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

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1 **A comparison of policies to reduce the methane emission intensity of smallholder dairy**

2 **production in India.**

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12 **Abstract**

13 Within the dairy sector, the effects of climate change are particularly diverse as cows are

14 affected by, and a significant contributor to climate change. With a burgeoning body of work

15 indicating the importance of livestock's contribution to climate change (via Greenhouse Gas

16 (GHG) emissions), the dairy sector will increasingly be targeted for emission reduction. Yet,

17 gaps in knowledge remain as to the effectiveness of interventions in achieving emission

18 reductions. The investigation examines two high-profile Indian policies to evaluate their

19 effectiveness in reducing the methane emission intensity of milk production in Odisha, India.

20 Selected policies included the installation of smallscale anaerobic digesters and the control of

21 Foot and Mouth Disease (FMD). The interventions were evaluated at the cow level informed

22 by data collected from 115 smallholder dairy producers in Puri (n=31) and Khurda (n=84)

23 districts in Odisha, India. The installation of an anaerobic digester was found to increase

24 methane emission intensity by 4.41-5.01%. Control of FMD reduced methane emission

25 intensity by 3.68-12.95% depending on the infection scenario considered. The findings

26 highlight the importance of contextually relevant and multi-sectoral approaches to mitigation

27 as the increase in methane emission intensity following anaerobic digester installation

28 represents movement of emissions from the energy sector into the dairy sector where

29 mitigation is inherently more complex. Thus, the long-term usefulness of anaerobic digester

30 installation as a mitigation strategy is limited.

32   **1. Introduction**

33   The livestock sector is a key feature of the Indian economy contributing approximately 4.1%

34   to GDP in 2012-2013 (Government of India, 2014a). The dairy sector is the most important

35   component of the Indian livestock sector contributing 65.1% of the total value (Government

36   of India, 2014b). The Indian dairy sector is the largest in the world composed of

37   approximately 44.5 million milking cows (Government of India, 2014b) representing 16.7%

38   of the world's dairy cattle population (FAO, 2013).

39   The Indian dairy sector is primarily composed of smallholders who are responsible for 70% of

40   India's bovine (cattle and buffalo) population (Datta *et al.*, 2015). Within India, smallholder

41   operations are characterized by small landholdings (< 2 ha) and small herd sizes (an average

42   of 0.89 female cattle per household) of low productivity (Datta *et al.*, 2015). The average

43   daily milk production of India's crossbred cows is 7.0 kg/cow and 2.4 kg/cow for indigenous

44   cows (Government of India, 2014b). However, a great deal of variability is noted between

45   states. For example, Odisha has lower average levels of milk production at 6.2 kg/cow per day

46   for crossbred and 1.5 kg/cow per day for indigenous cows (Government of India, 2014b).

47   Due to constraints associated with feeding, breeding, health and management (Government of

48   India, 2012b) the low levels of milk production make the Indian dairy sector one of the most

49   greenhouse gas (GHG) emission intensive (Gerber et al., 2011). Indian estimates of emission

50   intensity (see Swamy and Bhattacharya, 2006; Jha *et al.*, 2011; Patra, 2012) are considered

51   partial estimates as they are not weighted to consider the associated dairy population (such as;

52   replacement heifers, cull calves, etc.) and focus heavily on methane (CH_4) emission from

53   enteric fermentation and manure management practices. Nitrous oxide emissions receive little

54   attention due to their limited importance within the smallholder sector (Swamy and

55   Bhattacharya, 2006; Patra, 2012). Similarly, carbon dioxide produced during respiration is

56   excluded as this represents the return of photosynthesized carbon dioxide to the atmosphere

57   and does not affect net carbon dioxide emissions from livestock (IPCC, 2006a). Indeed,

58   emission inventories from India's National Communications to the United Nations

59   Framework Convention on Climate Change (UNFCCC) are considered complete emission

60   estimates (see Government of India, 2004, 2012a). However, these reports do not consider

61   the emission intensity of milk production.

62

63   Indian crossbred dairy cows are estimated to produce between 0.53 and 0.70 kg CO_2

64   equivalents/kg of milk (Swamy and Bhattacharya, 2006; Jha *et al.*, 2011). Indigenous Indian

65   cattle have a higher methane emission intensity producing between 1.03 and 2.40 kg CO_2

66   equivalents/kg of milk (Swamy and Bhattacharya, 2006; Jha *et al.*, 2011). In terms of Fat and

67   Protein Corrected Milk (FPCM), the emission intensity of indigenous and crossbred milk

68   production was found to 6.5 kg CO_2 equivalents/kg of FPCM milk and 1.4 kg CO_2

69   equivalents/kg of FPCM milk, respectively (Patra, 2012). Although the value offered by Patra

70   (2012) is a more complete estimate of emission intensity as it is weighted to consider the

71   associated dairy population, the author includes all cattle (including draft animals) within the

72   dairy sector. In doing so, the emission intensity offered is likely to be an overestimation.

73

74   Indian estimates of emission intensity appear comparable to the emission intensity estimates

75   from northern production systems. For example, in the United states Capper *et al.,* (2009)

76   found an emission intensity of 1.35 kg CO_2 equivalents/kg of milk for modern (year 2007)

77   intensive methods of production. Similarly, in the United Kingdom Foster *et al.,* (2007) found

78   emission intensity to be 1.14 CO_2 equivalents/kg of milk. However, these authors employed a

79   Life Cycle Assessment (LCA) approach which is common practice for dairy sector emission

80   estimates in the global north (see FAO, 2010; Kristensen *et al.*, 2011; Opio *et al.*, 2013). The

81   LCA approach provides a more comprehensive estimate of emission intensity as the

82   emissions associated with feed production and processing are included (in addition to enteric

83   and manure management sources) (FAO, 2010). Thus, it is likely that the emission intensity

84   of Indian milk production will be significantly larger should a LCA approach be used. Using

85   a LCA approach, Gerber *et al.,* (2013) estimated the average emission intensity of South

86   Asian integrated crop-livestock systems to be 5.5 kg CO_2 equivalents/kg of milk. The global

87   average was found to be   2.7 kg CO_2 equivalents/kg of milk (Gerber *et al.*, 2013).

88

89   It is inevitable that the Indian dairy sector will be targeted for GHG emission reduction due to

90   the high emission intensity and sheer size of the sector. However, achieving emission

91   reductions from the Indian dairy sector is inherently complex due to the contributions

92   livestock make to the country's economy and food security. As such, India is currently

93   without any dairy sector GHG emission mitigation policies. Yet, the Indian government

94   policy position can be gleaned from existing documents which indicate emission reductions

95   must be achieved without reducing productivity or dairy cattle population size (Government

96   of India, 2011b).

97

98   Internationally, authors have begun to question whether reductions in GHG emission can be

99   achieved without a reduction in livestock population. For example, Webb *et al.,* (2014) found

100 that achieving a 20% reduction in UK livestock sector GHG emissions was not possible

101 without reducing output (or exporting emissions overseas). Similarly, reduced stocking rates

102 were required to reduce emissions from the New Zealand dairy sector (Adler *et al.*, 2013;

103 Doole, 2014). Thus, achieving emission reductions without reducing the national herd size

104 represents a significant challenge. Indeed, the development of a low emission dairy sector

105 under the guise of sustainable intensification may be possible (Gerber *et al.*, 2011, 2013;

106 Herrero *et al.*, 2015). However, intensification is particularly challenging within India due to

107 chronic feed shortages (Government of India, 2012b, 2013). As such, questions remain as to

108 whether emission intensity can be reduced to the level required to offset the increases in

109 emission expected in response to increasing demand (Delgado et al., 1999; Pica-Ciamarra and

110 Otte, 2009).

111

112 A range of existing Indian policies are likely to have an impact on the GHG emission

113 intensity of the dairy sector. In this circumstance, policymakers could reconsider existing

114 policies within an overarching climate change framework. For example, over the past 30

115 years, the installation of smallscale anaerobic digesters has been a government priority. By

116 the end of 2017, 5.6 million smallscale anaerobic digesters will have been installed with over

117 6.5 million installations expected by 2022 (Government of India, 2011c). However, the effect

118 of anaerobic digesters on dairy sector GHG emissions is largely unknown as the energy sector

119 has been the focus of research. As a result, no studies have been undertaken to evaluate the

120 impact of anaerobic digesters on dairy sector emissions, despite system leakage being

121 identified as a potential concern (e.g. Bruun *et al.*, 2014).

122 Disease control is a stand-alone priority within Indian livestock policy (Government of India,

123 2013). From a mitigation perspective, disease control provides significant co-benefits as

124 improved productivity (and reduced cull rates) will reduce GHG emissions (Hospido and

125 Sonesson, 2005). Foot and Mouth Disease (FMD) could be targeted as significant resources

126 have been allocated to its control. During 2013-2014, the Indian government spent Rs. 2.5

127 billion on FMD control (Government of India, 2014b). It is estimated that the Indian bovine

128 (cattle and buffalo) population receive 150 million doses of FMD vaccination annually

129 (Knight-Jones and Rushton, 2013). Despite such investments India has the world's highest

130 incidence rate (along with China) at 3.39% (Knight-Jones and Rushton, 2013). During 2013,

131 it is estimated that 75 255 bovines (including cattle and buffalo) were affected by the disease,

132 resulting in the death of 7 736 individuals (Government of India, 2014b). However, such

133 infection levels likely underestimate the importance of the disease. For example, at a

134 prevalence of 3.39% (Knight-Jones and Rushton, 2013) assuming a herd size of 44.5 million

135 (Government of India, 2014b) it would be expected that approximately 1.5 million dairy cows

136 would be affected (assuming no vaccination program is in place). Such a figure is more

137 commensurate to the annual median cost of production losses (i.e. Rs. 126 billion (Knight-

138 Jones and Rushton, 2013)).

139 Therefore, the aim of the investigation was to compare two policies to determine their

140 effectiveness in reducing the GHG emission intensity of milk production in Odisha, India.

141 The installation of smallscale anaerobic digesters and the control of FMD in dairy cattle were

142 selected due to their high profile and importance within Indian livestock policy. Indeed, a

143 range of Indian policies will also affect the emission intensity of milk production. However,

144 the selected policies were locally relevant and had been implemented widely throughout the

145 research sites. The interventions were evaluated at the herd level informed by data collected

146 from 115 smallholder dairy producers in Puri (n=31) and Khurda (n=84) districts of Odisha,

147 India.

148 **2. Methods**

149 *2.1.Household-level sampling and data collection*

150 Villages were randomly selected within a 40 km area of the Odisha state capital,

151 Bhubaneswar. The villages were within a high potential dairying zone which was

152 characterized by sufficient water, market access, and relatively reliable animal health

153 infrastructure. Cattle owning households (n=115) were purposively sampled from Puri (n=31)

154 and Khurda (n=84) districts. Local community leaders helped to identify cattle owning

155 households. A portion (n=35) of the sampled households were found to be affected by FMD

156 in the 12-months preceding the interview. A total of 47 crossbred Jersey cows were identified

157 as being affected. Surveys were conducted in the local language (Oriya) with responses being

158 translated into English at the time of the interview. A voice recorder ensured all interviews

159 were recorded verbatim. Interviews were transcribed into Microsoft Access 2010.

160 *2.2.The interview*

161 Farmers were asked a range of questions detailing their dairy operation. Demographic and

162 socio-economic information of sampled households is provided in York *et al.* (2016). For

163 each cow, farmers were asked to detail milk production (L/cow/day) for each month of the

164 12-month period preceding the interview. A milk density factor of 1.033 (International Farm

165 Comparison Network, 2015) was used to convert milk yields into kg/day. Where possible,

166 farmer responses were corroborated with farm-level records of milk sales provided by local

167 milk collection agents. The records contained sales information only. It was necessary to rely

168 on farmer recall to estimate the quantity of milk kept for household consumption. The milk

169 yield of each sampled cow was not directly measured as it was not possible for the research

170 team to be present in each village at the time of milking (morning and evening) throughout

171 the entire lactation period.

172 Farmers estimated the quantity (kg/cow/day) of each item fed throughout the year. An

173 inventory of the feed offered to cattle was developed for each cow throughout the year. The

174 research team included an individual capable of identifying the various feed items in the event

175 that farmers were unable to identify the feed item and/or provided a local language name.

176 *2.3. FMD outbreak*

177 The surveyed villages experienced an outbreak of FMD with the earliest cases being

178 identified in July (early rainy season). No indigenous (non-descript) cows (n=15) kept by

179 sampled households were infected. Participation in the government subsidized vaccination

180 program prior to the FMD outbreak was variable between households. Following the first

181 confirmed cases a widespread vaccination program was implemented at which time all

182 sampled households had their cloven hooved livestock (cattle, sheep and goats) vaccinated.

183 Table 1 outlines the number of infected cows and prevalence of FMD amongst the sampled

184 households.

185 The feed intake of infected cows would be expected to reduce during periods of FMD

186 infection due to lesions in the mouth and on the tongue. Reduced feed intakes would reduce

187 GHG emission. The extent of intake reductions could not be determined as farmers were

188 unable to estimate the difference in feeding strategies during periods of infection.

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

202

203 *2.4. Calculating level of productivity*

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

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

210   The quantity of milk lost during infection does not include the losses associated with the

211   cows which died (n = 3) or were sold (n = 4). Thus, the overall loss in productivity could be

212   much greater than currently being examined if these cows were to be included. Similarly,

213   cows which did not recover to pre-infection levels (n = 5), stopped lactating completely (n =

214   2) died (n = 3) or were sold prior to recovery (n = 4) were excluded from length of infection

215   calculations.

216   The average milk production of uninfected crossbred Jersey cows was 1237 kg/cow/lactation

217   (n=52, SD = 620.81). The average lactation length was 250 days. FMD infected crossbred

218   Jersey cows yielded on average 1199 kg/cow/lactation (n=36, SD = 555.27). Indeed, this

219   appears as only a minor reduction in yield. However, the FMD infected cows were above

220   average yielding animals. Immediately prior to infection average yield was 6.1 kg/cow/day

221   (SD = 1.99). The FMD affected cows were assumed to reflect productivity under conditions

222   in which no FMD control had been in place.

223   A portion of the decline in milk yield during FMD infection can be attributed to normal

224   declines expected as the lactation progresses (Moran, 2005). The normal rate of decline was

225   calculated from the lactation curves of the sampled healthy Jersey crossbred cows present for

226   the entire 12-months preceding the interview (n=52). The average normal rate of decline in

227   milk yield was found to be 0.8 kg/month (12.7% per month, SD = 0.50). The quantity of milk

228   loss attributed to FMD infection was reduced by the monthly normal rate of milk decline for

229   the duration of the infection.

230   The duration of reduced milk yield due to FMD was 1.71 months (SD = 0.76). As the

231   majority of infections were noted in the rainy season (June – September) it was assumed milk

232   yield would be reduced for the months of June and July. Therefore, the entire month of June

233   (30 days) and a portion of July (71% or 22 days) would experience reduced milk yields.

234   Based on these assumptions, the total quantity of milk lost during an outbreak of FMD was

235   found to be 183 kg/cow/outbreak. Therefore, control of FMD will increase the productivity of

236   cows from 1199 kg/cow/lactation to 1382 kg/cow/lactation. The parameters and calculations

237   required to determine the level of improvement in milk yield following the control of FMD is

238   provided in Table 2.

Table 2: The parameters and calculations required to determine the level improvement in milk yield following

241 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

242

243 For comparability, it was assumed that the herd would consist of four adult crossbred Jersey

244 cows. Using the prevalence of FMD infection across the sampled villages (30.52%) it was

245 assumed that only one lactating cow would be affected. However, such a scenario does not

246 reflect the highly contagious nature of FMD. A second scenario was considered assuming that

247 all four cows were infected. The parameters used to inform each scenario are provided in

248 Table 3. As high producing cows were found to be more susceptible to FMD infectionit was

249 assumed that the FMD control would increase production to 1382 kg/cow/lactation.

250 The installation of smallscale anaerobic digesters would not have any direct influence on the

251 productivity of cows. It was assumed that the productivity of the cows would remain the same

252 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

282 analysis for each category of Jersey crossbred relevant to the dairy sector is provided in Table
283 4.

2.5.2. Manure methane emissions

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

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

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

297   Manure Methane Emission Factor = annual CH_4 emission, kg CH_4/cow per year
298   VS = daily volatile solid content of Indian dairy cow manure, kg per day
299   365 = basis for calculating annual VS production, days per year
300   B_o = maximum methane producing capacity for manure produced by an Indian dairy
301   cow, 0.13 m^3 CH_4 per kg of VS excreted
302   0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
303   MMCF = assumed manure methane conversion factor for a specific manure
304   management technique, %

305 Dung cake making was selected as the manure management strategy for comparison as it is
306 the dominant manure management system in the sampled sites (Government of India, 2011a).
307 The Manure Methane Conversion Factor (MMCF) for dung cake making was assumed to be
308 10% (IPCC, 2006a). The MMCF is used to indicate the extent to which maximum methane
309 producing capacity (B_o) is achieved under a specific manure management system (IPCC,
310 2006a). As outlined in Eq. (1), B_o is assumed to be 0.13 m^3 CH_4 per kg of VS excreted.

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

313   Khoiyangbam (2008) and Khoiyangbam *et al.* (2004). Ideally, leakage would have been

314   measured directly. However, the logistics and resources associated with measuring leakage

315   from a large number of anaerobic digesters was beyond the scope of this investigation. As

316   such, it was assumed that the leakage measured by Khoiyangbam (2008) and Khoiyangbam *et*

317   *al.* (2004) (and also used by Bruun *et al*. (2014) provided a sufficiently robust estimate.

318   The MMCF offered by Bruun *et al*. (2014) (i.e. 17%) could not be used as the author assumed

319   that 0.4 m3 of biogas is produced per $m^3$of digester size. Based on this assumption, to

320   calculate methane leakage as a percentage of total production in a 2 m^3 system, 0.8 m^3 of

321   biogas is produced per day. As biogas is 60% methane (Khoiyangbam *et al.*, 2004;

322   Khoiyangbam, 2008; Bruun *et al.*, 2014) a total of 0.48 m^3 of methane is produced per day.

323   Following a conversion to kilograms via a conversion factor of 0.67 (IPCC, 2006a) and

324   extrapolation across an entire year (365 days), annual methane production would be 117.38

325   kg CH_4/year. As such, the measured leakage of 53.2 kg CH_4/year would represent 45.32% of

326   total methane produced.

327   A simplified approach was developed to represent the measured leakage as a percentage of

328   total methane production (i.e. MMCF). It was assumed that that the system under

329   investigation (2 m^3) was achieving maximum methane production. The maximum methane

330   producing ability of cow manure (0.13 m^3 CH_4/kg VS) (IPCC, 2006a) and VS excretion rate

331   of Indian cows (2.6 kg VS/head/day) (IPCC, 2006a) were used. It was assumed four cows

332   were required to produce sufficient manure to ensure maximum working capacity. A total of

333   1.35 m^3 CH_4/day was calculated to be produced. Yearly methane production was calculated to

334   be 493.48 m^3. This value was converted to kilograms of a methane via a conversion factor of

335   0.67 (IPCC, 2006a). Total production was found to be 330.63 kg CH_4/year. Therefore,

336   leakage of 53.2 kg CH_4/year represents 16.09% of the total amount possible.

337   This method of converting digester leakage estimates to a MMCF was then applied to the

338   leakage estimate offered by Khoiyangbam *et al.,* (2004). Khoiyangbam *et al.,* (2004) found

339   methane leakage from a 2 m^3 Deenbandhu system to be 46.4 kg CH_4/year. Only leakage from

340   the fixed dome Deenbandhu system was considered as this is the most common type of

341   digester installed in India (Government of India, 2002). The calculation was repeated to

342   convert the value provided by Khoiyangbam (2008) to a MMCF. An average of the newly

343   calculated MMCFs (i.e. 14.0% (Khoiyangbam *et al.*, 2004) and 15.2% (Khoiyangbam, 2008))

344   was calculated. The average MMCF used in this analysis for anaerobic digestion was 14.6%.

345   N_2O emissions from manure were not included in this investigation as the manure

346   management systems under investigation (i.e. anaerobic digestion, dung cake making) are not

347   expected to emit N_2O (IPCC, 2006a).   Additional methane emission is also expected for any

348   manure that is left stacked in piles prior to dung cake making. Thse sources were not

349   included as they are expected to be relatively minor (Government of India, 2012a), Table 4

350   provides the MMEF for each category of Jersey crossbred cattle relevant to the dairy sector if

351   the manure is managed as dung cakes or anaerobic digestion.

352   *2.6.Calculating methane emission intensity*

353   Emission intensity is a measure of GHG emission in terms of productive output. As the

354   slaughter of cattle is illegal in Odisha (Government of Odisha, 1961) it was assumed that the

355   total quantity of GHG emitted can be assigned to milk production.

356   To ensure comparability between anaerobic digestion and FMD control, it was necessary to

357   assume that households kept four adult cows. This is the number of adult cows required to

358   produce sufficient manure for maximum anaerobic digester functionality (assuming a system

359   size of 2 m^3). However, the calculation of emission intensity requires inclusion of emissions

360   from non-productive components of the herd. The total number of cattle sampled was used to

361   indicate the number of non-productive cattle kept per adult cow. For example, for every adult

362   cow sampled, 0.27 young heifers were sampled.

363   Due to the inclusion of non-productive cattle in the herd, more manure will be produced than

364   can be utilised by a 2 m^3 Deenbandhu anaerobic digester. It was assumed excess manure

365   (from non-productive cattle) will be managed as dung cakes. All manure produced from the

366   four adult cows was assumed to be available for use in the anaerobic digester or made into

367   dung cakes. The interval of use (i.e. time taken to make into dung cakes, or load into the

368   digester) was not considered as emissions were not expected from these sources (Government

369   of India, 2012a). The herd size and structure is shown in Table 4.

370   Emission factors were scaled to herd structure (Table 4). Scaling was necessary as emission

371   factors are reported on a per head basis. Scaling was achieved by multiplying the number of

372   animals kept per four adult cows via the MEF, MMEF under dung cake making, and MMEF

373   under anaerobic digestion. For example, the MEF of male calves (6.33 kg CH_4/year) was

374   multiplied by the number of male calves (i.e. 0.41) kept.

375   Total methane production was converted to CO_2 equivalents by multiplication of the emission

376   estimate and the GWP of methane at a 100 year timeframe (IPCC, 2013). The GWP of CH_4

377   was assumed to be 25 (IPCC, 2007). The methane emission intensity was calculated by

378   dividing the CO_2 equivalents by the total quantity of milk produced from the herd under the

379   different manure management and disease scenarios.

380   **Table 4:** The average Methane Emission Factors (MEF) and Manure Methane Emission Factors (MMEF)

381   calculated from the diets of cattle subject to smallholder conditions in Odisha, India. Manure Methane Emission

382   Factors (MMEF) are provided for dung cake making and anaerobic digestion, Methane Emission Factors (MEF)

383   and Manure Methane Emission Factors (MMEF) are provided in kg of methane/animal per year. The herd

384   structure assumed for the comparison of GHG emission mitigation policies is also provided

	Sample size (n)	MEF	$MMEF_{Cake}$	$MMEF_{Digester}$	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

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386   Male calf = < 1 year old; Female calf = < 1 year old; Young heifer = 1 year - < 2.5 years; Older heifers = >2.5

387   years (not calved); Young males = 1 year - < 2.5 years.

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

389   2011)

390     $MMEF_{Cake}$ = Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for

391   dung cake making is 10% (IPCC, 2006a).

392     $MMEF_{Digester}$ = Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for

393   anaerobic digestion is 14.6%.

394   *Indicates that the manure will be made into dung cakes and assigned the $MMEF_{Cake}$.

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

396   period of 115 days.

397   **3. Results**

398   *3.1.Herd emission*

399   Table 5 provides the contribution to emissions made by each category of Jersey crossbred

400   within the herd. Table 5 indicates that enteric emissions are the most important source of

401   emissions. Manure methane emission of adult cows represents 17.6% and 24.8% of enteric

402   emissions when manure is managed as dung cakes and anaerobic digestion, respectively.

403   **Table 5:** The enteric methane and manure methane emissions calculated from the diets of cattle subject to

404   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

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421   Male calf = < 1 year old; Female calf = < 1 year old; Young heifer = 1 year - < 2.5 years; Older heifers = >2.5

422   years (not calved); Young males = 1 year - < 2.5 years.

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

424   (2005)

425   [b] Estimate based on the Indian specific value for ash (17%) (Gaur *et al.*, 1984) assuming MCF for dung cake

426   making is 10% (IPCC, 2006a).

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

428   digestion is 14.64%.

429   *3.2.Emission intensity and mitigation*

430   Table 26 provides the methane emission intensity of milk production in Odisha India. Control

431   of FMD reduces the methane emission intensity. However, the extent of reduction is

432   dependent on the scenario considered. Scenario 1 (only one adult cow infected) results in a

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433 minor reduction in emission intensity (3.68%) whilst Scenario 2 (all adults infected) results in

434 a more significant reduction of 12.95%. The installation of a smallscale anaerobic digester

435 will increase GHG emission intensity by between 4.41-5.01%.

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437 **Table 2:** The emission intensity of milk production in Odisha, India under different emission mitigation

438 strategies. Mitigation strategies include Foot and Mouth Disease (FMD) control and installation of smallscale

439 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	%

440 Scenario 1 = one adult cow was assumed to be infected with FMD as determined from prevalence of the disease

441 in the sampled sites; Scenario 2 = all adult cows were assumed infected with FMD as expected by the highly

442 contagious nature of FMD.

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448 **Table 6:** The emission intensity of milk production in Odisha, India under different emission mitigation

449 strategies. Mitigation strategies include Foot and Mouth Disease (FMD) control and installation of smallscale

450 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	%

451 Scenario 1 = one adult cow was assumed to be infected with FMD as determined from the prevalence of the

452 disease in the sampled sites; Scenario 2 = all adult cows were assumed infected with FMD as expected by the

453 highly contagious nature of FMD.

454 ## 4. Discussion

455 *4.1 Emission intensity*

456 The development of robust measures of emission intensity is a necessary first step from which

457 mitigation can be considered. The calculated emission intensities (i.e. 1.26-1.46 kg CO_2

458 eq/kg milk) are higher than existing methane estimates for Indian crossbred dairy cows (0.53-

459 0.70 kg CO_2 eq/kg of milk (Swamy and Bhattacharya, 2006; Jha et al., 2011). However, the

460 comparability is limited due to the incompleteness of previous research (as discussed in

461 Section 1). Additionally, the cows included in this investigation were Jersey crossbred cows.

462 It is unlikely that this cow type is comparable to 'crossbred' cows (most likely Holstein

463 Friesian crossbreds) considered by previous authors (see Swamy and Bhattacharya, 2006; Jha

464 et al., 2011).

465 *4.2 Mitigation*

466 The results clearly demonstrate the efficacy of different policy based interventions in

467 altering the methane emission intensity of milk production. The control of FMD was found to

468 reduce emission intensity by 3.68-12.95% whilst the installation of a smallscale anaerobic

469 digester was found to increase emission intensity by 4.41-5.01%. The ineffectiveness of the

470 anaerobic digester is due to the comparatively climate change-benign nature of traditional

471 Indian manure management practices (i.e. making dung cakes). If manure was managed in its

472 liquid form, as is the case in intensive production systems of the global north, the installation

473 of anaerobic digesters would be a more effective mitigation strategy than identified by this

474 investigation. Thus, smallscale anaerobic digesters lack contextual relevance and are ill-

475 suited to achieving emission reductions within the Indian smallholder dairy sector.

476 Conversely, the control of FMD resulted in a reduction in emission intensity. Indeed, it is

477 unsurprising that attempts to improve productivity (via improved health) reduces emission

478 intensity. Yet, Indian livestock policy is silent on the mitigation co-benefit that can result

479 from improved animal health. The results highlight the need for policymakers to explicitly

480 recognise the importance of the mitigation co-benefit associated with FMD control and

481 animal health policies more generally.

482 A number of authors discuss the potential usefulness of improved health as a means of

483 reducing emission intensity (see Gerber et al., 2013; Hristov et al., 2013). However, northern

484 production systems have primarily been the focus of studies. For example, using a LCA in

485 Spain, Hospido and Sonesson (2005) found control of mastitis to have a positive effect on

486 GHG emissions. Similarly, in the United Kingdom Stott *et al*. (2010) found a mastitis control

487 program could achieve a 1.5-2% improvement in productivity which reduced UK dairy sector

488 emissions by 8% (0.4 Mt CO_2 eq). Such results are largely unsurprising as the core outcome

489 of improved animal health is improved productive efficiency. Studies highlight the

490 importance of enhanced productivity in achieving dairy sector emission intensity reductions

491 (eg Beukes *et al*., 2010; Bell *et al*., 2013). Thus, it is the current low levels of productivity

492 which make the smallholder sector particularly responsive to such interventions.

493 Biogas leakage from anaerobic digesters has been an area of increasing research interest (e.g.

494 Khoiyangbam *et al.*, 2004; Khoiyangbam, 2008; Bruun *et al.*, 2014). However, previous

495 studies have been unable to estimate the importance of this leakage to increasing dairy sector

496 GHG emissions. Rather, studies have focused on the effect of anaerobic digester installation

497 on total emissions (Bhattacharya *et al.*, 1997; Pathak *et al.*, 2009). In doing so, the authors

498 have ignored important gaps in knowledge with regard to baseline estimates of digester

499 leakage. By not recognising the importance of digester leakage (compared to existing manure

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500 management strategies) such studies have overestimated the likely reduction in GHG
501 emission that can be achieved by digester installation.

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

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

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

528 Therefore, further research is urgently required in two key areas. Firstly, emissions arising
529 during dung cake making must be accurately measured to ensure that this method of manure
530 management is as climate-change-benign as authors assume it to be (USEPA, 1992; IPCC,
531 2006a; Government of India, 2010). Secondly, a thorough evaluation of biogas production

532   potential and leakage (including direct measurement) must be undertaken to gain a better

533   understanding of the usefulness of smallscale anaerobic digesters in terms of GHG emission

534   reduction from the dairy sector. The outcomes of such research will inform future revision of

535   IPCC values.

536   The study is also limited by relatively simple calculations used to predict milk yield following

537   the control of FMD. Such calculations are likely subject to large uncertainty as suggested by

538   the milk yield standard deviations. As such, future research should include a sensitivity

539   analysis and statistical analysis to better understand the significance of FMD impacts on milk

540   yields. Nonetheless, this study is an important contribution to knowledge as it an important

541   proof of concept that demonstrates the importance of developing contextually relevant

542   mitigation strategies. By not adequately considering baseline emission scenarios,

543   policymakers risk the use of ill-suited interventions which will inevitably fail to deliver

544   desired outcomes.

545   Importantly, the study indicates that a reduction in overall population size is not required to

546   achieve a reduction in emission intensity. It is recommended policymakers further explore

547   productivity improving interventions (eg FMD control) to identify and exploit co-benefit

548   mitigation opportunities. However, within the socio-cultural context of India questions

549   remain as to whether emission intensity reductions will ever be large enough to precipitate a

550   decline in total emissions due to the unpalatability of a reduced national dairy herd and

551   increasing demand for milk products (Delgado et al., 1999; Pica-Ciamarra and Otte, 2009).

552   In conclusion, this study highlights the need for policymakers to take a multi-disciplinary

553   approach to emission mitigation by implementing a broad agenda considering a range of

554   sectors and their interactions. By installing smallscale anaerobic digesters, emissions are

555   moved from the energy sector into the dairy sector where they are inherently difficult to

556   mitigate. Improving animal health will reduce the emission intensity of milk production with

557   no immediate overall effect on net emissions. Where the impacts of an intervention appear

558   discrete and there is no movement of emissions to other sectors (such as with FMD control) it

559   should be pursued. However, where an interaction between sectors is noted, care must be

560   taken as to move emissions into a sector where they are difficult to mitigate (e.g. the dairy

561   sector) may limit the long-term usefulness of the strategy. Indeed, the movement of emissions

562   between sectors is a purely political exercise. Yet, a failure to recognise such political

563   manoeuvring will likely limit the cost-effectiveness of economy wide emission reduction.

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