 35.6 % (1,253 GWh (4.32PJ); 0.5 % of total electricity generation) to bioenergy electricity generation.

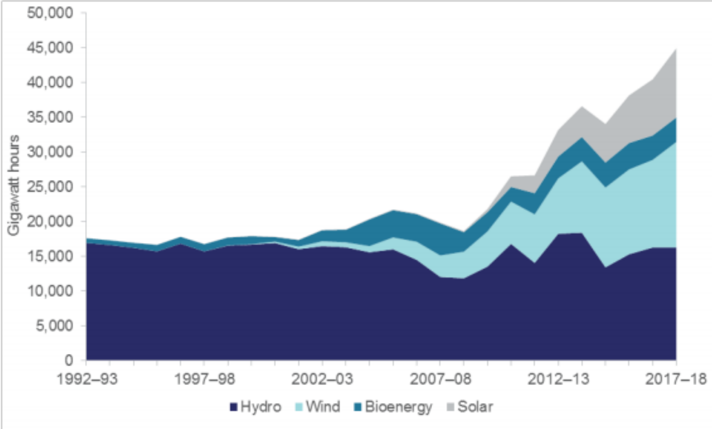


Figure 2-1: Electricity from renewable sources (Australian Government 2019)

Table 2-2: Breakdown of electricity generation from bioenergy for 2017-18, Australian Government (2019).

Bioenergy	GWh	PJ	Bioenergy share (%)	Total generation share (%)
Bagasse	1,425	5.04	40.5 %	0.5 %
Wood, wood waste	315	1.13	9.0 %	0.1 %
Municipal, industrial waste	95	0.34	2.7 %	0.0 %
Sulphite lye, biofuels	429	1.54	12.2 %	0.2 %
Landfill biogas	1,027	3.70	29.2 %	0.4 %
Wastewater treatment biogas	226	0.81	6.4 %	0.1 %
Total	3,517	12.66	100.0 %	1.3 %

Electricity generation from biogas can be further divided by source. Biogas from landfill contributed 1,027 GWh or 82 % while sludge biogas at 226 GWh or 18 % of electricity produced from biogas (Table 2-3). At present, biogas is not used as a liquified fuel in Australia.

Table 2-3: Proportion of electricity generation from biogas in 2017-18 with respect to category.

Percentage of Electricity Generation	Landfill biogas	Sludge biogas	Total biogas
% of biogas	81.96 %	18.04 %	100 %
% of bioenergy	29.19 %	6.42 %	35.61 %
% of renewables	2.30 %	0.51 %	2.81 %
% of total electricity	0.39 %	0.09 %	0.48 %

2.2 CANADA

The biogas industry in Canada is at the beginning of what could be achieved. The development to date can be divided into three general directions: municipal investment, industrial investment, and individual farm innovation and entrepreneurship, all of which are influenced by the provincial framework. The Provinces of Ontario, Québec, and British Columbia lead in terms of number of biogas installations (landfills and digesters), followed by the Prairie provinces. The location and density of the installations, shown in Figure 1-3, follow the patterns of higher population density and food processing activity. In general, provinces whose source of electricity was predominantly hydro based (British Columbia, Manitoba, and Quebec) saw slower adoption of AD systems.

Early development of on-farm digesters dates to mid-1980's when federal scientists worked with farmers in Ontario to build digesters on six farms. At the time, the work was used to test the viability of small AD systems to meet on-farm energy needs and produce single cell protein from the digestate (Van Die, 1987). With limited success and poor economics these digesters disappeared. Nevertheless, this work paved the way for future policy development when decarbonisation of the electricity grid became a provincial priority.

Canadian provinces differ significantly in terms of their population, energy resources and industrial infrastructure, and have adopted differing approaches to biogas development. According to its Constitution, jurisdiction is shared between federal and provincial governments. While agriculture is a shared responsibility, energy policy, environmental management and commerce tends to be provincial. In the early 2000's with the availability of AD technologies from European companies and increased interest in climate change mitigation, there was a renewed interest in biogas production as a source of less GHG-intensive electricity.

Provincial development of AD systems in the agriculture sector is summarized as follows, starting from the West Coast and following with the Eastern Provinces of Canada.

British Columbia was the first province to have an RNG program in 2011: its Greenhouse Gas Reduction Regulation was amended in 2017 to include a renewable portfolio allowance of up to 5 % RNG on the natural gas system. Utilities can pay up to CAD \$30/GJ for RNG (equivalent to \$1.08/m^3 methane or \$0.1/kWh). Currently agricultural AD systems are permitted to use up to 49 % off-farm feedstocks. The two on-farm systems in British Columbia have biogas upgrading systems and sell their RNG to utilities. As agricultural AD systems are not considered a normal farm practice in B.C., new facilities might require sites to be rezoned as industrial land.

In **Alberta**, a bioenergy producers program supported electricity generation from biogas, however no feed-in-tariff program was established in this Province. AD facilities can claim carbon offsets offering a new revenue stream. To date, adoption has been slow and some agricultural AD facilities have shut down as AD electricity production competes directly with large scale conventional generation in a deregulated energy market. Also, there has not been a clear permitting process for biogas projects, other than meeting Building Code requirements. With a new opportunity to sell RNG to neighbouring B.C., interest is growing in the production of RNG from AD of agriculture and agri-food wastes, as well as crop residues.

Saskatchewan invested in AD demonstration projects, but they did not gain much traction. Unfortunately, demonstration projects and renewable energy incentive programs offered by SaskPower for electricity generated little interest in anaerobic digestion on farms. A hog farm AD project closed its operation several years ago. Saskatchewan's Prairie Resilience Climate Change Strategy commits to prioritizing, under federal-provincial funding programs, projects to upgrade municipal waste and sewage management services to reduce, capture, and use biogas that would otherwise be emitted (Government of Saskatchewan, undated). Strategic plans and objectives to develop biomass or biogas energy potential in Saskatchewan have largely focused on generating energy from forestry by-products or landfill gas emissions (Government of Saskatchewan (2019), Sask Chamber of Commerce (2019)).

In **Manitoba**, the food processing industry operates at least one large digester and two anaerobic lagoons to treat its wastewater. A pilot scale and one farm AD system were built to treat hog and dairy manure, but none of these are operating due to a cumbersome regulatory framework, low electricity prices and problems operating in cold winter conditions.

The Province of **Ontario** has the most on-farm AD systems. In 2006, three policy drivers for biogas development were implemented simultaneously – a long-term electricity generation contract, financial assistance, and a capital grant program. As shown in Figure 2-2, the adoption of AD grew significantly because of these policies. Today, 35 on-farm AD systems are operating in the province. Most of these are located on dairy farms, and two are located with greenhouse operations. As the policy model was based on 250 to 500 kW of electricity generation farm AD systems needed access to off-farm waste to make such projects viable through tipping fees and increased biogas output. The Province's Feed-in-Tariff program paid the highest premiums of any province for electricity but the program has now ended.

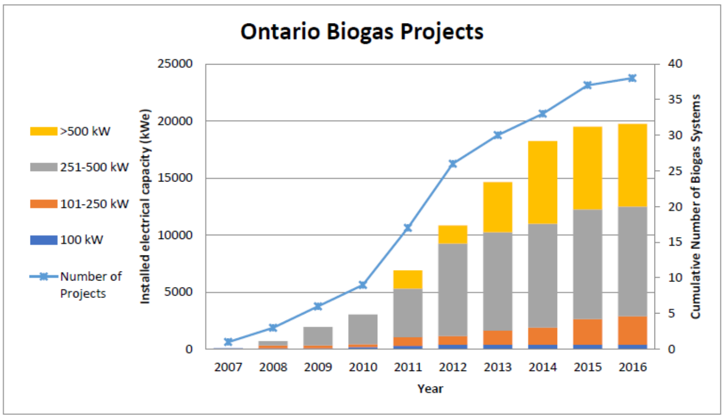


Figure 2-2: Growth in Ontario's Biogas Projects

In **Quebec**, environmental policies related to phosphorus loading led the way for AD of hog manure. Despite technical success at low temperatures, the two AD systems could not compete with low-cost hydroelectricity and were discontinued. Small AD units exist in the food processing industry. Since 2017, Quebec's natural gas utility is actively supporting the development of RNG projects supported by climate change goals, energy policy and organic waste management policy. In 2019, the province adopted an RNG mandate, and an AD feedstock cluster project is under development that involves eight dairy farms, a food processor and wastewater treatment plant.

The Atlantic provinces have few AD systems. New Brunswick has a dairy farm AD facility which also accesses food processing waste and a potato processing facility with a digester, but no specific policy support nor incentives. Prince Edward Island has the largest AD plant (treating potato processing waste), however the Province does not offer preferential tariffs and AD systems cannot compete with less expensive wind energy. Instead, a strategy proposes liquefied biogas be generated from biomass that is currently being composted, and the biogas be used as fuel for the municipal waste collection fleet. **Nova Scotia** offered a feed-in-tariff program from 2011 to 2015 and replaced it with the 'renewable to retail' framework. It has three on-farm digesters. **Newfoundland** and **Labrador** have one AD system on a dairy farm.

In general, AD and biogas production in Canada still must achieve a breakthrough in terms of further economic viability for the agricultural sector. In many parts of the country, agricultural areas are sparsely populated, and manure is directly applied to cropland without any issues. New RNG markets could offer opportunities in locations where feedstocks can be easily aggregated.

2.3 ITALY

Over 1,500 agriculture-based digesters are operating in Italy today. The Italian Biogas Consortium (CIB) estimates that over 4 billion euros in investments support 12,000 stable jobs in the supply and biogas services support chain. The production of biogas was initially developed under incentives to produce electricity to replace the use of coal in economic sectors that use electrical energy or require fossil fuels.

As shown in Figure 2-3, in the early period of development beginning in 2008, there was a rapid increase in the number of biogas plants. Over 1,000 plants were built largely in response to an incentivized electricity feed-in-tariff program offering good prices for biogas sourced electricity of up to 0.28 €/kWh (Governo Italiano, 2008). Energy produced from biogas is of the order of 95 PJ/a (equivalent to 2.5 billion m^3/a of methane). Subsequently, various decrees modified the types and amounts of the incentives, and expanded market access to transportation fuels.

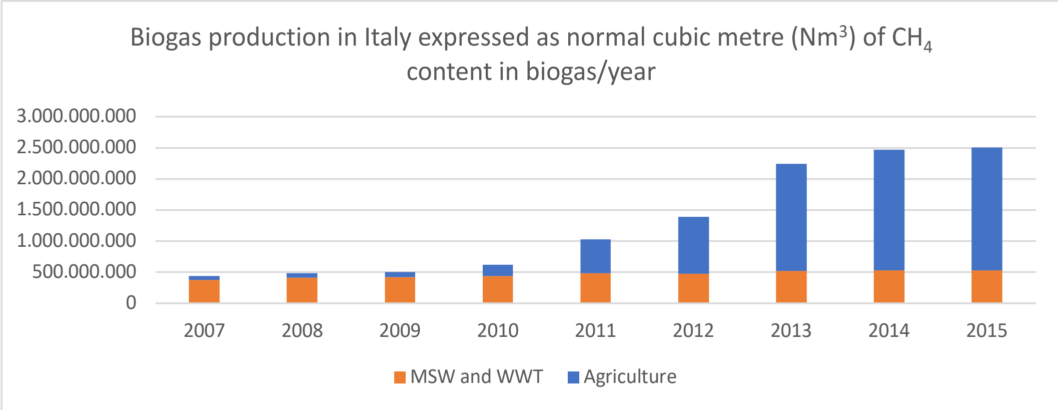


Figure 2-3: Growth of Italian biogas production from 2007 to 2015

In the summer of 2012, a new decree on biogas electricity was adopted (Governo Italiano, 2012) that introduced additional credits for projects capturing thermal energy as well as for projects that reduced the nitrogen content of digestate. A further Ministerial Decree of 2013 was dedicated specifically to the promotion of biogas/biomethane for uses other than electricity production including transportation (Ministero, 2013). More precisely, the 2012 Decree incentivized the production of electricity from biogas at the biogas production site, while the 2013 Decree incentivized the refining of biogas to methane for feeding into the grid and use for transportation, gas for high end uses and high efficiency cogeneration. However, only biogas-to-electricity systems succeeded. A number of factors made it difficult for biogas to enter new markets, including high costs, the long time needed to establish connection to the gas network, the need to organize a new offer linked to new technologies, and a lack of transparency of the biofuel market. Together they provided significant uncertainty in the development of business plans (Pezzaglia, 2015). During this period between 2012-2015 the number of plants increased to 1,555, and growth in AD in the agricultural sector was driven by biogas-to-electricity support.

In March 2018, a new Biomethane Decree (Ministero, 2018) enshrined a biomethane mandate in the advanced transportation fuel system solidifying biomethane's place in the bioenergy sector. The 2018 Decree introduced technical and economic rules: for connection to both the electrical grid and natural gas networks; quality standards for injection; and standards for operators to certify the environmental sustainability of the biomethane. This Decree concentrated solely on the transport sector which was a deliberate decision by the Italian government to tackle the shortfall in production of advanced biofuels in Italy - a critical issue that emerged during the development of Italy's National Energy Strategy. For the first time, biomethane production could also be derived from existing biogas plants while maintaining some of the previous electricity production, thereby initiating a biogas biorefinery model based on two different bioenergy products (Pezzaglia, 2018a).

While any other biofuel could be imported, the Italian government recognized that biomethane produced from agricultural or refuse materials in a biogas biorefinery concept is local and enables the development of a sustainable agricultural supply chain that creates value and environmental benefits. The conversion of biogas to biomethane by the agriculture sector, produced according to the "Biogasdoneright" model developed for Italy, uses less chemical fertilizer and fossil fuel while increasing farm competitiveness. Consequently, Italy's agriculture sector now produces and has access to biomethane for the transportation sector (Rienergia, undated).

Italy has mandatory quotas for biofuels, advanced biomethane and advanced fuels (other than biomethane). Therefore, advanced biomethane is a required fuel in the transportation fuel system (Maggioni et al, 2018). A biofuel is advanced if it is procured partly through co-digestion of inputs listed in Part A of Annex 3 of the Ministerial Decree of 10 October 2014. These inputs leading to advanced biomethane designation include biomass types: algae, biomass portion of industrial wastes, crop residues, manure, energy crops, and agri-industrial residues (Official Gazette).

Italy is the first European market with a fleet of almost 1 million natural gas vehicles, around 2.4 % of the total vehicle fleet, consuming about 1.1 billion m^3 of natural gas (c.42 PJ) every year. Fuel retailers are required to meet the quota on an annual basis by either providing consumers with the amount of biofuels dictated by the quota or by purchasing Certificates of Release to Consumption of Biofuels referred to as CICs. One CIC equates to one m^3 of methane containing approximately 42 MJ of energy. Biofuel producers have access to a variety of incentives, including the granting of CICs that are verified by the GSE, a company that is fully owned by the Ministry of Economy and Finance. Under the CIC scheme, biomethane receives one CIC per 10 Giga Calorie (GCal) while advanced biomethane produced from designated feedstocks receives one CIC per 5 GCal. Expiring in 2022, the 2018 Biomethane Decree limits incentives to a maximum of 1.1 billion m^3 of biomethane per year (c. 42 PJ).

The 2018 Decree also provides for the introduction of guarantees of origin (GoO) certification of feedstocks, serving as proof that sustainable renewable gas is sold to consumers and meets the requirements of the European Union's Emissions Trading Scheme (ETS). Although the system that guarantees the origin of the feedstock applies only to biomethane that is produced in a specified manner (e.g. from specific feedstocks), its introduction is considered to be important for effective development of the direct use of biomethane in agricultural transportation and heavy industrial transportation (Pezzaglia, 2018b). The 2018 Decree also includes measures to support the creation of a new selling infrastructure to deliver both compressed and liquefied biomethane to the transportation sector (Pezzaglia, 2018c).

2.4 UNITED KINGDOM

Anaerobic digestion had been used to treat municipal wastewater in the UK for about a century, but in the mid-1970s two companies applied their expertise of AD in sewage treatment to specialise in small scale AD systems designed mainly for dairy and pig farms to overcome problems with slurry and odours. Such plants, typically between 70 and 200 m^3 in capacity, mixed the digester contents using biogas introduced through a network of small vents in the base and sides of the vessel. These plants were generally installed for slurry management at the farmer's own expense.

Between 1985 and 2001, 50 % capital grants became available to assist with the installation of new facilities to improve manure management (EU, 1985). Some of the farms added an engine to produce electricity for their own use, others used the gas directly in stoves for domestic heating and cooking.

In 2001, the first centralised anaerobic digester was commissioned at Holsworthy in South West England. The main driving forces for this centralized plant were to:

- Provide storage facilities to reduce traffic congestion on narrow country roads caused by frequent slurry spreading by 'muck spreader'.
- Alleviate the pungent odours and droplet air pollution arising from the spreading of pig and dairy slurry and chicken manure; and
- Reduce pollution of water courses from slurry run off.

Farm slurry and manure were co-digested with agri-industrial residues from nearby milk processing plants, breweries, and food processors. The biogas plant provided tanks to each farm for sufficient digestate storage which led to more efficient on-farm nutrient management planning and use. Each load of digestate is accompanied with the delivery note which specifies the nitrogen, phosphorous, potassium and trace element content. The biogas plant also provides access to an agricultural adviser for nutrient management planning.

The Holsworthy project provided the proof of concept for the UK Government to use as a foundation for further program design (Defra 2005). This formed the basis for guidance and recommendations on good practice for AD and the regulatory framework. Thereafter, farmers, waste management companies and biogas plant suppliers were able to take advantage of opportunities to develop AD in the context of the UK's drive for renewable electricity. Also, the government's ban on the tipping of organic waste to landfill provided biogas plants with the opportunity to charge gate fees. This served as another incentive to install AD and provided supplementary income to the Feed-in-Tariff payments received for electricity production.

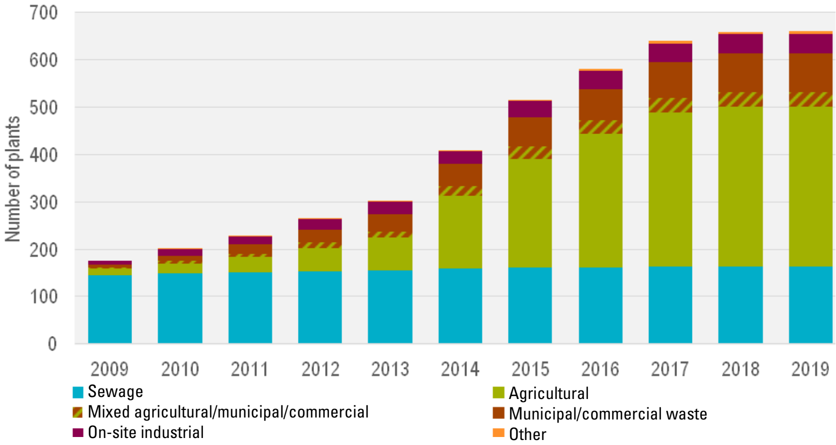


Figure 2-4: Number of biogas plants by feedstock sector (ADBA Annual Report, 2019)

Today the UK has 660 AD facilities of which 103 produce biomethane for injection into the gas distribution network. This equates to a capacity of 955 MWe. Figure 2-4 outlines the feedstock sources of these biogas facilities.

As shown in Figure 2-5, in addition to Renewable Obligations and Feed-in-Tariff, the UK introduced the Renewable Heat Incentive (RHI) in 2011. This incentive was intended to contribute to the 2020 ambition of 12 % of heating coming from renewable sources and included both a domestic and non-domestic component. It was to provide long-term guaranteed financial support for renewable heat installations, with AD systems (that met the programme criteria) being eligible to receive a tariff for a 20-year period.

Modelled biomethane generation, presented in Figure 2-5, shows that a substantial contribution can be made by the agriculture sector over the period 2020 to 2030. It assumes that by 2030 all organic wastes and AD-suitable bioenergy crops, which are sustainably produced and collectible by 2030, are processed using AD. The projected tonnage of each feedstock is multiplied by their average biogas potential (18 – 220 m^3/wet tonne) and its biomethane content (55-62 %) as estimated from the Anaerobic Digestion and Biogas Association (ADBA) industry figures. The total installed capacity required to generate this biomethane potential is subsequently calculated with a potential for over 5 GW_e installed electrical capacity by 2030.

The development of the UK biogas industry has been and still is an *ad hoc* reaction to external factors upon which the farmer and the industry alike can capitalise rather than a specific government policy to support anaerobic digestion. With a new vision, opportunities from 2020 onwards appear very positive.

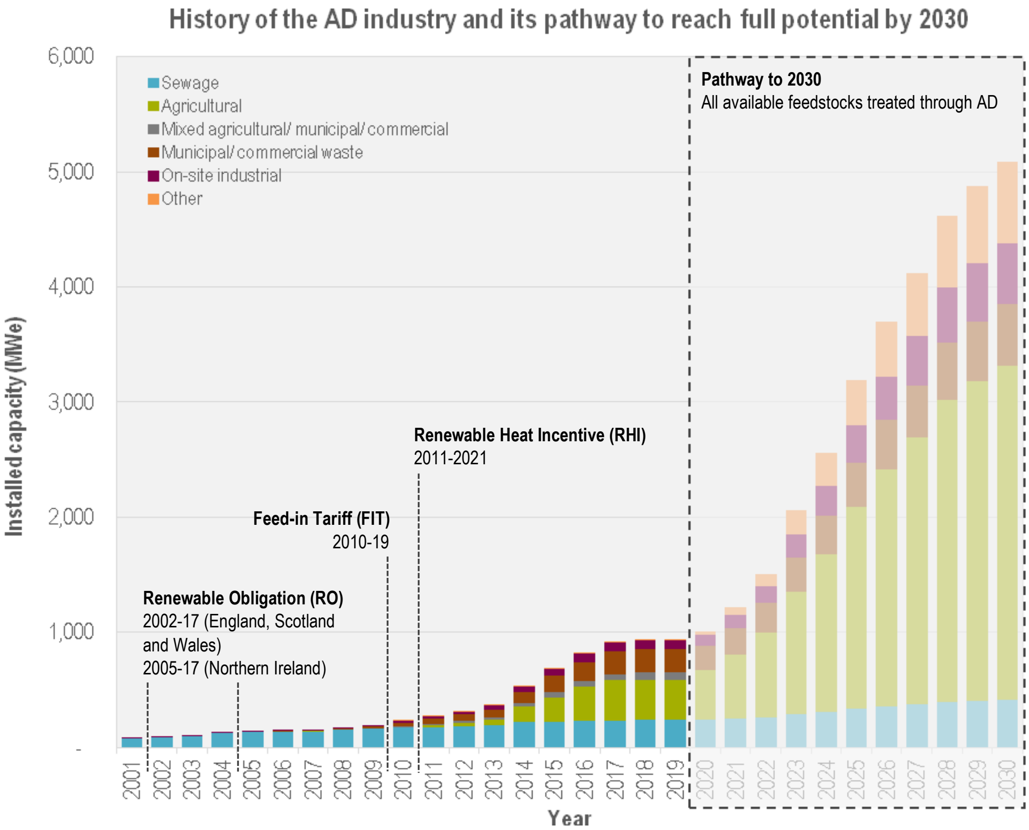


Figure 2-5: History of the AD industry in the UK and potential for future growth

Sources: Courtesy of ADBA and stakeholder companies; data derived from multiple sources including Department for Business, Energy and Industrial Strategy (2009), International Energy Agency Bioenergy Member Country Reports post 2009

Section 3
Environmental Sustainability of Agriculture

The environmental sustainability of agriculture has many facets. In this section, each country description provides a different lens on sustainability and the role of anaerobic digestion. In Australia, AD is primarily used to reduce the environmental impact of wastewaters from red meat processing and piggeries. The section by Canada describes the regulatory framework for AD in agriculture in the different provinces. Italy has seen widespread adoption of the Biogasdoneright[R] concept – a set of innovations that includes AD as a core technology. In the UK, AD of manure along with improved crop production technologies are reducing the environmental footprint of agriculture. Other environmental benefits such the destruction of pathogens and weed seeds are also noted.

3.1 AUSTRALIA

On-farm, intensive feed and processing sectors from Australian red meat, dairy and pork industries produce large quantities of residues rich in organic matter. The management of these residues poses significant environmental challenges such as greenhouse gas (GHG) emissions, odour, risk of damage to soils and water, and risk of adverse impacts on social license to operate. Waste recovery can create opportunities to produce energy, improving business profitability whilst reducing environmental impacts (Mehta et al. 2015).

Integration of anaerobic digestion into farming systems has been far less developed in Australia in comparison with its European and US counterparts. The largest adoption of AD is by the pork industry followed by the red meat processing sector. There could be some opportunities for the dairy sector related to changes in feeding regimes.

Dairy: For waste resource recovery (energy, carbon and nutrients) from dairy production, manure is the most important waste stream of interest, predominately collected as liquid effluent, and to a lesser extent as dry-scraped semi-solid (Figure 3-1) containing urine and dung mixed with wash water (including any cleaning chemicals), waste feed, and bedding material (Birchall et al., 2008). As feed pads or holding yards are mostly uncovered, rainfall runoff also ends up in the dairy effluent.

Figure 3-1: Typical dairy effluent systems used on-farm in Australia, showing a flush tank being used for flushing of a dairy feed pad area.
Photo courtesy of Dr. Scott Birchall and Dairy Australia.

Current practice is to treat manure in on-site treatment ponds prior to irrigation onto land to supplement synthetic fertilizer use. Alternatively, drier waste is collected, stockpiled, and spread onto agricultural land. While the feasibility of AD for dairy farms has been investigated (Dairy Australia, 2015), uptake has been slow. Dairy production is predominately pasture-based resulting in as little as 8 % of daily manure output being deposited onto hard surfaces from where it can be collected. Trends in increased milking herd size and changed practices for feeding where cows spend extended periods on feed pads (Dairy Australia 2017) could present opportunities to collect more manure as potential AD feedstock in the future.

Beef feedlots: Australia is a large domestic consumer and exporter of beef, with a national herd of 26 million head mostly on large cattle properties where manure collection is not possible. However, approximately 2.7 million cattle pass through feedlots annually whereby manure is collected. Cattle spend 90-120 days in feedlot pens in which manure is deposited onto the ground and compacted down by the cattle to form a hard, dry base. After the holding period, the base is scraped to or near the soil leaving a slight manure interface (Watts, McGahan, Bonner, & Wiedemann, 2011) (Figure 3-2). Scraping increases contamination with unwanted soil and stones. Collected manure is typically composted and or stockpiled and sold as fertilizer to nearby farms at cost. Consequently, biogas production from feedlot manure is economically unviable.

Figure 3-2: Manure is harvested from beef feedlots using different machinery (left, (Skerman, 2018), right, (Watts & McCabe, 2015))

Red meat processing: Red meat processing (RMP) has been under pressure to improve environmental standards which has resulted in considerable research into water, energy and waste minimisation. Waste streams which plague the RMP industry are solids including paunch, boiler ash, sludge, and wastewater high in chemical oxygen demand. While wastewaters are often treated on-site in anaerobic lagoons, solid organic waste is almost entirely processed into compost (AMPC, 2010). Liquid wastes are typically treated in uncovered or covered lagoons where biogas is recovered for energy production or flared for emissions reduction. Treated water which meets environmental regulatory compliance is typically irrigated out onto nearby agricultural land in regional areas or discharged to sewer in municipal areas.

Piggeries: Australia supports a pig herd of around 3 million pigs which spend 90 % of their time indoors, allowing for easily collectable manure with predictable quality (ABARES, 2019a; APL, 2018). Piggeries produce significant volumes of waste in the form of manure and spent bedding, with the waste treatment depending on the style of housing. Slatted floor sheds enable manure to pass through from a false floor through to a concrete base where manure is flushed with water periodically to transport manure to an adjacent covered or uncovered anaerobic lagoon. Covered lagoons offer opportunity to recover biogas and subsequent irrigation onto agricultural land of nutrients or recycle of liquors back to pig sheds as flush water to clean out manure as additional effluent (Pork CRC Bioenergy Support Program). Sludge from AD of piggery waste is also applied to land (APL, 2018). Spent litter, consisting of bedding material, pig excreta and spilt feed is stockpiled and composted prior to spreading onto nearby agricultural land.

3.2 CANADA

In Canada, farms must comply with environmental legislation of federal and provincial governments. Through federal-provincial consultation, legislative and regulatory initiatives are mostly complimentary and where overlap occurs, administrative protocols are in place to avoid duplication. Farms have access to a variety of tools, including best management practices, environmental farm planning and international certification schemes that are adopted mainly on a voluntary basis. In general, farm environmental sustainability activities are carried out in response to market demands for evidence of sustainability, e.g. canola producers acquiring International Sustainability and Carbon Certification (ISCC) for access to EU biofuel markets. Using precision agriculture information technologies, record keeping systems have improved and the transferability of information along a supply chain has become quite efficient. Farmers now rely on farm equipment systems for data recording, precision planting, yield monitoring, GPS technology for self-driven farm equipment (auto steer), satellite and drone imagery for scouting crops.

The adoption of AD systems in farming systems provides a number of environmental benefits, including a lower pathogen risk, reduced emissions of ammonia and GHGs from manure, improved nutrient availability (mineralized nitrogen) in digestate, as well as access to low carbon electricity, biogas and renewable natural gas that can offset fossil fuels.

Federal regulations under the *Fisheries Act*, the *Navigable Waters Protection Act*, the *Canadian Environmental Protection Act* and the *Canadian Environmental Assessment Act* are intended to minimize the environmental impacts of agricultural practices including AD systems. The trigger mechanism is usually linked to federal funding on a project or impairment of fish habitat. Currently, there is no requirement to reduce GHG emissions from manure management. The treatment of waste streams, including the application of manure and digestate on agriculture soils is provincially regulated. As the ground is frozen for a good part of the year in Canada, manure and digestate must be stored and applied in specific time windows. In the provincial context, digestate handling is most likely administrated under nutrient management and biosolids regulations. Several farm and food processing systems have secured a fertilizer designation for digestate under the federal *Fertilizer Act* allowing digestate products to cross provincial borders.

Across Canada, the CSA B149.6 Biogas Code provides safety standards for biogas systems. These requirements are implemented by each province usually via building codes and health and safety legislation. For instance, in the Province of Ontario, the Technical Standards and Safety Authority implements rules through their field inspection process for gaseous fuels to ensure safety (TSSA, 2016).

A summary of the provincial regulations follows. One of the most important elements is the allowance for off-farm materials. To make farm AD systems viable in terms of biogas yield and electricity or RNG production, in almost all cases manure needs to be co-digested with off-farm organic materials available in the local area.

In **British Columbia**, AD is regulated primarily through waste management regulations. Tier 1 farms with 100 % on-farm waste digestion are required to meet the Agricultural Waste Control Regulation. Tier 2 farms, with up to 25 % off-farm waste, are required to pasteurize off-farm feedstock, sample incoming waste for nutrients and heavy metals and must develop a Nutrient Management Plan. Tier 3 farms, with over 25 % off-farm waste, are required to follow additional regulations for nutrient and pathogen sampling, analysis, and digestate land application.

In **Alberta**, permits or approvals are not needed for on-farm AD systems relying on agricultural feedstock and digestate is handled like manure and subject to the *Agricultural Operations Act*. In case of new manure storage or modifying existing ones, approval from the Natural Resources Conservation Board is needed. For AD facilities below 1 MW of generation, micro-generation regulations under the Electric Utilities Act apply. Grid connection is applied for separately with an energy provider (Alberta Agriculture and Rural Development, 2014).

Biogas generation associated with intensive livestock operations in **Saskatchewan** falls under The *Agricultural Operations Act*, which provides a regulatory framework for protecting water resources by requiring intensive livestock operations to have adequate waste storage and waste management plans. The *Agricultural Operations Act* is only applicable to the feedstock entering and exiting a digester, and only if the feedstock is manure from an intensive livestock operation. There are no regulations specifically governing the use of digesters beyond the typical permits required by any business operating in Saskatchewan (Saskatchewan Ministry of Agriculture, undated).

In **Manitoba**, manure storage is regulated through Conservation and Climate Change Manitoba. Gas production is overseen by the Office of Fire Commission and subject to the Canadian Standards Association B149 Series-15 (Gas Code). Of all the provinces, on-farm AD facilities in Manitoba are subject to the most rules and regulations to the extent that they are a serious impediment to new construction.

In **Ontario**, most on-farm digesters are governed as a Regulated Mixed Anaerobic Digestion Facility (RMADF) under the Nutrient Management Act (O. Reg. 267/03) and municipal Minimum Distance Separation Guidelines. Up to 50 % off-farm materials can be fed to an on-farm digester, and the digestate is land-applied as an agricultural material. Alternatively, AD systems can be granted an Environmental Compliance Approval or a Renewable Energy Approval from the Ministry of Environment, Conservation and Parks, however this is a considerably longer process.

In **Quebec**, oversight over AD is conducted by the Province's environment ministry, and the approval process focusses primarily on interactions with the environment. For on-farm digesters, only 25 % of non-farm materials are allowed in the digester, though materials can come from other farms. Any animal inputs require additional approvals (Ministère du Dev, 2018). Digestate quality standards are under development in Quebec.

As **New Brunswick** does not have any regulation specific for AD systems, regulations for compost facilities could be utilized to regulate land application of digestate, in conjunction with regulations for fertilizer and manure spreading (Government of New Brunswick, 1998). The Province's environment ministry provides oversight. Manure (and thus digestate) handling and application is regulated through the Licensing of Livestock Operations, which needs to be renewed every 5 years (Eastern Canada Soil and Water (undated); Government of New Brunswick, 1998).

For **Nova Scotia**, the adoption of AD falls under the Province's environmental regulations (Nova Scotia Dept of Agriculture, 2004). There is no provincial manure storage regulation, however gas storage is regulated for holdings of more than 5,000 m^3 of liquid or gas. Municipal by-laws and building permits may apply. The Farm Practices Act deals with nuisances such as odour and noise (Nova Scotia Dept of Agriculture, 2011).

Finally, **Newfoundland** and **Labrador** have only one on-farm digester, and no applicable regulations could be identified (E4Tech, 2010).

Being in the early stages of development in Canada, the existing regulatory framework is not always amenable to the introduction of on-farm AD systems. Provinces wanting to advance the growth of AD need to undertake a review of their environmental, energy and agricultural laws and regulations.

3.3 ITALY

Through a concept known as Biogasdoneright[R] or BDR, Italy's agriculture sector has truly integrated AD into sustainable farming. Over 600 Italian farms have adopted BDR today and have an installed electrical capacity of about 1.4 GW of renewable electricity from biogas. The experience of farmers who have adopted the principles of BDR has shown not only that anaerobic digestion enables and strengthens food and fuel integration, but also that the changes made to farming systems have resulted in increasing photosynthesis (less land left bare), greater use of organic fertilizers, and increased adoption of precision and conservation farming practices (Dale et al, 2016).

Environmental benefits are obtained from avoided emissions released from the storage of animal manures or other residues, from the improved nitrogen efficiency of digestate relative to livestock manure, from the increase in the soil organic carbon stock due to the regular supply of digestate produced from double (sequential) cropping, and from improved agricultural practices favored by the BDR model.

The biomass required to support biogas production is produced by growing additional biomass on seasonally unused bare land via double-cropping (also known in the EU as sequential cropping) on the same farmland. Anaerobic digestion, ensiling and double cropping are well-established, relatively low-cost technologies with no intellectual property barriers to application. The innovation in the BDR system is to feed the ensiled second crop to the digester and then to return the digestate to all the farm acreage, thereby recovering mineral nutrients and recycling very stable carbon to the soil. In addition to the second crop feedstock, the digester can also process locally available agricultural by-products including livestock manures, crop residues and failed crops such as frost-killed or drought-killed immature corn/maize. Digestate liquid also serves as a source of irrigation water during times of drought.

To illustrate the BDR concept, Figures 3-3 and 3-4 describe two representative 38 month-long planting cycles for a wheat-corn/maize-soybeans rotation and a wheat-tomato rotation that are used on these farms. In the wheat, maize, and soybeans rotation (Fig. 3-3), the ground is bare about 17 months out of the 38 total months of the cycle or 45 % of the time. The land could be growing something during these months, but it is not. Farmers are not growing additional food and feed crops because those food/feed markets are already saturated and producing additional food and feed crops would only depress crop prices. Without this food market, the farmer's primary capital asset – land - is not providing any return on investment when the land is bare.

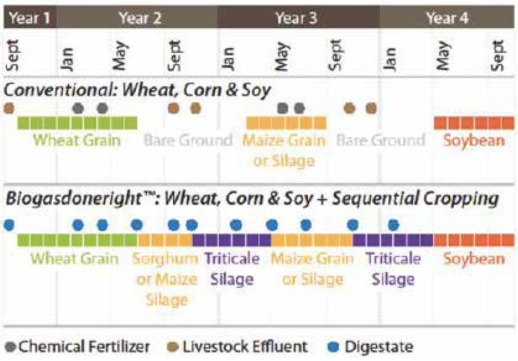


Figure 3-3: Wheat-corn-soy 38-month cropping cycle showing Biogasdoneright[R] cropping systems with timing of mineral fertilizers, manure and digestate application (Valli et al., 2017; doi.org/10.1002/bbb.178)

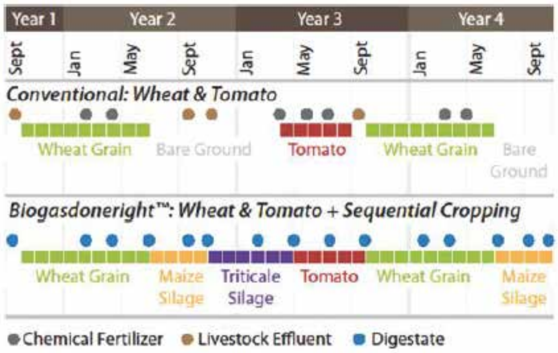


Figure 3-4: Wheat-tomato 38-month cropping cycle showing Biogasdoneright[R] cropping systems with the timing of mineral fertilizers, manure and digestate application (Valli et al., 2017; doi.org/10.1002/bbb.178)

Adopting the BDR concept, various crops (e.g. triticale, corn/maize, or sorghum) are planted during the months when the land would have otherwise been bare. These second crops are then ensiled to provide feed/substrate for the digester. Because the land is continuously planted, application of digestate as fertilizer is much less likely to produce the potent GHG nitrous oxide (by microbial metabolism of nitrogen fertilizers, since the digestate is quickly absorbed by a living crop cover). Also, less nitrate and phosphorus are lost to ground and surface waters than when mineral fertilizers or manure are applied on bare ground. Soil carbon levels are enhanced by the stable carbon resulting from microbial metabolism in the digesters. Other agricultural practices such as strip tillage, precision application of digestate, etc., can further enhance positive environmental outcomes and improve farm economics.

The application of BDR into a conventional wheat and tomato rotation is shown in Figure 3-4. In this case, the 38-month planting cycle consists of 15 months in which the ground is not planted, or about 39 % of the total time. Following the BDR principles, corn/maize and triticale silage are planted during the times when the ground would have otherwise been bare. It is worth noting that even if the wheat or tomato food crop fails due to frost, flood, hail or drought, for example, the failed crops can still be harvested, ensiled and fed to the digester, thereby reducing the farmer's losses while continuing to produce energy and environmental services. Thus, the environmental burdens of the BDR system are allocated among both food and bioenergy products, and the GHG emissions associated with bioenergy production result in much smaller footprints.

The necessary conditions for the development of the BDR concept had clean energy markets at its base. With full integration along the food system, investments supported innovation not only in the energy and transportation sectors, but throughout food production processes with benefits in terms of quality and safety of food products and reduced environmental impact. In agriculture, the change inspired different methods of farming which is now referred to as an alternative to conventional farming that is more organic, integrated and conservation focused. The anaerobic digestion plants are pivotal to bringing the various elements together. Italian agriculture is now positioned to talk about agroecology and modern agri-systems cohesively as an interdisciplinary approach that combines environmental and farm productivity elements with assurance that both goals can be achieved.

3.4 UNITED KINGDOM

Sustainable agriculture concepts in the UK focus on long term crop production practices and livestock production that minimize impacts on the environment. Farmers balance various objectives such as maintaining economic stability of the farm with whole farm environmental considerations. This has led to various strategies, including the use of AD technologies to reduce waste by transforming low value inputs to energy and better value fertilizers. Through an integrated approach, a reduction of net GHG emissions is achieved.

In the UK, 70 % of farms are owner occupied and a further 20 % are managed on secure tenancies which can be passed from one generation to the next assuring a vested interest in the long-term sustainability of the holding. The financial viability of the farm business depends upon its farm income and its ability to absorb the fluctuations in world prices for crops and farm inputs. AD systems can provide a new enterprise for the farm that helps stabilize revenues. Figure 3.5 outlines fluctuations in average farm business incomes over the years 2013 to 2018.

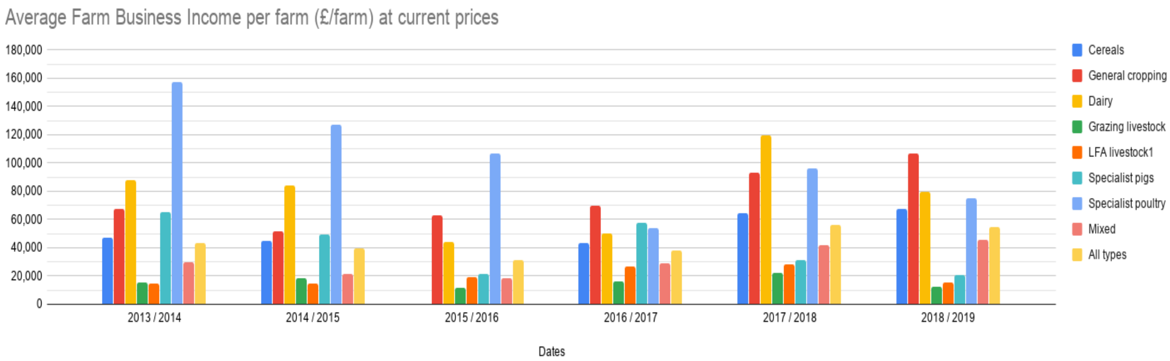


Figure 3-5: Fluctuations in average farm business incomes (2013 - 2018)
Source: Derived from Defra (2019) https://www.gov.uk/government/collections/farm-business-survey

Black grass is Western Europe's most economically significant weed and is resistant to herbicides. In the UK it is especially prevalent in the cereal crops in the Southern and Eastern Counties of England. It competes for nutrients, reduces yields and contaminates the grain with estimated losses of between £270 and £387/ha on individual farms and with a £400 million loss to the UK crop (Rothamsted Research Institute, 2019).

This economic challenge is in addition to annual price fluctuations and average annual incomes highlighted in figure 3-5. Figure 3-6 illustrates the long-term fall in real term wheat prices. Accordingly, increases in productivity and cost reductions are essential to remain viable. As black-grass seeds are destroyed during anaerobic digestion, AD creates an effective way to control the spread of black-grass.

On-farm emissions of ammonia and methane from manure management have negative environmental impacts and contribute to farm operating costs. UK farms are responsible for 245 kt of ammonia

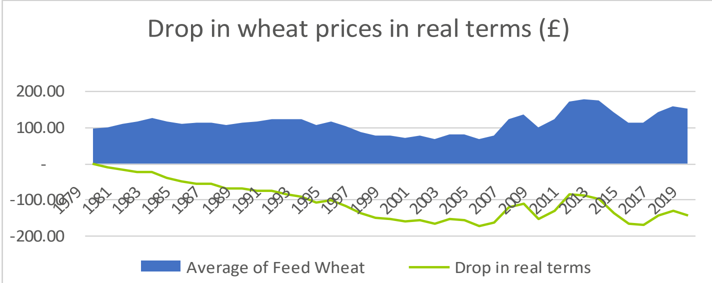


Figure 3-6: Drop in real term wheat prices in £/t.
Source: Rothamsted Research Institute (2019)

emissions a year with a theoretical financial loss in fertilizer value of £ 184,730 when UK N fertiliser is valued at £ 0.754 per kg (Redman, 2019). Table 3-1 summarizes losses of N sources (ammonia) and how these can be avoided or minimised from manure storage air controls and field application methods. AD systems take in feedstocks rich in volatile compounds and in the process create a digestate output with much lower ammonia loss potential. Losses during storage and application of manure and digestate as well as mineral fertilizer can be mitigated through better storage and land application management techniques which will have a positive impact on productivity and the environment.

Anaerobic digestion is also effective at destroying approximately 90 % of pathogens which are also becoming increasingly resistant to antibiotics and result in increased costs to the livestock industry (Bendixen, 1994; WRAP, 2016). At the same time, digestion of manure reduces the risk of diffuse pollution and run off into inland and coastal waters. Digestate, which is certified under the Biofertilizer Certification Scheme, does not need an environmental permit or exemption for land application. The core requirement is compliance with baseline quality specifications set by the British Standards Institution.

Table 3-1: Losses of ammonia nitrous oxide, potential mitigation from manure storage and from digestate application in UK agriculture

Source	Losses of ammonia (kt)	Potential mitigation from manure storage	% reduction in losses due to storage	Potential mitigation from application method	% reduction in losses due to application
Manure Storage	20.8	Lagoon with no crust or cover	Base line	Splash plate spreader	Base line
Manure Application	61.5	Crusted Slurry	50	Band spreader	30 - 35
Fertilizer Application	44.9	LECA Pebbles	60	Trailing hose	30 - 35
Digestate Application	12.8	Floating Cover	60	Trailing shoe	30 - 60
Total	140.0	Tight Roof/Lid/Tent	80	Shallow injection	70 - 90
		Ultra-flexible Polyethylene Bags	100		
		Pillow Tanks	100		

Source: Misselbrook, T.H.& Gilhespy, S.L. (2019)

The use of GPS guided precision equipment coupled with drone imaging, variable rate fertilization and yield monitoring ensures even distribution of nutrients to match crop nutrient need and delivers it with minimal contact with air. Conservation tillage, use of cover crops and other green farming practices are emerging (known as regenerative agriculture), which will contribute to further farm sustainability and soil health.

In terms of future opportunities, crop waste can be re-profiled through AD into higher value fertilizers. WRAP (2019) estimates between 0.9 million and 3.5 million tonnes (~3.2%) of primary production results in waste with a total value of £651 million. There are multiple factors leading to crop waste such as weather conditions during harvest, over supply, failure to meet quality standards, a fall in market prices below production costs and others. If this material were anaerobically digested for production of energy and biofertilizer, it could become an asset to increase overall farm productivity. Field grown vegetables, wheat, barley, sugar beet, oilseed rape and milk for which there is no market can become feedstock for AD systems.

Section 4. Potential for emissions reductions

Agriculture is a source of GHG emissions and also has the capacity to remove CO_2 from the atmosphere and sequester carbon in the soil. Anaerobic digestion and the production of biogas can reduce the GHG emissions from manure management and offset more GHG-intensive forms of energy, potentially resulting in overall GHG negative emissions per unit of energy produced. The GHG impact of AD depends on the availability (collectability) of feedstock and the GHG intensity of the energy system. In Australia, there are significant amounts of collectible manure and adoption of AD could reduce both manure emissions and energy related GHG emissions from the broader economy. In Canada, the potential varies significantly by province, depending on the amount of collectible manure, the percentage of hydroelectricity in a province's energy system, and renewable natural gas (RNG) policies and incentives. Upgrading biogas to RNG provides greater emission reductions but is only financially viable for large AD systems. In Italy, the adoption of the Biogasdoneright[R] concept can significantly increase soil carbon sequestration, reduce farm GHG emissions to close to zero and offset GHG emissions from the energy system. AD is a core technology in this concept that is complemented by the production of second crops and greater use of digestate for fertilization. Similarly, in the UK, emissions reductions involves precision farming, AD and the appropriate use of digestate - part of the trend towards more sustainable agriculture.

4.1 AUSTRALIA

In 2019, agriculture accounted for approximately 12.6 % of Australia's GHG emissions, or 67 Mt CO_{2e} of a total 532 Mt CO_{2e}. The sector's emissions are expected to increase to 74 Mt CO_{2e} (14.5 %) of 511 Mt CO_{2e} by 2030. The breakdown of sources is shown in Table 4-1. It is important to note that under current accounting rules, GHG emissions from the manufacture and transport of inputs including fuel for on-farm energy are not counted as agricultural emissions.

Table 4-1: Greenhouse gas emissions from Australian agriculture in 2013

Greenhouse gas source	Carbon dioxide (Mt $CO_{2\text{-}e}$)	Methane (Mt $CO_{2\text{-}e}$)	Nitrous oxide (Mt $CO_{2\text{-}e}$)	Total (Mt $CO_{2\text{-}e}$)	Agricultural emissions %
Enteric fermentation		56.38		56.38	66.3
Manure management		2.42	0.89	3.31	3.9
Rice cultivation		0.56		0.56	0.7
Agricultural soils			13.16	13.16	15.5
Prescribed burning of savannah		6.87	2.33	9.20	10.8
Field residue burning		0.24	0.15	0.39	0.5
Liming	0.76			0.76	0.9
Urea application	1.28			1.28	1.5
Agriculture total	**2.04**	**66.46**	**16.53**	**85.03**	**100**

Australia has potential to increase the adoption of anaerobic digestion for manure management that can reduce emissions from manure and offset GHG emissions from energy use and fertilizer application. Coupled with more efficient farming practices available because of precision farming, the cropping sector has the potential to significantly reduce its GHG emissions. Greater integration of precision farming in the cropping sector with waste management practices in the intensive livestock industry can lead to further emissions reductions in the Australian agricultural industry.

Precision cropping systems lead to GHG reductions

Various technologies currently in use in this sector have the potential to reduce GHG emissions (Clean Energy Finance Corporation, 2019). Capturing GHG savings from these practices listed below is difficult as there is no central database system to collect field by field information.

- **GPS Auto-Steer:** Automatic control of tractor results in reduced field passes.
- **Controlled Traffic Farming:** Use of predefined tracks for machinery during field operations.
- **Minimum tillage:** Reduction in soil disturbance reduces carbon release from soil and generates less energy intensive field operations.
- **Fertilizer application using variable rate technology** saves inputs while optimizing yield.
- **Precision sprayers:** Improves input efficiency and saves energy.

Producing biogas from dairy manure

The dairy industry stands to benefit significantly from increasing the adoption of anaerobic digestion. Using the equations reported by Dairy Australia (2008) to estimate manure production from milk, the industry could generate 4,725 TJ of energy from biogas based on 100 % utilization of manure and an electrical efficiency of 35 % (Figure 4-1). At current collection capacities, the industry could realistically offset 30-60 % of the dairy industry's energy consumption.

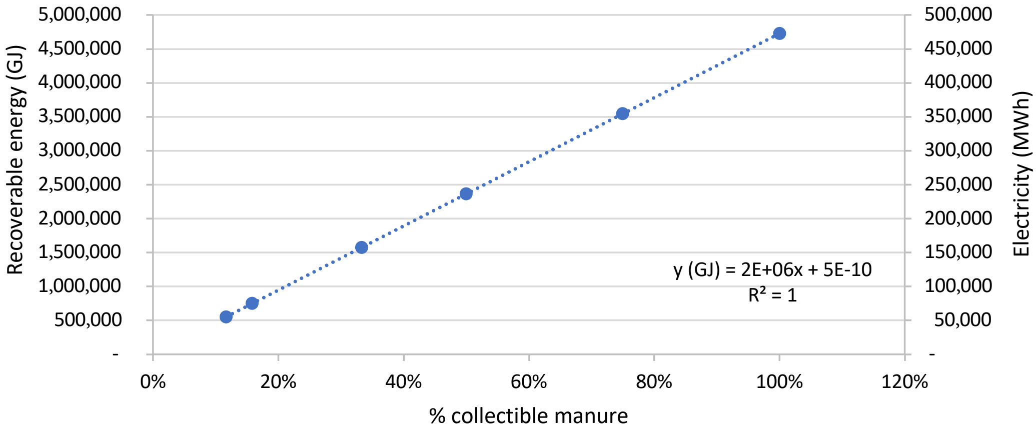


Figure 4-1: Energy yield and usable electricity from manure AD in Australia.

Beef feedlots and red meat processing

Meat and Livestock Australia (MLA) are proactive in reducing energy and water demands while simultaneously reducing waste and GHG emissions within the industry. While the industry still contributes 10 % of Australia's GHG footprint, emissions have been more than halved since 2005. Water consumption has also decreased by 65 %. In the future MLA intends to become carbon neutral by 2030 through research and adoption into key areas such as husbandry practices including feeding, production systems, genetics, feed additives to control fermentation, soil carbon sequestration and storage, waste management and renewable energy generation as a means of reducing the sector's footprint.

Work conducted by Jensen et al. (2014) across six cattle slaughterhouses in Queensland measured wastewater (WW) volume and methane potential at each site. The average WW produced per tonne of hot standard carcass weight was 8.5 m^3/tonne corresponding to an average daily volume of 4.33 Nm^3 CH_4/m^3 WW across the six sites. If these estimates are used as a proxy, the industry generated a total of 18.1 ± 1.18 billion L of WW in 2014 with a potential methane yield estimated at 78.4 billion L CH_4 or 3 PJ of energy.

Piggeries

Using standard conversion formula for manure production in swine rearing, a national output can be derived and adjusted for a confinement level of 90 %. With a national collectible volatile solids (VS) mass of 194,020 t VS/yr and specific methane yields ranging from 240 to 520 Nm^3 CH_4/t VS (Skerman et al., 2015), the annual industry methane yield potential ranges from 46 to 101 Billion L or 33,386,962 to 72,338,417 kg CH_4. Assuming an energy content of 55 MJ/kg, this amounts to 1.84 to 3.98 PJ/yr. of energy.

4.2 CANADA

Agricultural practices influence both the release of GHG emissions and amount of carbon that can be sequestered in the soil. Managing a farm's net GHG emissions to become carbon neutral or negative is done within the context of the farm type and its environmental objectives. Livestock farms have different sources of emissions and opportunities for removal (sequestration) than farms that only produce crops.

The major sources of GHG in farming are nitrous oxide (N_2O) from soils, enteric methane (CH_4) and methane from manure storage, and to a small extent CO_2 from fossil fuel use (in tractors and machinery). The agricultural management practices that are currently recognized on a national level as carbon sequestration options in Canadian agriculture focus on conversion from annual crops to perennial cover; the reduction of soil disturbance through no- or minimum-tillage; and the shift away from summer fallow in the prairies, a practice of leaving fields bare (Agriculture and Agri-Food Canada, 2020). This limited recognition is due to the lack of farm activity data that would allow a more detailed assessment from national statistical datasets (Statistics Canada). While it is accounted for in the National Inventory Report (UNFCCC, 2020), currently there is no financial remuneration to farmers for increasing the carbon content of soils.

Soil carbon sequestration is considered to be a viable way to achieve carbon neutral or negative emission farming. Options of carbon storage in woody perennials, wetlands and other features are not yet considered due to the high variability, and therefore uncertainty of sequestration over time. For grazing operations, stocking rate, biomass growth, paddock size and moving frequency are difficult to establish and quantify. Other steps are necessary to achieve negative emissions by reducing emission sources and increasing efficiencies through precision agriculture.

Reactive nitrogen (any N form other than N_2) is highly mobile in the environment and causes many undesired consequences. Emissions of nitrous oxide (N_2O) have been at the forefront of attention due to their high global warming potential. Unfortunately, of the nitrogen entering agricultural systems as fertilizer, at best half is captured by the growing plants, and the remainder remains in the system and atmosphere until it finally returns to its inert N2 form. Furthermore, to make N reactive (as done in fertilizer production), large amounts of natural gas are consumed that in turn increases the carbon footprint of crop production.

To reduce nitrogen related emissions, several pathways are being investigated. A better fit between the N applied and N taken up by the plant is necessary to lower the losses of reactive nitrogen. This can be achieved either by having the plant fix its own N from the atmosphere (such as the action of legumes), or by applying slow-release fertilizers that provide N in low rates over time, thus increasing the chance for plants to uptake in a continuous process. Recent commercial N-inhibitor products enable farmers to reduce N quantities applied by as much as 30 % while limiting losses to the air and water (Drury, 2017).

Methane has a much shorter lifespan than N_2O and a significantly lower global warming potential but is nevertheless an important GHG. Enteric methane is the result of a detoxification process in the fermentation chamber (rumen) of the digestive system of ruminant animals, and thus difficult to eliminate. As such, it is directly controlled by the feed quality, with higher quality feed decreasing both the methane formation potential as well as the passage rate (determining how long feed needs to be fermented). Therefore, pastured cow-calf systems are the highest emitters of enteric methane, while grain-based diets in feedlots result in the least methane. It must be noted that the assessment of the GHG footprint of pastured cow-calf systems as compared to cereal based calf to beef systems needs to be compared on a whole system level including for GHG footprint of feed and carbon sequestration in grass land.

Research into other mitigating practices focusses on reductions through diet additives, but effects can be variable and inconsistent. At this time, only the additives, fat and 3-nitrooxypropanol have been shown to lower enteric methane consistently; there is also interest in seaweed additives. Attempts to alter the microbial composition in the rumen have so far not resulted in viable outcomes. Capturing enteric CH_4 emissions from livestock barns has not yet been practically achieved as the CH_4 concentration is very dilute.

Methane, and more importantly, reactive nitrogen, can be lost once it passes through or is released from the animal. Deep bedded manure in feedlots can lose up to 90 % of the excreted nitrogen due to ammonia (NH_4^+) volatilization during summertime. While different manure storage systems have different GHG emission patterns, so far there is no zero-emissions option.

When applying manure (or digestate) back onto the land, the application method determines which emissions will be released and their amount. Broadcasting manure is known to result in significant ammonia losses, while injection has been found to increase the N_2O losses. Quick incorporation into the soil is usually recommended to limit the loss of nutrients over time or, in the case of liquid manure, injection into the soil to prevent transport to waterways when excessive rainfall occurs.

As manure needs to be stored for several months in Canada, limiting the exposure of manure to fresh air, such as in heaps, covered lagoons or closed storage tanks, can greatly limit the potential for emissions to air and/or leaching losses. Similarly, open digestate storage results in losses of CH_4 to the atmosphere.

Composting and anaerobic digestion of manure is considered an intermediate step between animal excretion and land application. Approximately 20 % of feedlot manure is composted in Alberta. Anaerobic digestion of livestock manure is only possible if the manure can be cleanly collected. That is, extensive livestock production and feedlots using dry packs are both unsuitable for manure collection for AD purposes. Farm practices for feedlot dry packs consist of adding bedding in the cattle yard to absorb manure. The bedding is left to accumulate in one area and additional bedding is added as required to keep the area dry. Cattle rest in this area and compact the bedding.

AD plants are options for dairy, pork, and poultry operations where the manure can be collected without contaminants. Anaerobic digestion offers the opportunity to utilize a fraction of the carbon in the manure (that is lost as CH_4 or CO_2) as an energy source by capturing it as CH_4. The methane in the biogas can be used to produce electricity and or be upgraded to RNG if the AD system is large enough. Upgrading biogas is expensive and generally not viable for small farms. The GHG reduction resulting from an AD system consists of the avoided emissions from manure storage and the avoided emissions from the displaced fossil fuel energy and non-renewable electricity or energy. This creates an opportunity for the farm to become carbon neutral or GHG negative per unit of energy produced in biogas on a whole life cycle basis. However, the opportunity varies by province and the percentage of hydroelectricity in the grid (when the biogas is used to make electricity). Biogas upgrading to RNG for use in transportation has the greatest potential GHG reduction in most provinces but requires a large AD system to be financially viable.

Renewable energy generation may become the future secondary focus of agricultural production, with both on-farm wind power and solar power generation offering the opportunity for some farms to become carbon neutral with respect to electricity demand, and possibly also powering machinery.

4.3 ITALY

Agriculture in Italy is both affected by climate change and a source of GHG emissions. Agricultural activity is complex, and fertile land can deteriorate in many ways depending on the pedagogical and physical parameters which are unique to each of its climatic territories. Close to 20 % of the land area is at risk of desertification, particularly in the southern areas of Italy. Agriculture plays a dual role with respect to GHG emissions as both a source and sink, having both the responsibility to reduce its GHG emissions, and the ability to increase carbon capture and sequestration using agro-ecological practices and producing renewable, low carbon energy. As such it has the potential to contribute substantially to the binding targets of the EU climate and energy framework for the year 2030 and to the 2050 long term strategy defined by the EU (EC, 2020a & b). Because there is no single solution to remedy climate change and all its consequences, a set of measures is needed to address three objectives: 1) increasing farm productivity or efficiency; 2) changing and improving soil management practices to reduce carbon losses and capture more carbon; and 3) promoting renewable energy and the bioeconomy. Through the adoption of several mitigation measures that are closely related to GHG emissions and soil conservation, the agriculture sector can help to achieve positive national outcomes such as:

- the reduction of the overall environmental impact from agricultural activity; and
- the production of renewable electricity and biomethane in substantial quantities, which is beneficial for the decarbonization targets.

Some critics of bioenergy note that using existing agricultural feedstocks for energy production does not generate sufficient additional carbon savings or sequester enough carbon to offset rising atmospheric CO_2 levels. These critics argue that carbon-neutral biofuels are insufficient. Instead, bioenergy systems should be designed to create large sinks for atmospheric carbon. It is possible for agriculture to operate as a net carbon sink and to address these criticisms of bioenergy limitations by applying existing technologies that are easily accessible to many farmers, such as the BDR concept illustrated in Figure 4-2. Farmers who have adopted BDR are producing both food *and* fuel. There is no indirect land use (iLUC) issue as food production continues as before while sequestering highly stable carbon in the soil. The BDR system is therefore also a "bioenergy with carbon capture and storage" (BECCS) system.

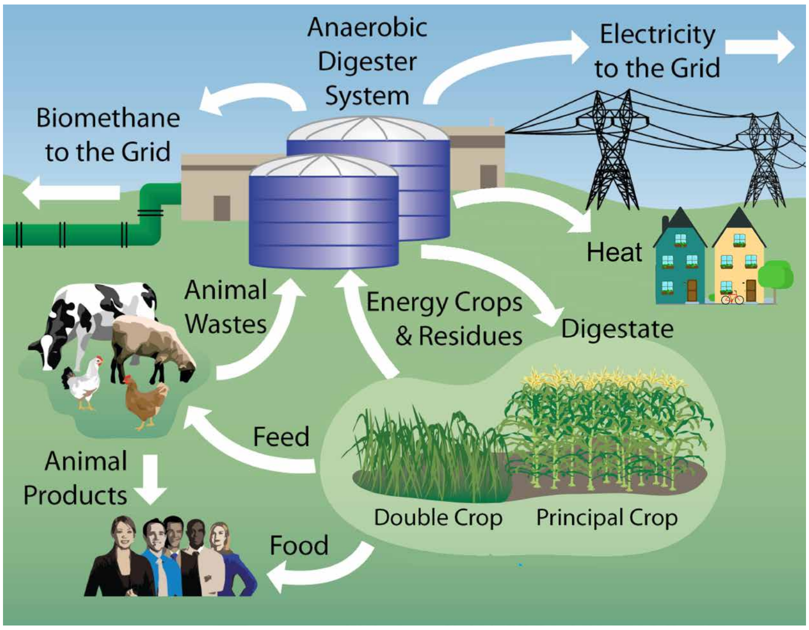
Each of the pillars in the BDR concept either avoids or offsets GHG emissions or sequesters carbon in the soil. For example, fugitive methane emissions from the storage of manure and disposal of agricultural wastes are avoided, more plant growth is carried out on the same land area, mineral fertilizer consumption is reduced (including its associated emissions incurred during fertilizer manufacture), and conservation tillage practices act to conserve soil carbon.

Currently, AD systems on Italian farms produce mainly renewable electricity. However, new decrees have been enacted to encourage biogas upgrading to biomethane that can be exported from the farm via the natural gas grid. Unlike the electricity grid, the natural gas grid can also provide substantial energy storage capacity which is essential for a reliable energy system. Both forms of energy carriers, electricity and biomethane from biogas, offset more GHG-intensive, fossil fuel energy.

Bioenergy production has been criticized as interfering with food production (the food versus fuel argument) and increasing the rate of indirect land use change (iLUC). According to iLUC theory, the carbon footprint of bioenergy should account for the GHG emissions that are released when additional land is used to produce agricultural feedstocks used for bioenergy production (Peters et al, 2016). One of the main issues related to advancing biogas development in Italy (from agricultural AD) has been its use of agricultural biomass. During the rapid development of biogas production between 2008 and 2014, the use of agricultural crops for biogas production aroused great interest from an agricultural land use policy perspective, and this was often referred to as the critical issue of the biogas supply chain.

A study conducted by Peters et al. (2016) confirmed that only a small amount of agricultural feedstock input to AD was in the form of maize silage. In the BDR concept for agriculture, farmers introduce a second crop immediately following a first crop harvest, thereby producing biomass on lands that would have remained bare through the winter period. This second crop is harvested as feedstock for the AD plants.

During the period 2015 to 2017, the use of utilized agricultural land (UAL) for maize silage used for biogas did not exceed 200,000 ha. As shown in Figure 4-3, the energy derived from maize accounted for 40-50 % of the biogas with the rest derived from livestock manure (25-30 %), agri-industrial by-products (5-10 %) and the second crop harvest (10-20 %). The first and second crops combined represented about



THE PILLARS OF BIOGASDONERIGHT[R]

- Valorization of livestock manure and agricultural and agriindu-strial residues
- Insertion of double crops in rotations
- Increased organic fertilizer use from digestate
- Abandonment of deep ploughing and the use of reduced tillage
- Overall reduction of inputs (mineral fertilizers, pesticides, water) for the same production

Figure 4-2: The Biogasdoneright[R] concept (CIB, 2017 and Dale et al., 2020; DOI: 10.1002/bbb.2134)

30 % of the total biomass used as substrate for AD plants but produced over 60 % of the biogas. As shown in figure 4-3, not all feedstocks types yield the same amount of methane. In practice, over time, Italian agriculture and the biogas industry have learned how to operate AD plants with other types of feedstocks besides silage. This has been possible with the adoption of biomass pre-treatment solutions before the digester, providing stability and good biogas yields.

This Italian biogas model supports agriculture by providing the economic means and technical tools to innovate, differentiate and strengthen its position in food markets while contributing to renewable energy production. Biogas is produced from the co-digestion of first and second harvest crops with manure and/or agri-industrial by-products. The production of these agricultural products is driven by a combination of factors including the desire to produce quality food, the need to constrain production costs, and the rapid development of the agri-industrial bioproducts market.

The carbon balance of the BDR system depends on the types of substrates fed to the AD system. The example included in Section 7 indicates the substantial reduction that can be achieved by adopting the BDR concept. As the proportion of manure in the system increase, the system becomes more GHG negative.

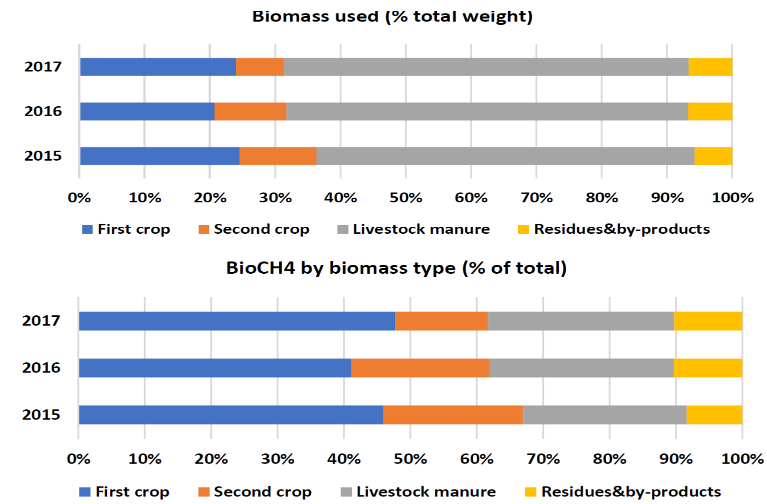


Figure 4-3: Type of agricultural biomass used in AD and associated biogas production (2015 to 2017)
(Source: CIB internal report)

4.4 UNITED KINGDOM

Agriculture generates 9 % of the UK's total GHG emissions. Methane contributes about 50 % of agricultural emissions, nitrous oxide 40 % and the remainder is carbon dioxide. The integration of an AD facility into the farming system and/or the use of the biofertilizer offers realisable potential to secure a significant reduction in emissions from farming. The opportunities arise from a combination of agricultural activities:

- Methane captured from livestock manure storage and management for biogas production and thence its use for combined heat and power and biomethane;
- Introduction of farming practices to sequester more soil organic carbon;
- Minimisation of mineral fertilizer use through replacement with digestate;
- Adoption of precision biofertilizer/mineral fertilizer application and crop nutrient matching to soil N, P and K reserves; and
- Use of fertilizer application techniques (such as trailing shoe instead of splash plate slurry spreading systems) that minimise N volatilisation and the generation of nitrous oxide.

The amount of GHG reduction that can be accrued by an on-farm AD plant can be substantial over a 20-year lifespan. By way of example, Vulcan Renewables Biomethane Plant converts 42,000 tonnes per year of whole crop maize, rye, sugar beet and grass silage. It produces electricity and heat via a 500 kW CHP and sells surplus electricity and biomethane. Since its commissioning in October of 2013, the AD plant has exported 14,000 MWh of renewable electricity and 186,000 MWh of biomethane which translate into GHG savings of 3,265 t CO_2e and 15,830 t CO_2e, respectively. Over 20 years, the Vulcan Renewables AD plant is expected to reduce GHG emissions by 95,450 t CO_2e (Aardvark, 2018).

The value of significant reductions in emissions in farming centred upon AD adds to the public good beyond the immediate and measurable effects of GHG emissions. The multi-functional process of AD makes it a pivot for the achievement of diversified cropping patterns with opportunities for soil carbon restoration, reduced GHG emissions, increased nitrogen productivity per tonne and per hectare applied, reduced operating costs and increased profitability. Furthermore, AD also provides other benefits such as weed control, for example. The presence of blackgrass, shown in Figure 4-4, is very costly for farmers due to cereal yield loss, contamination of the harvested grain and additional tillage requirements. Digestion can destroy these weed seeds.

Figure 4-4: Field with blackgrass weeds
Source: Rothamsted Research Institute (2019)

Figure 4-5: Strip tilling a crop into barley stubble

Precision farming also increases the potential for minimal emissions in farming. Farmers, mainly with larger holdings including those with an AD facility, have adopted precision farming methods to increase their efficiency, including better fertilizer and digestate field application to reduce nitrogen losses through volatilisation and reduce fertilizer costs (Defra, 2020). Table 4-2 summarises the key motivating factors and the type of adopting farms.

Table 4-2: Motivation for adoption of precision farming methods in England (Defra, 2020)

Objective	% all farms	Comments on farm types
Increase productivity and performance	78	Includes livestock farms
Improve accuracy	59	Motivation of 81% of cereal and 72% of other crops farms
Reduce input costs	55	Includes livestock farms
Improve soil conditions	44	Mainly in Eastern England
Reduce environmental impacts	38	Motivation of 60% cereal and 53% other crop farms

Precision farming usually incurs lower operating costs due to fewer cultivation passes. The benefits include a lower tractor diesel use and therefore GHG emissions, while delivering conservation agriculture benefits such as less soil compaction, better aeration and root growth. See strip tilling a crop into barley stubble in Figure 4-5. This is exemplified by the efforts of environmentally aware farmers of the Agri-Tec Innovatory Farmers Group Network in East Anglia. Six farms are each undertaking 20 ha field trials (120 ha in total) to gain measurable evidence of gains in crop yields, effects on soil structure, biology and worm counts with the introduction of cover crops and the use of digestate. Drones have been introduced on some farms to monitor precise crop response assessment for nutrients, herbicide and pesticide use.

Currently, agriculture is dependent on fossil fuels to run farm machinery. A recent innovation currently under demonstration in the UK is the use of a compressed natural gas (CNG) New Holland tractor which is advertised, when operating on biomethane, to reduce CO_2 emissions by 85 per cent and NOx by 50 to 70 % and emit zero particulates (Figure 4-6). It is said that these tractors, operate at 30 % lower cost than a similar size diesel tractor and can offset higher purchase prices. According to the National Farmers' Union, electric and dual fuelled tractors are expected to be operating within the next five years, further reducing the carbon footprint of UK farming and enhancing sustainability in agriculture.

Figure 4-6: New Holland Compressed Natural Gas (CNG) Tractor

Section 5
Financial sustainability of farming practices

The adoption of AD at Australian piggeries and sale of surplus electricity to the grid is financially profitable with pay back periods under 10 years. Offsetting on-farm energy costs and selling surplus power back to the grid are considered to be more reliable than revenue from carbon credits that can disappear with a change in government. In Canada, investment in on-farm AD systems has required a long term feed-in-tariff contract and revenue from tipping fees for off-farm material. Most FIT programs have ended and two Canadian Provinces are now offering premiums for RNG production that could offer opportunities for larger AD systems. In Italy, the incentive for producing energy from biogas has continued to decline since 2008. With the adoption of Biogasdoneright[R], farmers are expected to increase their revenue and reduce biomethane production costs by extracting more value from digestate nutrients, use less expensive second crop harvest (in place of first crops), and achieve greater first crop yields. In the UK, farm adoption of AD can change crop selection as well as the farm's business model. There are a number of different ways for a farm to finance new AD systems, ranging from being strictly a feedstock supplier to 100% ownership.

5.1 AUSTRALIA

While energy consumption patterns vary across farming enterprises and production systems, there are significant opportunities for some farm operations to become energy self-sufficient as well as lower energy-related GHG emissions (Clean Energy Finance Corporation, 2019). Integrating anaerobic digestion in the pork sector has shown to be profitable in Australia and is subject to least volatility. Covered anaerobic lagoons are the most common digester technology deployed to capture methane from manure at piggeries. These lagoon systems can be started with minimal farm regulatory requirements.

On-farm biogas systems rely on offsetting on-farm energy costs (primarily electricity, LPG and diesel costs) and selling surplus power to the grid for their basic financial viability. Connectivity to the grid is based on a regulatory framework for connection standards and a price based on net metering. These energy revenues ensure that the capital investment is recovered within the first decade of operation, regardless of possible changes in government policy relating to carbon credit systems (McCabe (2018)).

Direct on-site use of biogas energy provides the greatest financial benefit as it replaces over 50% of energy costs of a piggery. This is followed by carbon credits and Renewable Energy Credits which enable the capital investment to be recovered within the specified pay back period regardless of policy changes. The breakdown of the financial benefits of biogas production from a piggery is shown in Figure 5-1.

The IEA Bioenergy case story on profitable on-farm biogas in the Australian Pork Sector (McCabe, 2018) is based on five feasibility studies for a variety of piggeries (Pork CRC, 2013). Every one of these prospective projects was found to be economically feasible, with some showing short payback periods of 1.8 to 4.7 years, and all delivering a substantial positive return on investment over a 10-year project life.

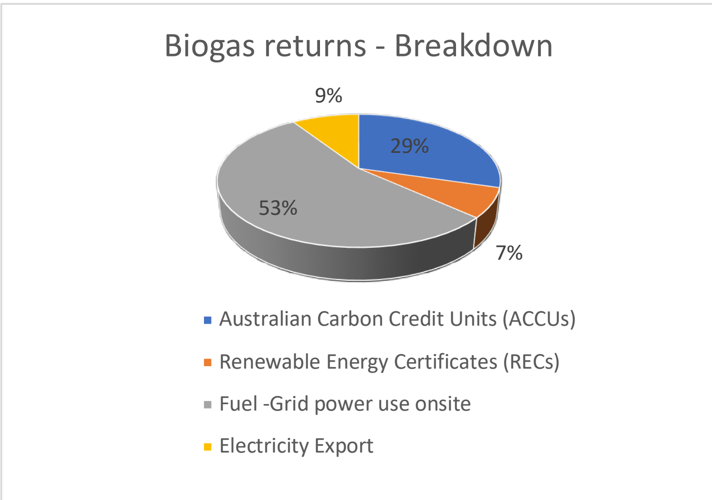


Figure 5-1: Percentage breakdown of the source of earnings of a pork producer implementing a biogas project (McCabe, 2018)

5.2 CANADA

Across Canada, on-farm AD systems depend on tipping fees for off-farm feedstock, energy sales, reduction of on-farm purchases of electricity and use of heat on farm to remain financially viable. Most development has taken place in provinces that had electricity feed-in-tariff (FIT) programs with long term contracts that offered sufficiently high premiums, and provided some form of capital assistance. To date, provinces with GHG-intensive electricity systems offered these FIT incentives. The long term contracts, typically lasting 15 to 20 years, provided sufficient security for farms to obtain bank loans.

More recently, Canada has implemented a national pollution pricing legislation aiming to lower GHG in line with its GHG reduction commitments (ECCC, 2019a). However, due to Canada's federal nature, it is up to each province to implement their respective system. Current legislation targets industries emitting more than 50,000 tonnes of carbon per year, but also aims to implement a federal offset system providing opportunities for sectors such as agriculture, municipal waste, and forestry (ECCC, 2019b). To date, there is no mention as to which agricultural practice would be deemed applicable, thus there are no financial benefits for the sector to reduce its GHG emissions, or other attributes such as pathogens, odour or nutrients escaping into watercourses. The federal government has also proposed a new regulation known as the Clean Fuel Standard that could provide an opportunity for biogas and RNG producers to earn carbon credits. This regulation is still under development.

As presented in Section 2, the Provinces differ in their support for AD systems, and provide different types of incentives described as follows. To date, carbon pricing can help to improve the cash flow and shorten the payback period of an AD investment, but it isn't sufficient for a farm to acquire a bank loan.

British Columbia, with no agricultural carbon credit program, provides carbon tax relief for farmers who use natural gas or propane as an energy source (Government of BC, undated a). The province runs a carbon neutral government program (Government of BC, undated b) which invests in projects that reduce GHG emissions such as a greenhouse operation, investment in a biomass boiler and insulating curtains to replace natural gas heating. As a hydro-based province, B.C. did not have a FIT program to incentivize electricity from biogas but it does financially encourage the production of RNG to green the natural gas network.

Due to the significant emissions from the Alberta oil industry, royalties were used early on to invest in carbon credit programs, which also targeted agricultural production. Current credit recognitions include direct seeding (no-till), feedlot cattle (feed quality), biogas production (heat or electricity), and small-scale electricity production (wind and solar) (Government of Alberta, undated). Alberta has supported biogas production with capital assistance, but does not have a FIT to support electricity production from biogas.

Similarly, neither Saskatchewan nor Manitoba had specific incentives to encourage the adoption of AD in agriculture. Saskatchewan has released a discussion paper that provides a framework for the implementation of a carbon credit program by 2021 (Government of Sask, 2019). Manitoba has listed mitigating practices in a suite of Best-Management-Practices (BMPs) (Manitoba Min of Ag, undated), which have been supported through a variety of different programs, but no formal carbon credit program has been implemented. Consequently, there are no on-farm AD systems in operation in these two provinces.

Ontario had the highest FIT program rates, and the most on-farm AD systems. The Province's FIT program has now ended and its cap and trade program was cancelled in 2018 due to a change in government (Government of Ontario, undated). Prior to the election, new policy proposals had included initiatives to reduce GHG emissions through a voluntary Renewable Natural Gas program delivered by the natural gas utilities.

The hydro-based province of Quebec did not have a FIT program to incentive electricity from biogas. However, it has ambitious climate change goals and does have a market for (carbon) offset credits in place. Currently the only protocol available for the agriculture sector is to cover manure storage facilities and flare or dispose of the captured emissions (Ministère de l'Environnement, 2020). The Province has adopted an RNG target to green its natural gas system and its natural gas utility Énergir has secured regulatory approval for an RNG purchase program that allows AD-based RNG to be purchased.

The four Atlantic Provinces have adopted the federal carbon pricing plan, but only Nova Scotia has offset mechanisms (Government of New Foundland and Labrador, 2018). The Province of Nova Scotia also had a FIT program that offered incentives for electricity production from biogas.

5.3 ITALY

In Italy, the incentives for biomethane production expressed in terms of feed-in-tariff (total production revenue) has declined since 2008 and it is expected to further decline over the next decades. Electricity production from biogas has been essential for the development of the Italian biogas market. The assigned incentive level should be directly correlated with production costs including entrepreneurial margin. As shown in Table 5-1, the incentive value for electricity from biogas can be translated into a hypothetical biomethane incentive by assuming a 45 % cogeneration efficiency for biogas conversion into electricity and adding additional costs for upgrading, compression and gas grid connection. Compared with electricity from biogas, for biomethane production alone, the cogeneration cost is less, however there are additional costs for grid connection, compression and upgrading.

Table 5-1: Biomethane incentive for the period 2008 to 2018 (Stürmer et al, 2016)

Energy from biogas	Time period	Electricity Feed-in-Tariff		Biogas	Biomethane
		Euro/MWh_e (number of years)	Euro/MWhe (normalized over 20 years)	45% efficiency	
				Euro/MWh_t	Euro/MWh_t
Electricity	2008 - 2012	280 (15 yrs.)	210	95	*170*
Electricity	2012 - 2016	120 (20 yrs.)	120	54	*97*
Electricity	2016 +	105 (20 yrs.)	105	47	*85*
Biomethane	2018				85

Farmers adopting the BDR concept are expected to increase their revenues and reduce their overall costs by extracting more value from digestate nutrients, using second crop harvest (in place of first crops) and achieving greater first crop yields. Figure 5-2 summarizes these estimated cost reductions for the farmer, where 25.3 Euro/MWh is assumed to be the current production cost for a 500 Nm^3/hr biogas plant. By applying the BDR approach, a cost reduction of 10 to 15 Euro/MWh is anticipated after 2030.

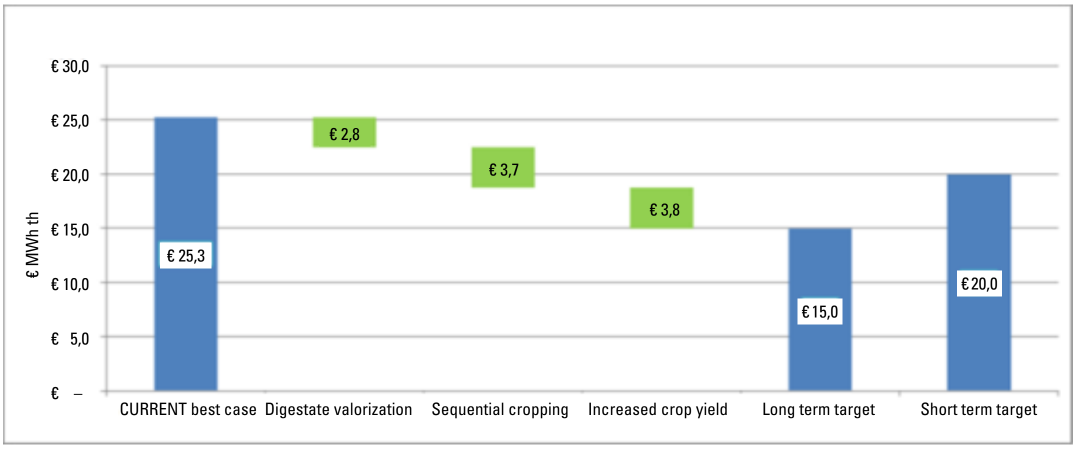


Figure 5-2: Estimated feedstock/AD cost reduction (Bozzetto et al, 2017)

5.4 UNITED KINGDOM

The financial or business sustainability of a farm depends on the complex interaction of many factors including the government policy framework. At the individual farm level, factors which contribute cost to the productivity of the various enterprises include costs of cultivation, fertilizers and sprays, storage and transport of agricultural products to market. The market prices achieved are outside of the business' control and subject to national and international demand and price fluctuations. The addition of an AD facility is a substantial capital cost for a farm. Table 5-2 identifies five possible financing strategies.

Table 5-2: Ways to Finance an On-Farm AD Project in the UK

Fully self-funded	The plant is designed to meet the specific needs of the farm such as: 1. Optimise value of existing products such as slurry, whey, any poorer grade silage from the sides and top of the clamp, vegetable trimmings, straw, etc. 2. Reduce operating costs for energy & fertilizers 3. Prevent nutrient losses through gaseous escapes and through leaching 4. Provide new income streams and financial security
Partly self-funded + capital grant	As above, but the burden of mortgage repayments is reduced. This system is used by dairy farms where costs were offset for high kerosene and fertilizer costs. This is the model used in the Holsworthy Biogas Plant where the business case was based on 50% grant, bank mortgage and partial private financing. This model was popular before the introduction of the Feed-in-Tariff and Renewable Heat Incentive (RHI).
Part self-funded + outside investment	Investors can include the biogas plant construction companies who take on the responsibility for remote AD management and monitoring, but the farmer is wholly in control of his own business and husbandry to supply the feedstock.
100% investment from an external source including some biogas companies	Farmer leases the land (approx. 2 ha) for the AD plant, supplies crop residues/grows crops such as corn/maize, rye, luzern and supplies a guaranteed quantity of high-quality feedstock at a predetermined price for the lifetime of the plant. Farmers receive high quality advice from agronomists on crop production and digestate nutrient management and emissions control.
Feedstock supplier/ digestate in return	Receiving farms are provided with digestate storage tanks at no cost and receive advice on crop husbandry and digestate use. Farmers receives guaranteed income from the feedstock supplied to the AD plant.

The above noted business models were compiled from examples some of which have been in operation more than 40 years (Bywater, 2013) and some as recently as 2016 (Pers. comm. with owners). They provide an indication of some of the significant variations in funding strategies, not least as to how the plants are incorporated into the farm management system. Rents on externally 100% funded plants will vary but investors can pay the host farmer in a range of £60,000 – £100,000 for an AD site. In addition, the farmer is likely to receive an additional annual income of 2 per cent of the profits as well as a regular income from the guaranteed price per tonne from the sale of the maize (silage) or other feedstock as specified in a long term contract.

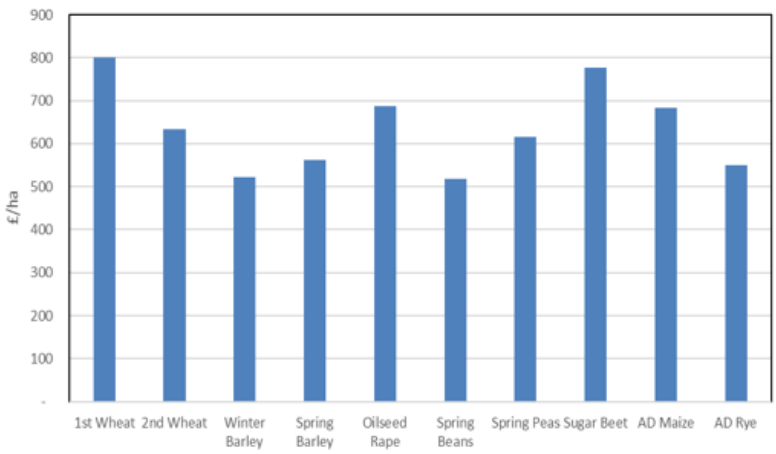


Figure 5-3: Gross margin (revenue minus cost) for various crops
Sourced with permission from Strutt and Parker and Future of Biogas

As in many countries, farmers grow different crops in rotation to optimize yields and suppress disease. Many other factors such as cost of production and the market price can influence a farmer's choice of crops to fulfil a contract. Selection of a crop also depends on the soil type and proximity to a processing plant, as in the case of sugar beet, and gross margins on crops used in AD systems. In the gross margin comparison shown in Figure 5-3, AD maize is competitive with oilseed rape for profitability, but rape is much more expensive to grow. Accordingly growing AD maize needs less working capital and so is more attractive to grow.

Table 5-3 shows changes in the type of crops and acreages grown before and after AD was introduced to a typical farm with a 5 MWt digester. The maize and rye silage have been introduced as the principal feedstock. The AD system was installed in 2014 to produce biomethane for export into the Scotia Gas Networks distribution grid, under the RHI initiative, and which was then sold under contract to third-party gas shippers. Heat and electricity from the 350 kWh combined heat and power (CHP) unit is used to operate the digester and for on-farm heating needs. Any surplus electricity is sold to the grid under the FIT scheme. The AD system provides this farm with a regular income for the next 20 years – the duration of the contract.

Table 5-3: Crop type and acreage before and after the installation of the AD (Lukehurst, 2019)

Crop types before AD	Area (ha) before AD	Crop types after AD	Area (ha) after AD
Wheat (milling)	420	Wheat (milling)	434
Barley (Spring)	140	Barley (Spring)	147
Oilseed rape	140		
Maize	-	AD Maize	77
Rye for silage	-	AD Rye	42

Also, there is less N fertilizer purchase and the farm is self-sufficient in terms of P and K (provided by the digestate). Turnips are grown as a cover crop and income is received from winter grazing of 2,000 ewes on this land. Consequently, the farm system with the AD plant now outperforms the crop only farm operation. It also has brought important benefits to crop production through longer crop rotations that suppress disease cycles as well as better weed control facilitating minimum tillage prior to seeding.

Similar results can be found for the addition of AD to mixed crop and vegetable production where the crop selection mix is expanded and the use of digestate has resulted in lower fertilizer costs per hectare. The farm can also market itself as having stronger green credentials which appeal to certain customers.

Section 6.
Opportunities and Challenges

In all four countries there are opportunities to increase the production of biogas and renewable energy from on-farm AD systems. In both Italy and the United Kingdom, energy from biogas is explicitly recognized as a mitigation measure in the respective countries' renewable energy and climate change policies, and AD is well integrated into crop production. The policy signals and financial incentives are significantly weaker in Australia and Canada and would need to be strengthened to encourage new investment that would achieve the growth potential for agricultural AD projects in these countries. Apart from the use of digestate on agricultural soils, here AD has not yet been integrated into crop production and the broader concept of sustainable agriculture.

6.1 AUSTRALIA

Despite the many benefits, the AD/biogas industry in Australia still faces challenges that slow the development of biogas projects. These challenges include lack of financial viability, poor policies supporting purchase agreements, complex project development and operation conditions, inconsistent state by state digestate regulations, difficult access to infrastructure, and climate. Of these the revenue gap is the primary challenge and due to a lack of green energy incentives this cannot be readily overcome under present policy. Secondly, access to feedstock is challenging but this is changing as the dairy sector modernizes. Also, the classification of digestate has implications on its economic value. When digestate is designated as a waste rather than compost, this further limits its revenue options.

Based on successes of the piggery model, opportunities exist to develop new projects in Australia's dairy sector using similar approaches to generate electricity when the cost-benefit analysis of projects is positive. New models for using dry manure and crop residue need to emerge.

A recent report **"Biogas Opportunities for Australia"** aimed at advancing Australia's biogas sector by ENEA Consulting (Carlu et al., 2019) and Bioenergy Australia, with the support from Australian Renewable Agency (ARENA), Clean Energy Finance Corporation (CEFC), Energy Networks Australia (ENA) and the International Energy Agency Bioenergy Technology Collaboration Programme (IEA Bioenergy), provide a number of recommendations for the Australian government and industry stakeholders to consider. These include the following:

- Setting renewable gas target(s);
- Launching industry stakeholder consultation for policy design based on **Biogas Opportunities for Australia**;
- Introducing waste management strategies to support feedstock quality and quantity including more manure collection opportunities and use of food sector waste through co-digestion; and
- Encouraging plant operators, especially landfill operators, to maximise biogas use.

The Australian bioenergy industry, through Bioenergy Australia, has organised itself into various national participation groups, including some with a focus on biogas. These groups comprise industry, researchers, and government representatives to exchange and disseminate knowledge, and develop guidelines and frameworks for organised and organic growth.

The Australian Agri-futures overview of bioenergy in Australia report estimated that 19.8 to 30.7 % of electricity generation will come from bioenergy in 2050. To achieve such targets, the bioenergy industry requires significant growth between 2020 and 2050, of the order of 1523-2362 % in 30 years. Others have estimated that potential exists to produce around 370 PJ of bioenergy per year, equating to ~6 % of national energy generation, 9 % of the national energy consumption, and 39.4 % of electricity consumption (Carlu et al., 2019). Given the current average size of biogas installations in Australia, this would represent up to 90,000 biogas installations (Carlu et al. 2019). This represents an investment opportunity for new circular economy bioenergy systems estimated at AUD 3.5 to 5 billion with GHG emission reductions of up to 9 Mt every year (Carlu et al., 2019).

The Australian Renewable Energy Agency (ARENA) is currently developing a roadmap to identify the role that the bioenergy sector can play in Australia's energy transition and in helping Australia further reduce its GHG emissions. The Bioenergy Roadmap will help to inform the next series of investment and policy decisions in the bioenergy sector in Australia.

6.2 CANADA

In Canada, anaerobic digestion and biogas production, either for electricity or RNG, still must achieve a breakthrough in terms of financial viability for the agricultural sector. The requirement for individualized installations on relatively small livestock farms and/or the need for non-agricultural feedstocks or clustering to achieve an economy of scale, pose a considerable economic entry barrier for farmers. Mini package digesters (Hein, 2019) offer a solution for manure only systems that are suitable for average size dairy farms in Canada. Their output range is 10 to 50 kW which allows for some scale, while the digestate can be pressed to remove solids that can be reused for bedding. Co-digestion and feedstock clustering are ways to increase the size of biogas production and, if located near a natural gas pipeline, may make them candidates for upgrading to RNG. With just under 11,000 dairy farms in the country (Canadian Dairy Farm Information Centre, 2020), it certainly appears that the feedstock potential exists.

New policy support and economic incentives are necessary to see further development. The ending of provincial electricity feed-in-tariff programs are a deterrent for farmers both from access to financing and as a revenue source. Weak policy signals that do not specifically refer to on-farm AD systems are likely insufficient to encourage growth. Long distances from electric and gas grids, and population centres, as well as complex regulatory processes further impede the expansion of AD on Canadian farms.

While electricity production is still a logical pathway for many small farms, there are less expensive forms of renewable energy. RNG production is only practical for large digesters and/or the clustering of several farms with other substrate suppliers to reduce operating costs and afford technologies to clean and compress the biogas into biomethane. Two provinces have RNG mandates and are willing to pay significant premiums for RNG, but again contracts will be awarded to the lowest bid for RNG supply, generally from municipal systems. As previously discussed, carbon credits and monetization of other environmental and social benefits could improve the business case for farmers and reduce the payback period. Here supportive policies are required that are maintained with a change in government.

The Canadian Biogas Association is developing a tool to facilitate assessment of the clustering potential of farms to support development of larger digesters with capacity to meet both electricity and biomethane markets. If successful it could result in several farms contributing manure and dry biomass to central facilities. Such facilities could aggressively pursue energy market contracts while realizing carbon credit benefits to top up energy market revenues. The greenhouse sector is also well positioned to support large digesters as these farms have on average over 40 hectares under glass and produce large quantities of residues. Residue from field grain and oilseed crops in the Prairie Provinces is plentiful however, these areas are also rich in fossil fuel energy reserves. Although there are no immediate provincial policies to support biogas production in the Prairies, the ability to sell RNG "virtually" to British Columbia, is generating interest in Alberta. Growth of on-farm AD is therefore expected to remain in areas of southern B.C., Ontario and Quebec's dairy, pork and poultry operations which have appropriate manure collection and storage systems and access to local organic wastes.

The RNG targets of 15 % and 5 % in B.C. and Quebec, respectively, combined with the ability of utilities to pay a significant premium for RNG is resulting in some farms to seriously consider expansion of their AD systems for sale of RNG to these other provinces. Also, as the first farm feedstock cluster system with third party ownership is successfully demonstrated in Warwick, Quebec, new opportunities may emerge for third party ownership and operation that could relieve the farmer of the day-to-day digester operation and business of carbon credit generation. This may prove to be an attractive model to participate in biogas and RNG projects for farms in different parts of the country. Similarly, as being carried out near Lethbridge, Alberta, agricultural producers may become feedstock suppliers to a municipal digester. Finally, as the hydrogen economy develops, there could be opportunities to add electrolyzers to produce more RNG (bio methanation can add 70 % to methane output from digesters) or onsite steam methane reformers to AD systems in rural areas to convert biomethane to hydrogen for transportation. Such a system could include for carbon capture, reuse or sequestration leading potentially to a negative emission technology circular economy system categorised as **B**io**E**nergy with **C**arbon **C**apture and **S**torage (**BECCS**).

6.3 ITALY

By 2030, with a supportive legislative framework, Italy's biogas sector could reach a production of 8 billion Nm^3 of biomethane per year (300 PJ). The Italian Biogas Consortium (CIB, undated) estimates that at least 6.5 billion Nm^3 can be generated from agricultural feedstocks (Table 6-1) and 2 billion Nm^3 from selected organic waste, non-biogenic sources, and gasification. Bozzetto et al. (2016) estimated that the agriculture sector's contribution could be achieved by double cropping more than 400,000 hectares of Utilized Agricultural Land (UAL) (effectively 800,000 ha), improving livestock management, and using by-products of the agri-industrial supply chain. This biomethane could be produced without reducing Italy's agricultural production for food and can increase the competitiveness and the economic and environmental sustainability of farms.

CIB's projections, based on the previous period 2015-2017 and projecting out to 2030, are presented in Table 6-1. This estimate was based on production data and energy yields achievable in the Italian agricultural context as previously demonstrated by BDR models. It is expected that the growth in biomethane will not result from the use of first crops, but from the digestion of livestock manure, agricultural by-products and second crops obtained from double cropping. As far as livestock manure is concerned, it is estimated that 50 to 70 % of the total available manure can be anaerobically digested and would immediately generate positive impacts in terms of avoided GHG emissions. Anaerobic digestion is considered a "must do" pathway to drastically reduce the overall impact of Italian livestock production practices while at the same time having a positive effect on soil fertility.

In terms of crop production, the CIB estimate anticipates that the expansion of second crops through double cropping will extend to approximately 900,000 hectares, based on 1st and 2nd crop areas, equal to 15 % of the total UAL cultivated arable cropland and 30 % of the UAL irrigated land in Italy.

Table 6-1: The biomethane potential from Italy's agricultural sector in 2030

Source of Agricultural Biomass	Units	Value in 2030
First crop harvest	Billion m^3/year	1.9
Second crop harvest	Billion m^3/year	1.9
Livestock manure	Billion m^3/year	2.2
Agri-industrial residues	Billion m^3/year	0.5
TOTAL	Billion m^3/year	6.5
Usable agricultural surface - First crop harvest	ha	350,000
Usable agricultural surface - Second crop harvest	ha	486,681

The Italian agricultural biogas potential is firmly based on efficient land use and changing farm practices to regenerate unusable agricultural land and integrate biomass as a double crop. According to a recent survey of 422 farms, it was confirmed that double cropping has taken hold in agriculture. More than 70 % of double crop cultivation takes place in the Po Valley Region where more than 80 % of the biogas plants are located. Also, double crop cultivation is taking place in the center and southern parts of Italy and attributed to the wide promotion of the BDR concept.

In a well-functioning agricultural biogas sector, there are further opportunities to derive value from the CO_2 such as micro-algae production for animal feed and the installation of electrolyzers on farms to produce hydrogen and carry out biomethanation using the CO_2 in the biogas, increasing the yield of methane by c. 70 %. These additional technologies could make use of the existing biomethane infrastructure (Thema et al., 2019). Achieving these objectives requires changes in both market and infrastructure design, away from the initial support scheme, to enable the massive development of cost-cutting initiatives. In addition, the increase in distributed biomethane production requires that the gas distribution and transmission system allows for the management of gas flows in a bidirectional manner between the two systems (Régions Pays de la Loire et Bretagne, 2017).

6.4 UNITED KINGDOM

After the closure of the Feed-in-Tariff scheme and the temporary change in the tariffs for the Renewable Heat Initiative, the UK's ambition to achieve net zero emissions by 2050 offers prospects for renewed growth of the AD/biogas industry. The Climate Change Committee (2020) has set out policies that are designed to underpin agriculture's contribution for achieving net zero emissions. The UK Government estimates that agriculture, land use and peat lands emitted 58 Mt CO_{2e} in 2017. The ambition is to reduce the emissions by 64 per cent to 21 Mt by 2050 (Committee on Climate Change, 2020).

The UK's 2020 national budget introduced new policy considerations that are beneficial to the AD sector while at the same time reduce the transport sector's emissions. The actions proposed by government include covered slurry/digestate storage by 2027 and upgrades to digestate spreading equipment by 2025 (moving away from band spreading to trailing shoe systems); universal food waste collection resulting in the diversion of 4 Mt away from landfill. This could create the potential equivalent of 187 MW of installed electrical capacity. A Green Gas Levy with an ambition to triple the amount of biomethane in the national gas grid is under consultation. Plans are also to solicit industry's feedback on the levy's design and implementation. The Smart Export Guarantee (SEG) program came into force in January 2020 and sets an obligation for licensed electricity suppliers to offer a tariff to small-scale low-carbon generators for electricity exported to the National Grid. Each AD plant will negotiate a tariff rate with electricity suppliers for the sale of their renewable power. This is expected to help plants adjust to the end of their FIT contracts.

Further government proposals are shown in the first two columns of Table 6-2, along with the responses from the National Farmers' Union detailing how the targets could be met (Committee on Climate Change, 2020; National Farmers' Union, 2019).

Table 6-2: Proposed actions for the reduction of GHG emissions from Agriculture

Actions Column [1]	Facilitating actions Column [1]	National Farmers Union proposals for CO_{2e} emissions reduction by 2040 [2]
Release 22 % of agricultural land by 2050 for actions that reduce emissions and sequester carbon	Increase productivity from rest of farmland	**Pillar 1 Boosting productivity** 11.5 Mt GHG/year reduction with increased productivity from improved soil quality, livestock breeding and health, on farm AD and energy efficiency of buildings and vehicles
Reduce GHG emissions from soils, livestock, and manure management by 10 Mtonnes/year of CO_{2e}	Reduce need for fertilizers, improve livestock health and diets, reduce acidification from slurry	**Pillar 2 Farmland and carbon storage** 9 Mt GHG/year by increasing carbon storage in soils through hedgerows, woodland, soil carbon practices and peat cover restoration
Deliver 2 Mt/year GHG savings in land use sector. Produce 11 million t/year of harvested biomass	Plant 23,000 ha/year of miscanthus, short rotation coppice and short rotation forestry	**Pillar 3 Coupling bioenergy to carbon capture, utilisation, and storage** 3 Mt GHG/year displacement of fossil fuels by land application of bio-digestate with potential for carbon credits

[1] Committee on Climate Change, 2020; [2] National Farmers' Union (2019)

The Energy Networks Association (ENA), working closely with the 13 major gas supply network operators, estimates that to meet their target for decarbonizing the gas networks (i.e. replace 50 % of the natural gas supply with biomethane and the rest with hydrogen), 1,500 new on-farm AD plants will be required by 2030 and at least 30 more AD plants will need to be built each year in the other sectors (such as municipal) (ENA, 2019). This industry growth should happen within a regulatory framework that includes environmental assessments, meeting sustainability criteria that specify feedstock type, land use and GHG emission reduction thresholds, and complying with digestate standards.

Section 7.
Success Stories and Case Studies

In the last section of the report, on-farm AD success stories are described by Australia, Canada and the United Kingdom. Italy uses a case study of a hypothetical farm in Northern Italy to illustrate, in quantitative terms, the potential GHG emissions reduction and carbon balance that could be achieved with the adoption of the BDR concept.

7.1 AUSTRALIA

Located near Young in New South Wales, Blantyre Farms has approximately 22,000 pigs. The farm was the first piggery in Australia to install a commercial-scale system to generate power from the methane that is captured from its anaerobic lagoon (covered pond) system, shown in Figure 7-1. The piggery was also the first farm-based project eligible to earn carbon credits for the electricity produced from biogas. Heat from the generators is also captured and used to heat water to meet heating needs in areas where piglets are raised during early stages of life, further reducing the power consumption of the piggery.

Figure 7-1: High Density Polyethylene (HDPE) covered anaerobic lagoon (left) and combined heat and power (CHP) unit (right)

The generated electricity powers the entire farm operation. The system, shown in Figure 7-1, was built by an Australian company, Quantum Power. Having researched European and Northern American systems suitable for the Australian Industry, Australian Pork Limited identified a transferable low-cost system based on New Zealand research, which has a similar industry and needs to Australia's. The system is scalable from smaller to larger piggeries and cost effective, and thus paved the way for sector wide implementation. The main features of the system are summarized in Table 7-1.

Table 7-1: Key Features of Blantyre Farms' AD System (McCabe & Schmidt, 2018)

Feedstock	**Pig manure and pig feed by-products**
Technology	Covered anaerobic pond
Use of biogas and by-products	Generation of electricity and heat used at the piggery for production benefits
Simple payback	Total capital investment \$AU967,000 3.5 years (paid off June 2016)
Energy saved	Blantyre Farms has reduced its power and gas bill from \$AU15,000 per month to now being paid in excess of \$AU5,000 per month for excess power sold to the grid.
Other attributes	Biological oxidation for H_2S removal in an external vessel, biogas chilling for moisture removal

7.2 CANADA

Seabreeze Dairy Farms milks 375 Holsteins on the flat, fertile land of the Fraser River Delta along the Boundary Bay Coast in British Columbia. An aerial view of the farm is shown in Figure 7-2, and its biogas storage facilities are shown in Figure 7-3.

Figure 7-2: Seabreeze Farm Setting

Figure 7-3: Biogas Storage

The farm utilizes a flush liquid manure system to feed its digester. CHFour Biogas designed the system to process dairy manure as well as up to 12,000 tonnes / year of off-farm organics. It generates 45,000 Gigajoules (12.5 GWh) per year of RNG, equivalent to heating 500 homes at 90 GJ per house. The biogas produced by the AD is upgraded (Figure 7-4) and injected into the FortisBC natural gas pipeline. Participating FortisBC customers can allocate between 5 and 100 per cent of the natural gas needs as RNG and receive a proportionate B.C. carbon tax credit. The additional cost for typical residential use is $3 to $50 per month depending on the allocation.

Figure 7-4: Biogas upgrading system (left) and digestate tea water (right)

The resulting digestate is separated into three fractions by a nutrient recovery system (Figure 7-5). Coarse fibrous solids are extracted with a screw-press and used for cow bedding. Additional processing and de-watering on-site then create a nutrient-rich cake (approx. 25 % solids) that is used as fertilizer for cropland located 30-minutes away. The separated liquid portion (similar to a low nutrient tea-like water) is either irrigated onto the farm's nearby crops and/or used as flush-water in their manure handling system. The nutrient recovery system is the start of the feedback loop of the P and N cycles of a circular economy.

Figure 7-5: Trident Nutrient Recovery

The AD system enabled Seabreeze Dairy Farms to expand their herd without the acquisition of additional expensive farmland, as farm nutrients are exported to cropland a distance away. As a result, the herd size could increase significantly without inducing a negative environmental impact. A summary of the system is presented in Table 7-2.

Table 7-2: Summary of Seabreeze Farms' AD System

Feedstock	Dairy manure & off-farm organic waste
Technical	2500 m^3 mesophilic complete mix reactor 250 m^3 hydrolyzer 200 m^3 liquids receiving tank *Trident* nutrient recovery system for circular economy
Use of biogas	Upgraded and compressed to FortisBC pipeline using a water-scrubber system from *Greenlane Renewables*
Use of by-products	Bedding for 375 cows & cake fertilizer for cropland Liquid tea fertigation for 40 hectares
Payback	Cost-benefit with unique attention to impact on nutrient management and animal units at the site.
Energy saved	Produces 150 to 250 m^3 CH_4 per hour
Attributes	Enables growth on existing land base, and efficient and cheaper distribution of nutrients in the Fraser Valley

7.3 ITALY

This case study demonstrates the potential impact of Biogasdoneright[R] concept on GHG emissions at a typical farm in Northern Italy. As described in Figure 7-6, this hypothetical 1,000-kW anaerobic digestion plant in the Lombardy Region is co-located with a 600-head dairy cattle production system that has 280 lactating cows. Feedstock for the digester (for scenario 2 CRP + MAN) is a mixture of 71% first and second crops (mostly maize silage), 15 % cattle manure slurry and 14 % by-products from nearby cereal grain mills and potato processing plants to achieve full integration of cropping and livestock systems (Valli et al., 2017).

This farm has 255 hectares (ha) of cropland divided into seven different plots, as shown in Figure 7-7. Of these seven plots, in the summer 80 ha are used for a mono-crop of corn/maize silage (50 % for animal feed and 50 % for the digester), 160 ha are for maize silage in double cropping (sequential cropping) with a winter cereal (triticale or ryegrass) used as forage for the animals, and 15 ha are used to grow perennial forage (alfalfa) for cattle. Some acreages on this farm are used exclusively for food and/or feed production, some are used exclusively for biogas production, and some used for both food and biogas production.

It should be noted that not all the farmland is used sequentially according to BDR principles. Some land is left bare part of the year because the current structure of the feed-in tariff program for renewable electricity in Italy does not provide market access for all the electricity that could be produced by the farm.

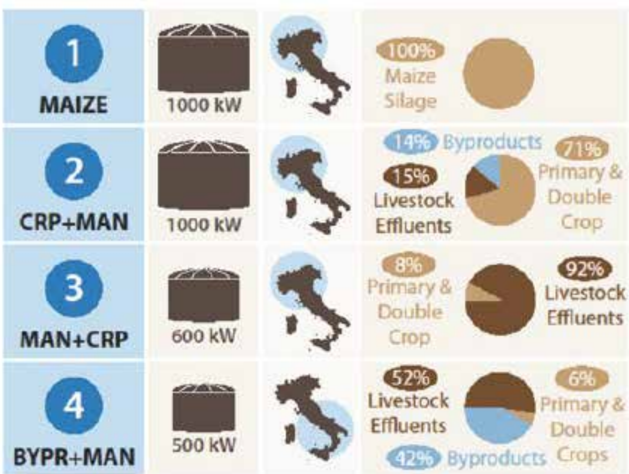


Figure 7-6: Case Study for Biogasdoneright[R] Concept (Valli et al., 2017; doi.org/10.1002/bbb.178)

Digestate is applied at the following times during the cropping cycle: (i) prior to sowing the next crop (using an umbilical system and strip distribution with combined equipment), (ii) during weed control (via digestate injection), and (iii) during crop growth (using fertigation or pivot distribution with drip lines). Digestate is applied using best practices with machinery that minimizes nitrogen losses. About 65 % of the nitrogen requirements and essentially all of the potassium and phosphorus requirements of the crops are met by the applied digestate. The use of mineral fertilizers (nitrogen, phosphorus and potassium) is limited and significantly below what is used in conventional agriculture.

Figures 7-8 and 7-9, respectively, present the GHG emissions and carbon footprint per kWh of electricity. This compares GHG emissions from marginal fossil electricity in the EU with conventional biogas production based on maize silage and a BDR scenario for mostly crop inputs with some manure and byproducts. Life cycle assessment methods were used to quantify the carbon footprints shown in Figure 7-9.

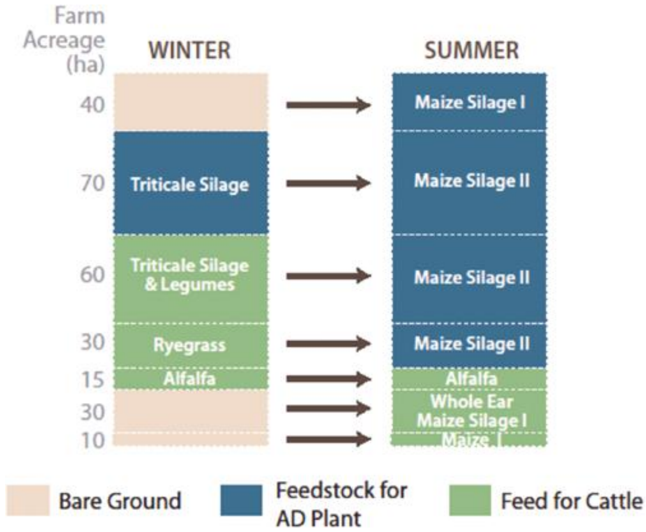


Figure 7-7: Field crop strategies in the winter and summer (Valli et al., 2017; doi.org/10.1002/bbb.178)

This case study confirms that anaerobic digestion of agricultural feedstocks to produce energy (electricity and biomethane) has great potential to reduce GHG emissions associated with fossil energy use in

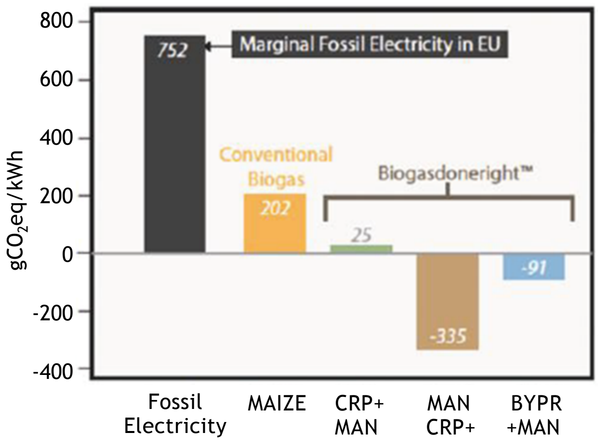


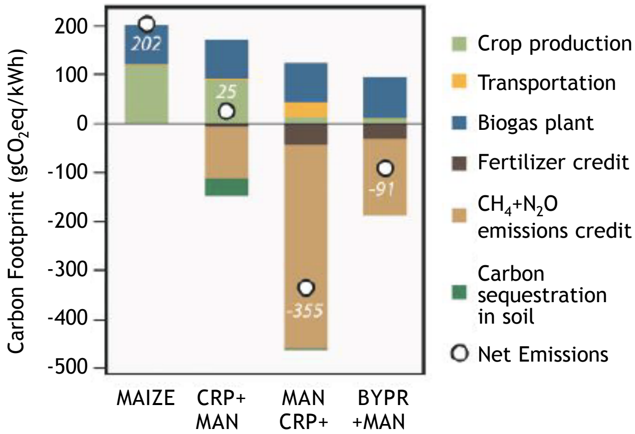
Figure 7-8: Comparison of GHG emissions on a kWh basis (Valli et al., 2017; doi.org/10.1002/bbb.178)

GHG emissions of Electricity from marginal EU fossil sources, Biomethane from conventional biogas (maize silage) and the BDR scenarios:

CRP+MAN (71% first and second crops + 15 % manure + 14 % byproducts)

MAN+CRP (92 % manure, 8 % crops)

BYPR+MAN (52 % manure, 42 % by-products and 6 % first and second crops)



Contribution analysis of the carbon footprint for conventional biogas (maize silage) and the BDR scenarios as per figure 7-8

Figure 7-9: Breakdown of Carbon Budgets by Emissions Source and Sink (Valli et al., 2017l; doi.org/10.1002/bbb.178)

Italy. The BDR system consists of agricultural crops grown under sequential cropping that continuously cover the soil, the use of animal manures and agricultural residues, recycling of the digestate to the farm using innovative techniques to substitute for mineral fertilizers and increase soil organic matter. Using these feedstock combinations for AD and agricultural practices, carbon negative (defined here as negative CO_{2eq} emissions per unit of energy produced) farming can be achieved. In another BDR scenario where the digester feed consisted of 92 % manure and 8 % crops (Scenario 3 MAN + CRP in figure 7.6), negative GHG emissions (- 335 g CO_2/kWh) were estimated (Valli et al., 2017). Scenario 4 (BYPR + MAN in figure 7.6) consisting of 52 % manure, 42 % by-products and 6 % first and second crops yielded a negative emission of -91 g CO_2/kWh (figure 7.8 and 7.9).

The BDR model increases the land area in production (more photosynthesis) and nutrient use efficiency compared to the base case of conventional production of food crops alone. Here, food and feed production coexist with renewable energy production to their mutual advantage. The adoption of BDR practices also increases soil carbon sequestration and improves soil quality. This is particularly beneficial in the drier areas of the country that are prone to desertification.

7.4 UNITED KINGDOM

The Copy's Green Farm is a wholly owned prize winning 230 ha mixed dairy and arable farm with a 126 cow Brown Swiss herd and 79 young stock. The landowner, Dr. Stephen Temple, has won awards since 2009 for Excellence in Practical Farming, Best Integration of AD into a Farming Business, Farmers Weekly Green Energy Farmer of the Year, Campaign to Protect Rural England, the Show Farms Competition Livestock Cup, and Gold awards for cheeses. The farm, shown in Figure 7-10, is located on flinty soils in one of the driest parts of eastern England where rainfall averages 600 mm a year and enjoys long spells of hot summer weather but also prolonged periods of drought. Conservation of soil organic matter and moisture content are important objectives for this farm.

Figure 7-10: Copy's Green Farm (Photo: Courtesy of Stephen and Catharine Temple)

As shown in Figure 7-11, AD lies at the very heart of this farm. The digester, entirely self-funded, was installed in 2009 to harness both the energy and nutrient value of the 2,600 tonnes of slurry produced each year and to diversify the cropping pattern, lengthen the crop rotation and to protect the farm from rising fertilizer and energy costs. The focus and lesson to be learned from this farm are that the AD is part of a wholly integrated farm system. The digester is part of a continuous development process to achieve the highest standards in farming practice along with best environmental management and conservation including that for energy use. Since building the AD system, the farm has changed from a seven crop to an eight crop rotation with the cessation of winter wheat and sugar beet which have been replaced with a larger area of corn/maize that is grown as a forage crop for the cows and as feedstock for the digester.

The digester characteristics include: 800 m^3 tank with a 40-50 days residence time and a temperature range of 37 to 42 °C. Every day seven tonnes of slurry are co-digested with eight tonnes of corn/maize silage, fodder beets and whey from the on-farm cheese making operation. The pH of the digestate liquid is lowered using sulphuric acid which in turn generates a GHG benefit by capturing volatile ammonia, making this portion of the digestate more nutrient valuable. The digestate is separated and stored in two lagoons and when applied to land uses GPS technology that incorporates features to apply nutrients to the soil where required. The CHP unit is equipped with a 170 kWh engine and a 198 kWh gas boiler as a backup. The heat is used on farm for cheese making as well as heating four houses. Energy saving and conservation are part of the farm's carbon sensitive approach. The diesel fuelled car (driven about 30,000 km/yr) has been replaced with a fully electric vehicle and the purchase of a dual fuelled electric tractor and other machinery are being explored. Copy's Green Farm provides a model for the integration of the AD into a mixed dairy and arable farm system which could be replicated countrywide.

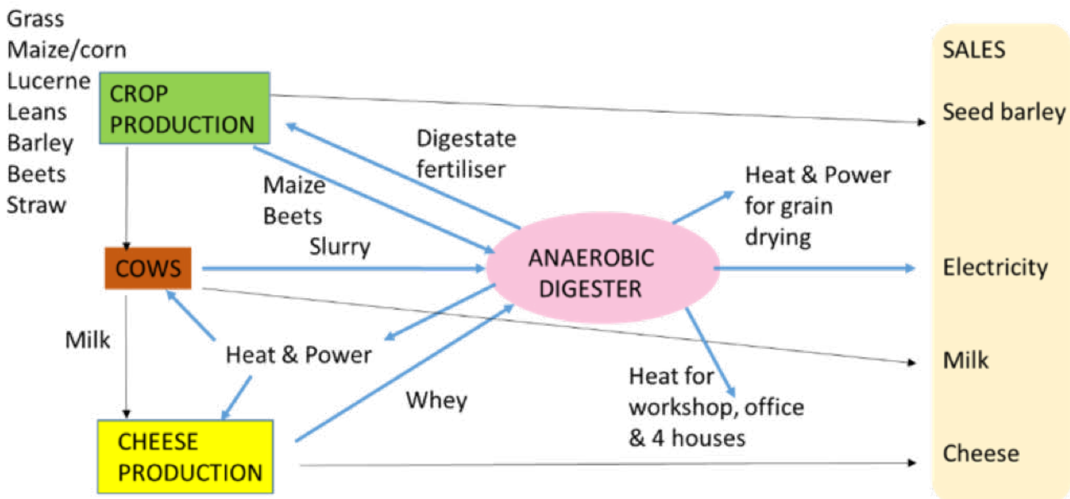


Figure 7-11 Copy's Green Farm Strategy for Material and Energy Flows
Reproduced courtesy of Dr Simon Temple

8. Conclusion

The ambition of renewable energy technologies (including anaerobic digestion) is to reduce the carbon footprint of energy and eventually lead to a decarbonised world, ideally before 2050. Of issue for a net carbon neutral world are the hard to decarbonise sectors, such as agriculture. Agriculture is seen as a source of greenhouse gases, be it methane from belching ruminants, fugitive methane release from open storage of slurry, carbon release for tilled soils, desertification of agricultural land due to over use and droughts, reduction in soil organic carbon content, use of fossil fuels to make fertiliser, and NO_2 release from agriculture lands. Futher environmental isssues relate to the volatilisation of ammonia, eutrophication, smells and ground water pollution.

This report assesses the role of biogas integrated into the farming system through examination of policy, practices and strategies in four very distinct countries with very different climatic conditions. These countries include Australia (6th largest country by area, driest inhabitated continent, low levels of population density), Canada (2nd largest country by area, incredibly cold in the north, while warm in the south, sparsely populated), Italy (mountain, continental and mediteranean climates with very fertile regions such as the Po valley with potential for year round agriculture) and the UK (well populated industrial country with temperate oceanic climate).

Practice is such that both Italy and the UK have mature biogas industries and in particular see biogas systems integrated into the farming system, to the extent that crop rotations are changed with the existance of a nearby digester. This is exemplified by the Italian concept of Biogasdoneright^{R} (BDR) whereby anaerobic digestion enables and strengthens food and fuel integration, but also that the changes made to farming systems have resulted in increasing photosynthesis (less land left bare), greater use of organic fertilizers, and increased adoption of precision and conservation farming practice.

The opportunities offered by biogas systems associated with farming practices include:

- Reduction in fugitive methane emissions (with global warming potential (GWP) of 28) from livestock manure storage and associated sustainable manure management associated with biogas production and thence its use for combined heat and power and/or biomethane with full combustion yielding CO_2 (with a GWP of 1) and as such the entire circular economy system potentially yielding a neutral or negative GHG emission per unit of energy produced;
- Minimisation of mineral fertilizer use (and associated fossil fuel use) through replacement with digestate from biogas system coupled with adoption of precision biofertilizer/mineral fertilizer application, crop nutrient matching to soil N, P and K reserves;
- Use of fertilizer application techniques (such as trailing shoe instead of splash plate slurry spreading systems) that minimise N volatilisation and the generation of nitrous oxide (GWP of N_2O = 265 to 298 that of CO_2).
- Increase carbon sequestration and soil organic content, by the production and use of catch crops (fast growing crop grown between successive planting of main crop) which reduce periods of bare soil, increase photosynthesis and improve soil health. Catch crops can dispel food-fuel and land use change concerns as catch crop, slurries, and damaged primary crops (such as from drought) may be used as the source of biogas feedstock.

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