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

2 **production in India.**

3 L. York[a], C. Heffernan[1, a] and C. Rymer[b]

4 *aLivestock Development Group (LDG), Faculty of Life Sciences, University of Reading,*

5 *Reading RG6 6AR, UK*

6 *bSustainable Agriculture and Food Research Division, Faculty of Life Sciences, University of*

7 *Reading, Reading RG6 6AR, UK*

8 *[1] Current address: School of Veterinary Sciences, University of Bristol, Langford House,*

9 *Langford, Bristol, BS40 5DU*

10 Corresponding author: Luke York. Email: luke_york@live.com.au,

11 l.e.york@pgr.reading.ac.uk (L. York)

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.

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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.

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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).

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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).

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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).

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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.

## 2.  Methods

### 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.

*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 $\pm$ 18.24 |

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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).

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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.

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**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.

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**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.

284    *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.

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

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 |

385
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.

## 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

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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%.

436

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

17

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

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 $21^0$C)

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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