Piggery: from environmental pollution to a climate change solution

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ABSTRACT

Pig farms are a vital component of rural economies in Australia. However, disposal of effluent leads to many environmental problems. This case study of the Berrybank Farm piggery waste management system in Victoria estimates greenhouse gas (GHG) benefits from three different activities. Analysis reveals that the capturing and combusting of methane from piggery effluent could save between 4859 and 5840 tCO_2e yr^{-1} of GHG emissions. Similarly, using methane for replacing fuels for electricity generation could save another 800 tCO_2e yr^{-1} of GHGs. Likewise, by utilising the biogas wastes to replace inorganic fertilisers there could be a further saving of 1193 to 1375 tCO_2e yr^{-1} of GHG, depending on the type of fertilisers the waste replaces. Therefore, a well-managed piggery farm with 15,000 pigs could save 6,852 to 8,015 tCO_2e yr^{-1}, which equates to the carbon sequestrated from 6,800 to 8,000 spotted gum trees (age =35 year) in their above plus belowground biomass. Implementation of similar project in suitable areas in Australia could have significant environmental and financial benefits.

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INTRODUCTION

Australia produces 362,850 t per annum of pig, representing 0.5% of global production. [1] However, Australia has relatively higher costs of production than Canada, USA or Brazil, the major world suppliers of pork. [1] In order to make the pig industry in Australia financially attractive, some value adding is necessary. This study explores the possibilities of value adding through carbon credits in the pig industry. This research is timely, as the Australian government is implementing a domestic emissions trading scheme by 2012. [2]

The pig industry plays a vital role in sustaining Australian rural economies and supplying valuable employment; however, piggeries are renowned for generating a host of environmental issues. For instance, pigs return more than half of the feed they consumed as waste: ~15,000 pigs (800 t) produce 275,000 L of sewage effluent per day, equivalent to the sewage output of a town with a population of 50,000 people. [3] The disposal of effluent from intensive piggeries can generate water pollution (both surface and ground), eutrophication and phosphate leaching. [4] They can also spread putrid odours, fly infestation, and diseases in the adjoining neighbourhoods. [5] In addition, current piggery waste treatment methods (anaerobic lagoon and direct land application) in Australia leads to the production of biogas consisting of methane, which has 21 times more global warming potential than carbon dioxide.[6] If this methane could be captured this could be

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used for electricity generation (replacing other fuels), that would reduce GHG emissions and would help reduce odour, pest, disease and water contamination problems.

Furthermore, due to intensive cultivation systems, cropping lands are highly degraded across the world. To help improve the productivity of cropped areas, fertilisers are increasingly used, as they are considered as an integral part of intensive cultivation. [9,10] Compared to the 1950s, the global use of fertilisers in 1999 was about 23 times in the case of nitrogen (N), almost eight times for phosphorus (P) and more than four times for potassium (K). [9] In Australia, between 1987 and 2000, nitrogen fertiliser use increased by 325%. [10] The production, packing, transportation and application of these fertilisers need huge investment of energy which leads to GHG emissions. [11] If it is possible to collect wastes after biogas production and replace the energy intensive fertiliser, multiple environmental and financial benefits can be achieved for piggeries.

Capturing methane and producing electricity from methane is highly desirable with regard to three GHG reduction public policies: (1) the Australian Government's Mandatory Renewable Energy Target Scheme requires electricity retailers and other large electricity buyers to source an additional 9.5 TWh of their electricity per year from renewable or specified waste-product energy resources by 2010; (2) the New South Wales Greenhouse Gas Abatement Scheme needs electricity retailers and large users to meet their mandatory targets of emissions reduction; and (3) the Queensland Government's new 13% Gas Scheme requires electricity retailers and other liable parties to source at least 13% of their electricity from gas-fired generation. [7, 8]

Therefore, the aims of this study are to estimate: (1) methane emissions from currently used barn flushing wastewater treatment systems; (2) GHG emissions by generating electricity from biogas (replacement of other fuel sources); and (3) GHG emissions by replacing inorganic fertilisers with biogas sludge and mineralised water.

METHODOLOGY

There are currently piggery projects in Thailand and India that capture methane from animal wastes and used for electricity generation. [16] However, in Australia only one such initiative, the Barrybank Piggery Farm (in Victoria), has been reported. [3, 7, 12, 13] Therefore, in this study data from Barrybank Farm were used to estimate GHG benefits.

Berrybank Farm has 15,000 pigs (approximately 53.33kg/pig), which produces 275,000 litres of sewage effluent on average per day. Given the size of the waste stream, Berrybank Farm developed a sophisticated waste management system in November 1989 involving a two-stage anaerobic digestion system. In this system, the pig effluent is transformed into odourless fertiliser and methane gas, which is captured and used for electricity generation. Each day the farm recovers: (1) approximately seven tonnes of waste solids, used as fertiliser; (2) 100,000 litres of recyclable water; (3) 100,000 litres of mineralised water, used as fertiliser; and (4) 180 KWh of electricity for 16 hours per day. The capital cost of the Berrybank Farm project was approximately $2 million with an estimated payback period of six years. The annual estimated saving for Berrybank Farm

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is $425,000 which includes $125,000 in electricity, $50,000 in water saving and $250,000 in fertiliser sale. [3, 7, 12, 13] However, the Berrybank Farm has not considered the greenhouse benefits of the project.

Barrrybank Farm is estimated to have GHGs benefits at three levels: (1) capturing and avoiding of methane emissions; (2) reducing of GHG emissions by generating electricity from captured methane (replacement of other fuel sources); and (3) reduction of GHG emissions by replacing inorganic fertiliser with biogas sludge and mineralised water. Therefore, the total GHG benefit would be calculated as:

$$\text{Tot. CO}_{2e \text{ avoidance}} = CO_{2e \text{ avoided CH}_4} + \text{CO}_{2e \text{ avoided electicity}} + \text{CO}_{2e \text{ avoided fertiliser}} \dots (1)$$

Where,

Tot. $CO_{2e \text{ avoidance}}$ = total CO_2 equivalent of GHG emissions avoidance from the whole project (tCO$_2$e yr^{-1})

$CO_{2e \text{ avoided}} CH_4$ = CO_2 equivalent of methane emissions avoided through recovery and combustion of biogas ((tCO$_2$e yr^{-1})

$CO_{2e \text{ avoided}}$ electricity = CO_2e emissions avoided through biogas-powered electricity generation (tCO$_2$e yr^{-1})

$CO_{2e \text{ avoided}}$ fertiliser = CO_2 equivalent of GHG emissions avoided by replacing chemical fertiliser

RESULTS AND DISCUSSIONS

Avoidance of Methane Emissions

In Australia, there are two dominant piggery waste treatment methods: anaerobic lagoon system and direct land application method. In the anaerobic lagoon system, wastewater is released into settling ponds which allows water to be separated from the entrained solids. Solids are then collected and used as fertilisers, however there is little demand for undigested solid pig waste. The direct land application method involves wastewater being directly released onto paddocks. [6] The anaerobic lagoon system releases 6.074 $kgCO_2e$ yr^{-1} of methane per kg of meat while the direct land application method releases 7.304 $kgCO_2e$ yr^{-1}. [6] Regardless of the approach used at Berrybank, we considered both waste treatment methods to help develop a range of scenarios to guide future piggery project developers.

For the size and number of pigs at Berrybank, calculations revealed that, about 4,859 tCO_2e yr^{-1} of methane could be avoided as emissions, if the biogas plant replaces the anaerobic lagoon system, and about 5,840 tCO_2e yr^{-1} for direct land application. Thus, by capturing and using the resultant methane for electricity production, a biogas plant would avoid about 4,859 to 5,840 tCO_2e yr^{-1} methane from being emitted into the atmosphere. Considering the average weight of pigs, climatic condition and waste treatment system, there figures are comparable with Ratchaburi Farms Biogas Project in Thailand. [16]

Estimation of Carbon Dioxide Equivalent (CO_2e) Emissions Reduction through Biogas-Powered Electricity Generation

In Australia, a range of fuels are used for electricity generation each with differing carbon emissions factors (CEF). For example, hydropower and renewable energy do not generate GHG: therefore, their CEF is zero whereas coal's CEF is 0.895 tCO_2/MWh (Table 1). Since we assume that the biogas-powered electricity will be sold to the Australian government, and connected in some form of national grid system, we need average weighted CEF for all fuels. The share of electricity generation in Australia (in 2003) from various sources (fuels mix) was taken from International Energy Agency and their respective CEF were taken from IPCC. [14, 15] The average weighted CEF for the Australian electricity sector was found to be 0.761 tCO_2 per megawatt hour (MWh) of energy.

To estimate CO_2e emissions reduction from biogas-powered electricity generation (tCO_2e yr^{-1}), the following formula [16], was used.

$$CO_{2\,e\,avoidance} = MW_{E.\,generated} \ x \ T \ x \ CEF_{Australian\,electricity\,generation} \ .....(2)$$

Where,

$CO_{2e\,avoidance}$ = CO_2e emissions avoided through biogas-powered   electricity generation (tCO_2e yr^{-1})

$MW_{E.\,generated}$ = Electricity energy generated in biogas generation sets (MWh)

T   = Time (days yr^{-1})

CEF_{AEG} = Average weighted CEF for Australian electricity generation

The Berrybank Farm has been generating 180 KWh electricity for 16 hours a day [3, 12], with the total amount of electricity generated per day of 2.88 MWh ($MW_{E. generated}$ = 2.88 MWh). Thus CO_2 avoidance through biogas-powered electricity generation (tCO_2e yr^{-1}) at Berrybank Farm is 800 tCO_2e yr^{-1}.

Reduction of GHG Emissions by Replacing Inorganic Fertiliser by Biogas Solid Sludge and Mineralised Water

Kim and Dale [17] estimated a global warming impact (GWI) value for most fertilisers (Table 2). The GWI value included all three greenhouse gases (CO_2, CH_4 and N_2O) and their impact on emissions to their production, packing, transportation and application. In this study, we used these values to estimate GHG emissions by fertilisers. In the case of mixed fertiliser such as N and P, an average value was used. However, we considered the replacement of chemical fertilisers by biogas wastes, and the transportation and application of biogas wastes which also consume energy[2]. Therefore, the GWI value which also considers energy used for transportation and application of fertilisers needs to be adjusted. The transportation and application of N, P and K fertilisers require 10%, 40% and 40% of the total energy, respectively, with the reminder used in production and packaging. [18] In light of these additional considerations, the GWI value was recalculated for production and packing of fertilisers alone (Table 2). Calculations revealed that the production and packing of one kg of N, P, K and mixed (N & P) fertilisers emit 2943,

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[2] It can be argued that due to the bulky nature of biogas waste, the transportation and application of this waste may need more energy than for chemical fertilisers. However, fertilisers are transported from a long distances, sometimes from overseas, therefore, we assumed that this does not make a big difference.

804, 385 and 1729 $gmCO_2e$ of GHGs, respectively. Nitrogen fertiliser is usually produced from ammonia. The production of ammonia through Haber process, the most renowned method, requires significant amounts of energy. [18] Therefore, compared to other fertilizers, N fertilizer has higher GWI value.

In order to determine the amount of GHG benefits by replacing chemical fertilisers with biogas wastes (solid sludge and mineralised water), it is crucial to know two things: (1) what are the commonly used fertilisers in Australia; and (2) the percentage of different nutrients in chemical fertilisers and biogas wastes. In Australia, urea, di-ammonium phosphate (DAP) and muriate of potash (MOP, potassium chloride) are commonly used fertilisers for nitrogen, phosphorus and potassium. [19] Among them, urea contains 46% nitrogen, MOP contains 49.5% K, and the DAP contains 18% N and 20% P (Table 3).

At Berrybank Farm, on average, the solid sludge contains 3.1% N, 3.5% P and 1% K (Table 4). [4] Likewise, the mineralised water contains 0.24%, 0.12% and 0.12% of N, P and K. [4] We assumed that the biogas sludge replaced DAP and MOP, as the sludge contains both N and P in approximately the same proportion, and the DAP also contains both N & P in similar proportion (18% N and 20% P). But in the case of mineralised water, the N percent is much higher than that of P. Therefore, we analysed both scenarios: replacement of urea and MOP; and DAP and MOP.

From the percentages of N, P, and K in the sludge, we found that 7 t of sludge can produce 217 kg of N, 245 kg of P and 70 kg of K (Table 4). Therefore, 7 t of sludge can

work as 1206 kg of DAP for N and 1225 kg of DAP for P. However, we erred on the side at conservative estimates, so the lowest value was considered. This means we assumed that the solid sludge replaces 1206 kg of DAP for N. Similarly, from the percentages of N, P, and K in mineralised water, it is found that the 100,000 L[3] of mineralised water can give 240 kg of N, 120 kg of P and 120 kg of K. Hence, 100,000 L of mineralised water can work as a 1333 kg of DAP for N and 600 kg of DAP for P, but as before, lower more conservatives were considered. Thus, mineralised water replaces 600 kg of DAP for P. This is more realistic if the sludge and mineralised water need to be transported long distances, as more energy is consumed and thus more GHG emissions will be released.

It is estimated that the replacement of 1206 kg of DAP for nitrogen fertiliser with biogas sludge can save 2084 $kgCO_2e$ of GHG emissions per day, whilst the added replacement of 141 kg of MOP can save another 54 $kgCO_2$ of GHGs per day (Table 4). Therefore, replacement of DAP and MOP with biogas sludge can reduce 780 tCO_2e yr^{-1} of GHG emissions. Likewise, if we replace inorganic fertilisers by mineralised water, ~ 413 tCO_2e yr^{-1} (if we replace DAP and MOP) to 595 tCO_2e yr^{-1} (if we replace urea and MOP) of GHG emissions can be reduced (Table 4). Therefore, 1193 t to 1375 tCO_2e of GHGs can be reduced annually by using sludge and mineralised water during biogas generation.

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[3] 1 L of mineralised water would be >1 kg in weight as the water is not pure. However, for simplicity 1 L of mineralised water is assumed as 1 kg.

Estimation of Total Greenhouse Gas Benefit

By capturing methane piggery effluent, utilising that methane for replacing conventional fuels used in electricity generation, and using wastes for replacing inorganic fertilisers could have significant GHG benefits (Table 5). Capturing and combusting methane could save 4859 tCO_2e yr^{-1} (by replacing the anaerobic lagoon system) to 5840 tCO_2e yr^{-1} (by replacing the direct application system) in GHG emissions. Similarly, using the methane for replacing fuels for electricity generation could save another 800 tCO_2e yr^{-1}. Likewise, using the biogas wastes to replace inorganic fertilisers could save 1193 tCO_2e yr^{-1} (if it replaces DAP and MOP) to 1375 tCO_2e yr^{-1} (if it replaces urea and MOP).

In total, a well-managed piggery farm with 15,000 pigs could save 6,852 to 8,015 tCO_2e yr^{-1} (Table 5). This is equivalent to the carbon sequestered from 6,800 to 8,000 spotted gum trees (of 35 years age) in their aboveground and belowground biomass. [20] If the size of the pig farm operation is larger (>15,000 pigs), the GHG benefit could be higher due to enhanced economies of scale of production.

The biogas waste not only adds N, P and K but also adds zinc, sulphur, and organic matter which are very important for better soil structure and cation exchange capacity. [21] Similarly, the biogas waste also helps to increase soil pH thereby reducing the use of lime and GHG emissions associated with production, packing, transportation and application of lime. Likewise, bio-fertilizers produce growth-promoting substances such as hormones, vitamins, amino-acids and anti-fungal chemicals, thereby accelerating the plants' establishment. In addition, this project helps to:

- reduce the odour and fly nuisance problem;

- eliminate some pests, and reduce mosquitoes breeding areas and thereby improve working and living conditions;

- encourage farmers and other potential project developers to value add;

- reduce potential surface and ground water pollution problems;

- recycle water and thereby reduce water usage;

- promote technological excellence and innovation in the country; and

- encourage integrated farming system (grains for pigs, electricity to make warm pigs and wastes for increased grain production. [3, 7, 16]

Apart from the GHG saving, the added benefits listed above provide considerable support for similar initiatives elsewhere.

CONCLUSION

The analysis undertaken in this study suggests that capturing methane from piggery effluent, using the methane for replacing fuels for electricity generation, and using wastes for replacing inorganic fertilisers could have significant GHG plus economic benefits. Implementation of similar projects in suitable areas in Australia could have both environmental and financial benefits.

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Table 1 Electricity generation in Australia from various sources and their carbon emissions factor (CFA)

Type of fuel	% of total[1]	CEF (tCO$_2$/MWh)*
Coal	77.2	0.895
Gas	13.8	0.454
Hydro	7.0	0.00
Oil	1.0	0.747
Renewable & waste	0.6	0.00
Solar/wind/other	0.3	0.00
Average weighted carbon emissions factor (CEF)		0.761

[1] adopted from IEA [14] and * adopted from IPCC [15]

Table 2 Global warming impact (GWI) (gm CO$_2$ equivalent kg^{-1}) of agrochemicals

• Chemicals	• GWI (PPTA)	• GWI (production & packing only)
• Nitrogen fertiliser	• 3270	• 3270 * 0.90 = 2943
• Phosphorus fertiliser	• 1340	• 1340 * 0.60 = 804
• Nitrogen + phosphorus fertilisers	• 2305	• 2305 * 0.75 = 1729
• Potassium fertiliser	• 642	• 642 * 0.60 = 385

Source: Kim and Dale [17]

Note: PPTA stands for production, packing, transportation and application

Table 3 Major fertilisers used in Australia for N, P & K and their percentages

Fertilisers	N%	P%	K%
Urea	46	0	0
Di-ammonium phosphate (DAP)	18	20	0
Potassium chloride (MOP)	0	0	49.5

Adopted from Fertiliser Industry Federation Australia Inc [19]

Table 4 Average contents of different nutrients in piggery sludge and mineralised water in Berrybank Farm, Victoria, Australia

Mineralised water (100,000 L/d, water content 98.7%)						
Nutrient	%	Amount (kg/d)	Replace (DAP & MOP)	GHG (kg CO_2e/d)	Replace (urea & MOP)	GHG (kgCO_2e/d)
Nitrogen	0.24%	240	600 kg DAP	1037.4	521.7 kg urea	1535.5
Phosphorus	0.12%	120				
Potassium	0.12%	120	242.4 kg MOP	93.3	242.4 kg MOP	93.3
Total GHG (kgCO_2e/yr) saved/day				1130.7		1628.8
Total GHG saved (kgCO_2e/yr)				412,706		594,512
Solid sludge (7 t/d, water content 70%)						
Nutrient	%	Amount (kg/d)	Replace (DAP & MOP)	GHG (kg CO_2e/d)		
Nitrogen	3.1%	217	1205.6kg DAP	2084.4		
Phosphorus	3.5%	245				
Potassium	1%	70	141.4kg MOP	54.4		
Total GHG (kgCO_2e/yr) saved/day				2138.9		
Total GHG saved (kgCO_2e/yr)				780,370		

Note: Percentage of nutrients in sludge and mineralised water is taken from Charles IFE Pty Ltd Company. [3]

Table 5 Estimation of total GHGs benefits (tCO_2e yr^{-1}) from 15,000 pigs

	Avoidance of CH_4 emissions from		Reduction of GHG emissions by making electricity	Reduction of GHG emissions by replacing ino. fertiliser by biogas waste		Total (tCO_2ey^{-1})
	Open lagoon	Direct application		Scenario A	Scenario B	
GHG (tCO_2ey^{-1})	4,859	5,840	800	1,193	1,375	6,852 to 8,015

Note: Scenario A = both sludge and mineralised water replace DAP and MOP
Scenario B = sludge replace DAP and MOP, and mineralised water replace urea and mop