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A comparison of policies to reduce the methane emission intensity of smallholder dairy production in India.

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Abstract

Within the dairy sector, the effects of climate change are particularly diverse as cows are affected by, and a significant contributor to climate change. With a burgeoning body of work indicating the importance of livestock's contribution to climate change (via Greenhouse Gas (GHG) emissions), the dairy sector will increasingly be targeted for emission reduction. Yet, gaps in knowledge remain as to the effectiveness of interventions in achieving emission reductions. The investigation examines two high-profile Indian policies to evaluate their effectiveness in reducing the methane emission intensity of milk production in Odisha, India. Selected policies included the installation of smallscale anaerobic digesters and the control of Foot and Mouth Disease (FMD). The interventions were evaluated at the cow level informed by data collected from 115 smallholder dairy producers in Puri (n=31) and Khurda (n=84) districts in Odisha, India. The installation of an anaerobic digester was found to increase methane emission intensity by 4.41-5.01%. Control of FMD reduced methane emission intensity by 3.68-12.95% depending on the infection scenario considered. The findings highlight the importance of contextually relevant and multi-sectoral approaches to mitigation as the increase in methane emission intensity following anaerobic digester installation represents movement of emissions from the energy sector into the dairy sector where mitigation is inherently more complex. Thus, the long-term usefulness of anaerobic digester installation as a mitigation strategy is limited.

Keywords: Climate change, India, Odisha, anaerobic digester, Foot and Mouth Disease.

1. Introduction

The livestock sector is a key feature of the Indian economy contributing approximately 4.1% to GDP in 2012-2013 (Government of India, 2014a). The dairy sector is the most important component of the Indian livestock sector contributing 65.1% of the total value (Government of India, 2014b). The Indian dairy sector is the largest in the world composed of approximately 44.5 million milking cows (Government of India, 2014b) representing 16.7% of the world's dairy cattle population (FAO, 2013).

The Indian dairy sector is primarily composed of smallholders who are responsible for 70% of India's bovine (cattle and buffalo) population (Datta *et al.*, 2015). Within India, smallholder operations are characterized by small landholdings (< 2 ha) and small herd sizes (an average of 0.89 female cattle per household) of low productivity (Datta *et al.*, 2015). The average daily milk production of India's crossbred cows is 7.0 kg/cow and 2.4 kg/cow for indigenous cows (Government of India, 2014b). However, a great deal of variability is noted between states. For example, Odisha has lower average levels of milk production at 6.2 kg/cow per day for crossbred and 1.5 kg/cow per day for indigenous cows (Government of India, 2014b).

Due to constraints associated with feeding, breeding, health and management (Government of India, 2012b) the low levels of milk production make the Indian dairy sector one of the most greenhouse gas (GHG) emission intensive (Gerber et al., 2011). Indian estimates of emission intensity (see Swamy and Bhattacharya, 2006; Jha *et al.*, 2011; Patra, 2012) are considered partial estimates as they are not weighted to consider the associated dairy population (such as; replacement heifers, cull calves, etc.) and focus heavily on methane (CH_4) emission from enteric fermentation and manure management practices. Nitrous oxide emissions receive little attention due to their limited importance within the smallholder sector (Swamy and Bhattacharya, 2006; Patra, 2012). Similarly, carbon dioxide produced during respiration is excluded as this represents the return of photosynthesized carbon dioxide to the atmosphere and does not affect net carbon dioxide emissions from livestock (IPCC, 2006a). Indeed, emission inventories from India's National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) are considered complete emission estimates (see Government of India, 2004, 2012a). However, these reports do not consider the emission intensity of milk production.

Indian crossbred dairy cows are estimated to produce between 0.53 and 0.70 kg CO_2 equivalents/kg of milk (Swamy and Bhattacharya, 2006; Jha *et al.*, 2011). Indigenous Indian cattle have a higher methane emission intensity producing between 1.03 and 2.40 kg CO_2 equivalents/kg of milk (Swamy and Bhattacharya, 2006; Jha *et al.*, 2011). In terms of Fat and Protein Corrected Milk (FPCM), the emission intensity of indigenous and crossbred milk production was found to 6.5 kg CO_2 equivalents/kg of FPCM milk and 1.4 kg CO_2 equivalents/kg of FPCM milk, respectively (Patra, 2012). Although the value offered by Patra (2012) is a more complete estimate of emission intensity as it is weighted to consider the associated dairy population, the author includes all cattle (including draft animals) within the dairy sector. In doing so, the emission intensity offered is likely to be an overestimation.

Indian estimates of emission intensity appear comparable to the emission intensity estimates from northern production systems. For example, in the United states Capper *et al.,* (2009) found an emission intensity of 1.35 kg CO_2 equivalents/kg of milk for modern (year 2007) intensive methods of production. Similarly, in the United Kingdom Foster *et al.,* (2007) found emission intensity to be 1.14 CO_2 equivalents/kg of milk. However, these authors employed a Life Cycle Assessment (LCA) approach which is common practice for dairy sector emission estimates in the global north (see FAO, 2010; Kristensen *et al.*, 2011; Opio *et al.*, 2013). The LCA approach provides a more comprehensive estimate of emission intensity as the emissions associated with feed production and processing are included (in addition to enteric and manure management sources) (FAO, 2010). Thus, it is likely that the emission intensity of Indian milk production will be significantly larger should a LCA approach be used. Using a LCA approach, Gerber *et al.,* (2013) estimated the average emission intensity of South Asian integrated crop-livestock systems to be 5.5 kg CO_2 equivalents/kg of milk. The global average was found to be 2.7 kg CO_2 equivalents/kg of milk (Gerber *et al.*, 2013).

It is inevitable that the Indian dairy sector will be targeted for GHG emission reduction due to the high emission intensity and sheer size of the sector. However, achieving emission reductions from the Indian dairy sector is inherently complex due to the contributions livestock make to the country’s economy and food security. As such, India is currently without any dairy sector GHG emission mitigation policies. Yet, the Indian government policy position can be gleaned from existing documents which indicate emission reductions must be achieved without reducing productivity or dairy cattle population size (Government of India, 2011b).

Internationally, authors have begun to question whether reductions in GHG emission can be achieved without a reduction in livestock population. For example, Webb *et al.*, (2014) found that achieving a 20% reduction in UK livestock sector GHG emissions was not possible without reducing output (or exporting emissions overseas). Similarly, reduced stocking rates were required to reduce emissions from the New Zealand dairy sector (Adler *et al.*, 2013; Doole, 2014). Thus, achieving emission reductions without reducing the national herd size represents a significant challenge. Indeed, the development of a low emission dairy sector under the guise of sustainable intensification may be possible (Gerber *et al.*, 2011, 2013; Herrero *et al.*, 2015). However, intensification is particularly challenging within India due to chronic feed shortages (Government of India, 2012b, 2013). As such, questions remain as to whether emission intensity can be reduced to the level required to offset the increases in emission expected in response to increasing demand (Delgado et al., 1999; Pica-Ciamarra and Otte, 2009).

A range of existing Indian policies are likely to have an impact on the GHG emission intensity of the dairy sector. In this circumstance, policymakers could reconsider existing policies within an overarching climate change framework. For example, over the past 30 years, the installation of smallscale anaerobic digesters has been a government priority. By the end of 2017, 5.6 million smallscale anaerobic digesters will have been installed with over 6.5 million installations expected by 2022 (Government of India, 2011c). However, the effect of anaerobic digesters on dairy sector GHG emissions is largely unknown as the energy sector has been the focus of research. As a result, no studies have been undertaken to evaluate the impact of anaerobic digesters on dairy sector emissions, despite system leakage being identified as a potential concern (e.g. Bruun *et al.*, 2014).

Disease control is a stand-alone priority within Indian livestock policy (Government of India, 2013). From a mitigation perspective, disease control provides significant co-benefits as improved productivity (and reduced cull rates) will reduce GHG emissions (Hospido and Sonesson, 2005). Foot and Mouth Disease (FMD) could be targeted as significant resources have been allocated to its control. During 2013-2014, the Indian government spent Rs. 2.5 billion on FMD control (Government of India, 2014b). It is estimated that the Indian bovine (cattle and buffalo) population receive 150 million doses of FMD vaccination annually (Knight-Jones and Rushton, 2013). Despite such investments India has the world’s highest incidence rate (along with China) at 3.39% (Knight-Jones and Rushton, 2013). During 2013, it is estimated that 75 255 bovines (including cattle and buffalo) were affected by the disease, resulting in the death of 7 736 individuals (Government of India, 2014b). However, such infection levels likely underestimate the importance of the disease. For example, at a prevalence of 3.39% (Knight-Jones and Rushton, 2013) assuming a herd size of 44.5 million (Government of India, 2014b) it would be expected that approximately 1.5 million dairy cows would be affected (assuming no vaccination program is in place). Such a figure is more commensurate to the annual median cost of production losses (i.e. Rs. 126 billion (Knight-Jones and Rushton, 2013)).

Therefore, the aim of the investigation was to compare two policies to determine their effectiveness in reducing the GHG emission intensity of milk production in Odisha, India. The installation of smallscale anaerobic digesters and the control of FMD in dairy cattle were selected due to their high profile and importance within Indian livestock policy. Indeed, a range of Indian policies will also affect the emission intensity of milk production. However, the selected policies were locally relevant and had been implemented widely throughout the research sites. The interventions were evaluated at the herd level informed by data collected from 115 smallholder dairy producers in Puri (n=31) and Khurda (n=84) districts of Odisha, India.

2. Methods

2.1.Household-level sampling and data collection

Villages were randomly selected within a 40 km area of the Odisha state capital, Bhubaneswar. The villages were within a high potential dairying zone which was characterized by sufficient water, market access, and relatively reliable animal health infrastructure. Cattle owning households (n=115) were purposively sampled from Puri (n=31) and Khurda (n=84) districts. Local community leaders helped to identify cattle owning households. A portion (n=35) of the sampled households were found to be affected by FMD in the 12-months preceding the interview. A total of 47 crossbred Jersey cows were identified as being affected. Surveys were conducted in the local language (Oriya) with responses being translated into English at the time of the interview. A voice recorder ensured all interviews were recorded verbatim. Interviews were transcribed into Microsoft Access 2010.

2.2.The interview

Farmers were asked a range of questions detailing their dairy operation. Demographic and socio-economic information of sampled households is provided in York *et al.* (2016). For each cow, farmers were asked to detail milk production (L/cow/day) for each month of the 12-month period preceding the interview. A milk density factor of 1.033 (International Farm Comparison Network, 2015) was used to convert milk yields into kg/day. Where possible, farmer responses were corroborated with farm-level records of milk sales provided by local milk collection agents. The records contained sales information only. It was necessary to rely on farmer recall to estimate the quantity of milk kept for household consumption. The milk yield of each sampled cow was not directly measured as it was not possible for the research team to be present in each village at the time of milking (morning and evening) throughout the entire lactation period.

Farmers estimated the quantity (kg/cow/day) of each item fed throughout the year. An inventory of the feed offered to cattle was developed for each cow throughout the year. The research team included an individual capable of identifying the various feed items in the event that farmers were unable to identify the feed item and/or provided a local language name.

2.3. FMD outbreak

The surveyed villages experienced an outbreak of FMD with the earliest cases being identified in July (early rainy season). No indigenous (non-descript) cows (n=15) kept by sampled households were infected. Participation in the government subsidized vaccination program prior to the FMD outbreak was variable between households. Following the first confirmed cases a widespread vaccination program was implemented at which time all sampled households had their cloven hooved livestock (cattle, sheep and goats) vaccinated. Table 1 outlines the number of infected cows and prevalence of FMD amongst the sampled households.

The feed intake of infected cows would be expected to reduce during periods of FMD infection due to lesions in the mouth and on the tongue. Reduced feed intakes would reduce GHG emission. The extent of intake reductions could not be determined as farmers were unable to estimate the difference in feeding strategies during periods of infection.

Table 1: The number of crossbred Jersey cows infected with Foot and Mouth Disease (FMD) within the sampled households of Puri and Khurda districts in Odisha, India. The total number of crossbred Jersey cows sampled and the prevalance of FMD within the sampled population is also provided (mean ± SD).

District	Village	Households sampled	Cattle sampled	Cattle infected	Prevalence (%)
Puri	Kalapanchana	25	17	1	5.88
	Madhi Brahmapur	6	2	1	50
Khurda	Kendubilwa	23	44	16	36.36
	Nana Kara	17	30	12	40
	Raula	29	31	10	32.26
	Saheb Nagar	2	1	0	0
	Uparashai	13	29	7	24.14
Total number		115	154	47	30.52 ± 18.24

2.4.Calculating level of productivity

The lactation curve of the sampled uninfected cows (n=52) and FMD infected cows (n=36) were used to determine:

- average milk production throughout the year
- quantity of milk lost during an FMD outbreak,
- and the length of infection (as indicated by a restoration in milk yield).

The quantity of milk lost during infection does not include the losses associated with the cows which died (n = 3) or were sold (n = 4). Thus, the overall loss in productivity could be much greater than currently being examined if these cows were to be included. Similarly, cows which did not recover to pre-infection levels (n = 5), stopped lactating completely (n = 2) died (n = 3) or were sold prior to recovery (n = 4) were excluded from length of infection calculations.

The average milk production of uninfected crossbred Jersey cows was 1237 kg/cow/lactation (n=52, SD = 620.81). The average lactation length was 250 days. FMD infected crossbred Jersey cows yielded on average 1199 kg/cow/lactation (n=36, SD = 555.27). Indeed, this appears as only a minor reduction in yield. However, the FMD infected cows were above average yielding animals. Immediately prior to infection average yield was 6.1 kg/cow/day (SD = 1.99). The FMD affected cows were assumed to reflect productivity under conditions in which no FMD control had been in place.

A portion of the decline in milk yield during FMD infection can be attributed to normal declines expected as the lactation progresses (Moran, 2005). The normal rate of decline was calculated from the lactation curves of the sampled healthy Jersey crossbred cows present for the entire 12-months preceding the interview (n=52). The average normal rate of decline in milk yield was found to be 0.8 kg/month (12.7% per month, SD = 0.50). The quantity of milk loss attributed to FMD infection was reduced by the monthly normal rate of milk decline for the duration of the infection.

The duration of reduced milk yield due to FMD was 1.71 months (SD = 0.76). As the majority of infections were noted in the rainy season (June – September) it was assumed milk yield would be reduced for the months of June and July. Therefore, the entire month of June (30 days) and a portion of July (71% or 22 days) would experience reduced milk yields. Based on these assumptions, the total quantity of milk lost during an outbreak of FMD was found to be 183 kg/cow/outbreak. Therefore, control of FMD will increase the productivity of cows from 1199 kg/cow/lactation to 1382 kg/cow/lactation. The parameters and calculations required to determine the level of improvement in milk yield following the control of FMD is provided in Table 2.

Table 2: The parameters and calculations required to determine the level improvement in milk yield following the control of Foot and Mouth Disease (FMD) in Odisha, India.

Parameter	Calculation method	Value	Standard deviation	Unit
Uninfected cow	Field data (n = 52)	1237	620.81	kg/cow/lactation
Normal rate of decline	Field data (n = 52)	0.8	0.50	kg/cow/day
FMD infected cow	Field data (n = 36)	1199	555.27	kg/cow/lactation
Production lost during infection	Field data (n = 29)	4.89	2.55	kg/cow/day
Duration of reduced yield	Field data (n = 22)	1.71	0.76	Months
Duration of reduced yield	Field data (n = 22)	52	0.76	Days
Normal quantity lost over 1.71 months	Duration of reduced yield (months) x Normal rate of decline	1.37	-	kg/cow/day
Loss due to FMD infection	Production lost during infection – Normal quantity lost over 1.71 months	3.52	-	kg/cow/day
Total quantity lost during a FMD outbreak	Loss due to FMD infection x Duration of reduced yield (days)	183	-	kg/cow/outbreak
Yield following FMD control	Total quantity lost during a FMD outbreak + FMD infected cow	1382	-	kg/cow/lactation

For comparability, it was assumed that the herd would consist of four adult crossbred Jersey cows. Using the prevalence of FMD infection across the sampled villages (30.52%) it was assumed that only one lactating cow would be affected. However, such a scenario does not reflect the highly contagious nature of FMD. A second scenario was considered assuming that all four cows were infected. The parameters used to inform each scenario are provided in Table 3. As high producing cows were found to be more susceptible to FMD infectionit was assumed that the FMD control would increase production to 1382 kg/cow/lactation.

The installation of smallscale anaerobic digesters would not have any direct influence on the productivity of cows. It was assumed that the productivity of the cows would remain the same as outlined in Table 3.

Table 3: The effect of Foot and Mouth Disease (FMD) on milk yields as considered in two scenarios representing different rates of infection in a herd of four cows in Odisha, India.

	Level of production (kg/lactation)			
	Scenario 1		Scenario 2	
	No FMD control	FMD controlled	No FMD control	FMD controlled
Cow 1	1199	1380	1199	1382
Cow 2	1237	1237	1199	1382
Cow 3	1237	1237	1199	1382
Cow 4	1237	1237	1199	1382
Total herd production	4910	5091	4796	5528

Scenario 1 = one adult cow was assumed to be infected with FMD as determined from prevalence of the disease in the sampled sites; Scenario 2 = all adult cows were assumed infected with FMD as expected by the highly contagious nature of FMD.

2.5. Calculating total GHG emissions

A detailed account of emission calculation is provided in York (2017). A summary of the methods employed is provided.

2.5.1. Enteric methane emissions

Methane emissions were based on the quantity of feed offered to animals relevant to the dairy sector. Feeding strategies were provided by farmers. The nutritional value of each feed item was determined from Feedipedia (2012). Average emission estimates were derived on a per head basis with the use of IPCC (2006a) protocols. However, the Indian specific Methane Conversion Factor (MCF) (Singhal *et al.*, 2005; Jha *et al.*, 2011) was used.

Adult cow emissions were scaled to reflect the different productive states over a 12-month period. Lactation length was determined from field data (n=78) and found to be an average of 250 days (SD = 78.95) for Jersey crossbred cows. Scaling was achieved by dividing the annual Methane Emission Factor (MEF) by the number of days per year (i.e. 365) to obtain a daily MEF for lactating and non-lactating periods. The daily MEFs were then multiplied by the average length of the lactation (250 days) and dry periods (115 days). The figures were added to provide an annual MEF. Only emissions of crossbred Jersey cows were considered as no indigenous (non-descript) cows were affected by FMD. The MEF used to inform the analysis for each category of Jersey crossbred relevant to the dairy sector is provided in Table 4.

2.5.2. Manure methane emissions

Manure methane emissions were calculated based on IPCC (2006a) protocols. However, the Indian specific value for ash (17%) (Gaur *et al.*, 1984) was used. Volatile Solid (VS) content was calculated from feed offered to the animal with the use of IPCC (2006a) protocols. To calculate the Manure Methane Emission Factor (MMEF), it was assumed all manure was either made into dung cakes or placed into an anaerobic digester. The IPCC (2006a) formula was adapted by removing the weighting factor (Equation 1)). The manure emissions from adult cows were scaled (as outlined in Section 2.5.1) to account got lactation and non-lactation periods.

Equation 1: The adapted IPCC (2006a) equation used to determine the total quantity of methane emitted per cow as determined from feed offered to sampled cows in Odisha, India.

$$Manure\ Methane\ Emission\ Factor = [VS * 365] * \left[B_o * 0.67 kg/m^3 * \frac{MMCF}{100}\right]$$

Manure Methane Emission Factor = annual CH_4 emission, kg CH_4/cow per year
VS = daily volatile solid content of Indian dairy cow manure, kg per day
365 = basis for calculating annual VS production, days per year
B_o= maximum methane producing capacity for manure produced by an Indian dairy cow, 0.13 m^3 CH_4 per kg of VS excreted
0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
MMCF = assumed manure methane conversion factor for a specific manure management technique, %

Dung cake making was selected as the manure management strategy for comparison as it is the dominant manure management system in the sampled sites (Government of India, 2011a). The Manure Methane Conversion Factor (MMCF) for dung cake making was assumed to be 10% (IPCC, 2006a). The MMCF is used to indicate the extent to which maximum methane producing capacity (B_o) is achieved under a specific manure management system (IPCC, 2006a). As outlined in Eq. (1), B_o is assumed to be 0.13 m^3 CH_4 per kg of VS excreted.

The MMCF for the anaerobic digester was determined from the rate of leakage (Khoiyangbam *et al.,* 2004; Khoiyangbam, 2008; Bruun *et al.,* 2014) based on the works of

Khoiyangbam (2008) and Khoiyangbam *et al.* (2004). Ideally, leakage would have been measured directly. However, the logistics and resources associated with measuring leakage from a large number of anaerobic digesters was beyond the scope of this investigation. As such, it was assumed that the leakage measured by Khoiyangbam (2008) and Khoiyangbam *et al.* (2004) (and also used by Bruun *et al.* (2014) provided a sufficiently robust estimate.

The MMCF offered by Bruun *et al*. (2014) (i.e. 17%) could not be used as the author assumed that 0.4 m3 of biogas is produced per $m^3$of digester size. Based on this assumption, to calculate methane leakage as a percentage of total production in a 2 m^3 system, 0.8 m^3 of biogas is produced per day. As biogas is 60% methane (Khoiyangbam *et al.*, 2004; Khoiyangbam, 2008; Bruun *et al.*, 2014) a total of 0.48 m^3 of methane is produced per day. Following a conversion to kilograms via a conversion factor of 0.67 (IPCC, 2006a) and extrapolation across an entire year (365 days), annual methane production would be 117.38 kg CH_4/year. As such, the measured leakage of 53.2 kg CH_4/year would represent 45.32% of total methane produced.

A simplified approach was developed to represent the measured leakage as a percentage of total methane production (i.e. MMCF). It was assumed that that the system under investigation (2 m^3) was achieving maximum methane production. The maximum methane producing ability of cow manure (0.13 m^3 CH_4/kg VS) (IPCC, 2006a) and VS excretion rate of Indian cows (2.6 kg VS/head/day) (IPCC, 2006a) were used. It was assumed four cows were required to produce sufficient manure to ensure maximum working capacity. A total of 1.35 m^3 CH_4/day was calculated to be produced. Yearly methane production was calculated to be 493.48 m^3. This value was converted to kilograms of a methane via a conversion factor of 0.67 (IPCC, 2006a). Total production was found to be 330.63 kg CH_4/year. Therefore, leakage of 53.2 kg CH_4/year represents 16.09% of the total amount possible.

This method of converting digester leakage estimates to a MMCF was then applied to the leakage estimate offered by Khoiyangbam *et al.*, (2004). Khoiyangbam *et al.*, (2004) found methane leakage from a 2 m^3 Deenbandhu system to be 46.4 kg CH_4/year. Only leakage from the fixed dome Deenbandhu system was considered as this is the most common type of digester installed in India (Government of India, 2002). The calculation was repeated to convert the value provided by Khoiyangbam (2008) to a MMCF. An average of the newly calculated MMCFs (i.e. 14.0% (Khoiyangbam *et al.*, 2004) and 15.2% (Khoiyangbam, 2008)) was calculated. The average MMCF used in this analysis for anaerobic digestion was 14.6%.

N_2O emissions from manure were not included in this investigation as the manure management systems under investigation (i.e. anaerobic digestion, dung cake making) are not expected to emit N_2O (IPCC, 2006a). Additional methane emission is also expected for any manure that is left stacked in piles prior to dung cake making. Thse sources were not included as they are expected to be relatively minor (Government of India, 2012a), Table 4 provides the MMEF for each category of Jersey crossbred cattle relevant to the dairy sector if the manure is managed as dung cakes or anaerobic digestion.

2.6.Calculating methane emission intensity

Emission intensity is a measure of GHG emission in terms of productive output. As the slaughter of cattle is illegal in Odisha (Government of Odisha, 1961) it was assumed that the total quantity of GHG emitted can be assigned to milk production.

To ensure comparability between anaerobic digestion and FMD control, it was necessary to assume that households kept four adult cows. This is the number of adult cows required to produce sufficient manure for maximum anaerobic digester functionality (assuming a system size of 2 m^3). However, the calculation of emission intensity requires inclusion of emissions from non-productive components of the herd. The total number of cattle sampled was used to indicate the number of non-productive cattle kept per adult cow. For example, for every adult cow sampled, 0.27 young heifers were sampled.

Due to the inclusion of non-productive cattle in the herd, more manure will be produced than can be utilised by a 2 m^3 Deenbandhu anaerobic digester. It was assumed excess manure (from non-productive cattle) will be managed as dung cakes. All manure produced from the four adult cows was assumed to be available for use in the anaerobic digester or made into dung cakes. The interval of use (i.e. time taken to make into dung cakes, or load into the digester) was not considered as emissions were not expected from these sources (Government of India, 2012a). The herd size and structure is shown in Table 4.

Emission factors were scaled to herd structure (Table 4). Scaling was necessary as emission factors are reported on a per head basis. Scaling was achieved by multiplying the number of animals kept per four adult cows via the MEF, MMEF under dung cake making, and MMEF under anaerobic digestion. For example, the MEF of male calves (6.33 kg CH_4/year) was multiplied by the number of male calves (i.e. 0.41) kept.

Total methane production was converted to CO_2 equivalents by multiplication of the emission estimate and the GWP of methane at a 100 year timeframe (IPCC, 2013). The GWP of CH_4 was assumed to be 25 (IPCC, 2007). The methane emission intensity was calculated by dividing the CO_2 equivalents by the total quantity of milk produced from the herd under the different manure management and disease scenarios.

Table 4: The average Methane Emission Factors (MEF) and Manure Methane Emission Factors (MMEF) calculated from the diets of cattle subject to smallholder conditions in Odisha, India. Manure Methane Emission Factors (MMEF) are provided for dung cake making and anaerobic digestion, Methane Emission Factors (MEF) and Manure Methane Emission Factors (MMEF) are provided in kg of methane/animal per year. The herd structure assumed for the comparison of GHG emission mitigation policies is also provided

	Sample size (n)	MEF	$\mathrm{MMEF}_{\mathrm{Cake}}$	$\mathrm{MMEF}_{\mathrm{Digester}}$	Herd structure calculation	Herd structure
Cow[a]	116	43.91	7.74	10.88	-	4
Male calf	12	6.33	0.85	-	(Male calf÷Cow)x4	0.41
Female calf	14	15.89	2.24	-	(Female calf÷)*4	0.48
Young heifers	31	21.74	2.99	-	(Young heifer÷Cow)x4	1.07
Older heifers	22	25.02	3.45	-	(Older heifer÷Cow)x4	0.76
Young males	1	6.35	0.82	-	(Young male÷Cow)x4	0.03
Total herd size	-	-	-	-		6.76

Male calf = < 1 year old; Female calf = < 1 year old; Young heifer = 1 year - < 2.5 years; Older heifers = >2.5 years (not calved); Young males = 1 year - < 2.5 years.

MEF = Estimate based on the Methane Conversion Factor (MCF) provided by (Singhal *et al.*, 2005; Jha *et al.*, 2011)

$\mathrm{MMEF}_{\mathrm{Cake}}$ = Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for dung cake making is 10% (IPCC, 2006a).

$\mathrm{MMEF}_{\mathrm{Digester}}$ = Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for anaerobic digestion is 14.6%.

*Indicates that the manure will be made into dung cakes and assigned the $\mathrm{MMEF}_{\mathrm{Cake}}$.

[a] The estimates of methane emission have been scaled to account for a lactation period of 250 days and dry period of 115 days.

3. Results

3.1.Herd emission

Table 5 provides the contribution to emissions made by each category of Jersey crossbred within the herd. Table 5 indicates that enteric emissions are the most important source of emissions. Manure methane emission of adult cows represents 17.6% and 24.8% of enteric emissions when manure is managed as dung cakes and anaerobic digestion, respectively.

Table 5: The enteric methane and manure methane emissions calculated from the diets of cattle subject to smallholder conditions in Odisha, India. Manure is managed as dung cakes or anerobic digestion.

	Scaled contribution to emission intensity (kg CH_4/year)		
	Enteric emission[a]	Manure emission – Dung cakes[b]	Manure emission – Digester[c]
Cow	175.64	30.96	43.52
Male calf	2.62	0.35	0.35
Female calf	7.67	1.08	1.08
Young heifers	23.24	3.20	3.2
Older heifers	18.98	2.62	2.62
Young males	0.22	0.03	0.03
Total	228.37	38.23	53.75
CO_2 eq (kg CO_2 eq/year)	5709.23	955.87	1343.85

Male calf = < 1 year old; Female calf = < 1 year old; Young heifer = 1 year - < 2.5 years; Older heifers = >2.5 years (not calved); Young males = 1 year - < 2.5 years.

[a] Estimate based on the Methane Conversion Factor (MCF) provided by Jha *et al.*, (2011) and Singhal *et al.*, (2005)

[b] Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for dung cake making is 10% (IPCC, 2006a).

[c] Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for anaerobic digestion is 14.64%.

3.2.Emission intensity and mitigation

Table 26 provides the methane emission intensity of milk production in Odisha India. Control of FMD reduces the methane emission intensity. However, the extent of reduction is dependent on the scenario considered. Scenario 1 (only one adult cow infected) results in a minor reduction in emission intensity (3.68%) whilst Scenario 2 (all adults infected) results in a more significant reduction of 12.95%. The installation of a smallscale anaerobic digester will increase GHG emission intensity by between 4.41-5.01%.

Table 2: The emission intensity of milk production in Odisha, India under different emission mitigation strategies. Mitigation strategies include Foot and Mouth Disease (FMD) control and installation of smallscale anaerobic digesters.

Scenario 1		Value	Unit
No FMD control	Manure managed as dung cakes	1.36	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.44	kg CO_2 eq/kg milk
FMD controlled	Manure managed as dung cakes	1.31	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.39	kg CO_2 eq/kg milk
Change in emission intensity following anaerobic digester installation		+5.50	%
Change in emission intensity following FMD control		-3.56	%
Scenario 2			
No FMD control	Manure managed as dung cakes	1.39	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.47	kg CO_2 eq/kg milk
FMD controlled	Manure managed as dung cakes	1.21	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.28	kg CO_2 eq/kg milk
Change in emission intensity following anaerobic digester installation		+5.50	%
Change in emission intensity following FMD control		-13.12	%

Scenario 1 = one adult cow was assumed to be infected with FMD as determined from prevalence of the disease in the sampled sites; Scenario 2 = all adult cows were assumed infected with FMD as expected by the highly contagious nature of FMD.

Table 6: The emission intensity of milk production in Odisha, India under different emission mitigation strategies. Mitigation strategies include Foot and Mouth Disease (FMD) control and installation of smallscale anaerobic digesters.

Scenario 1		Value	Unit
No FMD control	Manure managed as dung cakes	1.36	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.42	kg CO_2 eq/kg milk
FMD controlled	Manure managed as dung cakes	1.31	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.37	kg CO_2 eq/kg milk
Change in emission intensity following anaerobic digester installation		+4.41	%
Change in emission intensity following FMD control		-3.68	%
Scenario 2		**Value**	**Unit**
No FMD control	Manure managed as dung cakes	1.39	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.46	kg CO_2 eq/kg milk
FMD controlled	Manure managed as dung cakes	1.21	kg CO_2 eq/kg milk
	Manure managed in anaerobic digester	1.26	kg CO_2 eq/kg milk
Change in emission intensity following anaerobic digester installation		+5.01	%
Change in emission intensity following FMD control		-12.95	%

Scenario 1 = one adult cow was assumed to be infected with FMD as determined from the prevalence of the disease in the sampled sites; Scenario 2 = all adult cows were assumed infected with FMD as expected by the highly contagious nature of FMD.

4. Discussion

4.1 Emission intensity

The development of robust measures of emission intensity is a necessary first step from which mitigation can be considered. The calculated emission intensities (i.e. 1.26-1.46 kg CO_2 eq/kg milk) are higher than existing methane estimates for Indian crossbred dairy cows (0.53-0.70 kg CO_2 eq/kg of milk (Swamy and Bhattacharya, 2006; Jha et al., 2011). However, the comparability is limited due to the incompleteness of previous research (as discussed in Section 1). Additionally, the cows included in this investigation were Jersey crossbred cows. It is unlikely that this cow type is comparable to ‘crossbred’ cows (most likely Holstein Friesian crossbreds) considered by previous authors (see Swamy and Bhattacharya, 2006; Jha et al., 2011).

4.2 Mitigation

The results clearly demonstrate the efficacy of different policy based interventions in altering the methane emission intensity of milk production. The control of FMD was found to reduce emission intensity by 3.68-12.95% whilst the installation of a smallscale anaerobic digester was found to increase emission intensity by 4.41-5.01%. The ineffectiveness of the anaerobic digester is due to the comparatively climate change-benign nature of traditional Indian manure management practices (i.e. making dung cakes). If manure was managed in its liquid form, as is the case in intensive production systems of the global north, the installation of anaerobic digesters would be a more effective mitigation strategy than identified by this investigation. Thus, smallscale anaerobic digesters lack contextual relevance and are ill-suited to achieving emission reductions within the Indian smallholder dairy sector.

Conversely, the control of FMD resulted in a reduction in emission intensity. Indeed, it is unsurprising that attempts to improve productivity (via improved health) reduces emission intensity. Yet, Indian livestock policy is silent on the mitigation co-benefit that can result from improved animal health. The results highlight the need for policymakers to explicitly recognise the importance of the mitigation co-benefit associated with FMD control and animal health policies more generally.

A number of authors discuss the potential usefulness of improved health as a means of reducing emission intensity (see Gerber et al., 2013; Hristov et al., 2013). However, northern production systems have primarily been the focus of studies. For example, using a LCA in Spain, Hospido and Sonesson (2005) found control of mastitis to have a positive effect on GHG emissions. Similarly, in the United Kingdom Stott *et al*. (2010) found a mastitis control program could achieve a 1.5-2% improvement in productivity which reduced UK dairy sector emissions by 8% (0.4 Mt CO_2 eq). Such results are largely unsurprising as the core outcome of improved animal health is improved productive efficiency. Studies highlight the importance of enhanced productivity in achieving dairy sector emission intensity reductions (eg Beukes *et al*., 2010; Bell *et al*., 2013). Thus, it is the current low levels of productivity which make the smallholder sector particularly responsive to such interventions.

Biogas leakage from anaerobic digesters has been an area of increasing research interest (e.g. Khoiyangbam *et al.*, 2004; Khoiyangbam, 2008; Bruun *et al.*, 2014). However, previous studies have been unable to estimate the importance of this leakage to increasing dairy sector GHG emissions. Rather, studies have focused on the effect of anaerobic digester installation on total emissions (Bhattacharya *et al.*, 1997; Pathak *et al.*, 2009). In doing so, the authors have ignored important gaps in knowledge with regard to baseline estimates of digester leakage. By not recognising the importance of digester leakage (compared to existing manure management strategies) such studies have overestimated the likely reduction in GHG emission that can be achieved by digester installation.

Additionally, as biogas leakage occurs prior to combustion this source of emission must be assigned to the dairy sector (IPCC, 2006b). AS a result, net emissions from the energy sector are reduced (via a substitution of burning fossil fuels and/or firewood) to the detriment of dairy sector emissions. This is concerning as there are currently no interventions available that can directly (and easily) reduce dairy sector emissions. Yet, there are alternate mitigation options available to the energy sector (eg solar). Thus, it may be advantageous to utilise methods within the energy sector that do not transfer emissions into the dairy sector due to the difficulties in mitigating dairy sector emissions.

Alternatively, it may be necessary to redesign the anaerobic digesters to reduce the risk of leakage. This is advantageous as emissions could be reduced to zero as noted in northern large scale anaerobic digesters (eg Kaparaju and Rintala, 2011). Redesigning the anaerobic digester will also ensure that the significant benefits accrued to the household following installation are retained.

There are significant gaps in knowledge regarding methane emissions from dung cakes and the extent to which leakage is a problem for anaerobic digesters. Thus, there is an inherent level of uncertainty arising from such gaps in knowledge. Specifically, this investigation assumes that the maximum methane emission is achieved during anaerobic digestion. Although the assumption is logical as the objective of anaerobic digestion is to provide conditions conducive to methane production, it is possible that maximum methane emission is not achieved. For example, manure managed in a lagoon system has a MCF of 78% (at 21^0C) (IPCC, 2006a). Therefore, the current sudy may underestimate the importance of the leakage measured by Khoiyangbam *et al.*, (2004) and Khoiyangbam (2008). As such, future research should explicitly consider leakage as a percentage of total methane produced during digestion. Additionally, although the measures provided by Khoiyangbam *et al.*, (2004) and Khoiyangbam (2008) are average annual estimates, methane emission is temperature dependent. Variability in the rate of leakage should also be considered.

Therefore, further research is urgently required in two key areas. Firstly, emissions arising during dung cake making must be accurately measured to ensure that this method of manure management is as climate-change-benign as authors assume it to be (USEPA, 1992; IPCC, 2006a; Government of India, 2010). Secondly, a thorough evaluation of biogas production potential and leakage (including direct measurement) must be undertaken to gain a better understanding of the usefulness of smallscale anaerobic digesters in terms of GHG emission reduction from the dairy sector. The outcomes of such research will inform future revision of IPCC values.

The study is also limited by relatively simple calculations used to predict milk yield following the control of FMD. Such calculations are likely subject to large uncertainty as suggested by the milk yield standard deviations. As such, future research should include a sensitivity analysis and statistical analysis to better understand the significance of FMD impacts on milk yields. Nonetheless, this study is an important contribution to knowledge as it an important proof of concept that demonstrates the importance of developing contextually relevant mitigation strategies. By not adequately considering baseline emission scenarios, policymakers risk the use of ill-suited interventions which will inevitably fail to deliver desired outcomes.

Importantly, the study indicates that a reduction in overall population size is not required to achieve a reduction in emission intensity. It is recommended policymakers further explore productivity improving interventions (eg FMD control) to identify and exploit co-benefit mitigation opportunities. However, within the socio-cultural context of India questions remain as to whether emission intensity reductions will ever be large enough to precipitate a decline in total emissions due to the unpalatability of a reduced national dairy herd and increasing demand for milk products (Delgado et al., 1999; Pica-Ciamarra and Otte, 2009).

In conclusion, this study highlights the need for policymakers to take a multi-disciplinary approach to emission mitigation by implementing a broad agenda considering a range of sectors and their interactions. By installing smallscale anaerobic digesters, emissions are moved from the energy sector into the dairy sector where they are inherently difficult to mitigate. Improving animal health will reduce the emission intensity of milk production with no immediate overall effect on net emissions. Where the impacts of an intervention appear discrete and there is no movement of emissions to other sectors (such as with FMD control) it should be pursued. However, where an interaction between sectors is noted, care must be taken as to move emissions into a sector where they are difficult to mitigate (e.g. the dairy sector) may limit the long-term usefulness of the strategy. Indeed, the movement of emissions between sectors is a purely political exercise. Yet, a failure to recognise such political manoeuvring will likely limit the cost-effectiveness of economy wide emission reduction.

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