

Scotland's Rural College

The greenhouse gas abatement potential of productivity improving measures applied to cattle systems in a developing region.

Salmon, GR; Marshall, K; Tebug, SF; Missohou, A; Robinson, T; MacLeod, M

Published in:
Animal

DOI:
[10.1017/S1751731117002294](https://doi.org/10.1017/S1751731117002294)

First published: 27/09/2017

Document Version
Peer reviewed version

[Link to publication](#)

Citation for published version (APA):

Salmon, GR., Marshall, K., Tebug, SF., Missohou, A., Robinson, T., & MacLeod, M. (2017). The greenhouse gas abatement potential of productivity improving measures applied to cattle systems in a developing region. *Animal*, 12(4), 844 - 852. <https://doi.org/10.1017/S1751731117002294>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 **Assessing greenhouse gas abatement potential for low input cattle systems**
2 **through productivity improving measures**

3 G. R. Salmon^{1,2}, K. Marshall³, S. F. Tebug³, A. Missohou⁴, T. Robinson⁵, and M.
4 MacLeod¹

5 ¹*SRUC, West Mains Road, Edinburgh, EH9 3JG, UK*

6 ²*The University of Edinburgh, King's Buildings, West Mains Road, Edinburgh EH9 3JN,*
7 *UK*

8 ³*The International Livestock Research Institute, PO 30709, Nairobi 00100, Kenya*

9 ⁴*Service de Zootechnie-Alimentation, Ecole Inter-Etats Des Sciences Et Médecines*
10 *Vétérinaires (EISMV) de Dakar, Sénégal*

11 ⁵*FAO-AGAL, Viale delle Terme di Caracalla, 00153 Rome, Italy*

12 Corresponding author: Gareth Salmon. Email: gareth.salmon@sruc.ac.uk

13 Short title: Low input cattle system greenhouse gas abatement

14 **Abstract**

15 Developing countries are experiencing an increase in total demand for livestock
16 commodities, as populations and per capita demand increase. Increased production is
17 therefore required to meet this demand and maintain food security. Production increases
18 will lead to proportionate increases in greenhouse gas (**GHG**) emissions unless this is
19 offset by reductions in the emissions intensity (**Ei**) (i.e. the amount of GHG emitted per
20 kg of commodity produced) of livestock production. It is therefore important to identify
21 measures that can increase production while reducing emissions intensity cost-
22 effectively. This paper seeks to do this for low input cattle systems in Senegal, West

23 Africa. Specifically, it identifies a shortlist of mitigation measures that could be applied to
24 these systems and estimates their abatement potential and cost-effectiveness. The
25 abatement potentials are estimated using GLEAM, with input data derived from primary
26 and secondary sources. Marginal abatement cost curves are presented for different herd
27 systems and the limitations and future requirements are discussed. This paper
28 demonstrates the emission intensity of meat and milk from a livestock system in a
29 developing region can be reduced through measures that would also benefit food
30 security, many of which are likely to be cost-beneficial. The ability to make such
31 quantification can assist future sustainable development efforts.

32 **Keywords:** greenhouse gases, ruminant, productivity, mitigation, Senegal

33 **Implications**

34 This cost-effectiveness analysis suggests measures that could reduce greenhouse gas
35 emission intensity from varying baselines of a selection of Senegalese cattle systems,
36 while improving the productivity and profitability of systems. The implementation of
37 policies could encourage adoption of these measures, which would provide both private
38 and social benefits.

39 **Introduction**

40 Developing countries are experiencing an increase in total demand for livestock
41 commodities, as populations and per capita demands increase. The increased
42 production, required to meet this demand and maintain food security, will lead to
43 proportionate increases in greenhouse gas (**GHG**) emissions; unless they are offset by
44 reductions in the emission intensity (**Ei**) of livestock production (Gerber *et al.* 2013).

45 Emission intensity is a measure of the amount of GHG emitted per unit of output, e.g. kg
46 of carbon dioxide equivalent (kgCO₂eq) per kg of milk. Meat and milk produced by cattle
47 in developing countries often have a higher Ei than the same commodities produced in
48 developed countries. A recent study suggested the regional average Ei of milk from Sub
49 Saharan Africa (**SSA**) is around 9 kgCO₂eq per kg milk, compared to 2 kgCO₂eq per kg
50 milk in North America and Western Europe (Opio *et al.* 2013). High Ei often reflects low
51 levels of productivity, e.g. low milk yields, slow growth rates and high mortalities. It is
52 therefore suggested it should be possible to reduce Ei, and increase food availability, by
53 improving productivity (Gerber *et al.* 2013).

54 Previous studies investigating GHG Ei of SSA cattle systems are frequently based on
55 Intergovernmental Panel on Climate Change (**IPCC**) inventory guidelines (IPCC 2006).
56 However, Ei estimations vary considerably; for example Opio *et al.* (2013) estimate Ei
57 for SSA milk at around 270 kgCO₂eq/kg protein, whilst Weiler *et al.* (2014) and Udo *et*
58 *al.* (2016) estimate for Kenyan milk 50 kgCO₂eq/kg protein to 60 kgCO₂eq/kg protein (Ei
59 converted to kgCO₂eq/kg protein by author assuming protein content of milk is 3.3%). It
60 is likely that differences in productivity are responsible for this variation, Opio *et al.*
61 (2013) assume milk yields to be less than 500 kg/cow/year, whilst Weiler *et al.* (2014)
62 and Udo *et al.* (2016) assume more than 1 500 kg/cow/year. This variation
63 demonstrates the importance of herd level analysis to improve accuracy of Ei
64 estimations, from which development opportunities can be accurately assessed.

65 Functional allocation of GHG emissions remains a contentious topic. Weiler *et al.*
66 (2014) and Udo *et al.* (2016) demonstrated Ei decreased by around 20% when
67 changing from allocating to protein only to allocating to a broader range of cattle

68 functions (e.g. protein, finance, insurance, perceived wealth and dowry). Whilst it is
69 important to recognise that cattle in SSA have functions beyond protein production, and
70 some non-market products can be economically quantified using opportunity value (Udo
71 *et al.* 2016); other socio-cultural functions remain a challenge to value (Weiler *et al.*
72 2014). However, in the context of GHG mitigation, a priority for success is the
73 identification of potential options to improve productivity that both reduces emissions
74 and increase net profits for livestock keepers, who are the key actors in any successful
75 development.

76 This paper presents a herd level assessment of low input cattle systems in Senegal,
77 with the specific aims of: a) defining 'baseline' GHG Ei of produce, b) identifying a set of
78 mitigation measures to apply to the systems, and c) estimating the abatement potential
79 and cost-effectiveness (**CE**) of these measures.

80 Livestock rearing supports more than a third of the population and contributes to around
81 4.8% of Senegal's gross domestic product (Ministère du Commerce 2013). It is also
82 recognised as an opportunity for poverty alleviation, deserving of appropriately applied
83 development policies (Roland-Holst and Otte 2007). Analysis was primarily based on
84 data collected by the International Livestock Research Institute (ILRI) Senegal Dairy
85 Genetics project (<https://senegaldairy.wordpress.com/>), from 220 cattle keeping
86 households in the Thies and Diourbel regions of Senegal. Situated in the peanut agro-
87 ecological zone this region is semi-arid with an average rainfall of 400 mm in short wet
88 season (July to October). Cattle are reared for milk and meat in agro-pastoral or pastoral
89 systems (Tebug *et al.* 2015).

90 Households were categorised depending on: a) the dominant breed type kept (Table 1),
91 and b) the level of management input (defined as either poorer or better, and based on a
92 households average test-day milk yield being above or below the average for the
93 respective breed group (Marshall *et al.* 2016)).

94 *<Insert Table 1 here>*

95 **Methods**

96 *<Insert Figure 1 here>*

97 Figure 1 illustrates the method steps followed; the specific steps are described in the
98 following sections.

99 *A. Model 'baseline' systems to calculate emission intensity for protein*

100 An Excel version of the Food and Agriculture Organization of the United Nations' (**FAO**)
101 Global Livestock Environment and Assessment Model (**GLEAM**)
102 (<http://www.fao.org/gleam/en/>) was used to calculate 'baseline' system GHG Ei for meat
103 and milk production. The system boundary is cradle to farm-gate, and emission
104 categories included are detailed on page 13 of Opio *et al.* (2013). Ei was calculated for
105 protein output (milk and meat); other functions of cattle in these systems are not
106 included in GHG allocation due to difficulties in accurately quantifying them. Input data
107 and sources used for modelling are detailed in Supplementary Table S1.

108 A sensitivity analysis for the Ei result was carried out by altering each model parameter
109 that could be changed when 'baseline' systems are altered to demonstrate the

110 application of mitigation measures by +10% and -10%. The results of this analysis are
111 presented in Supplementary Figures S2 to S8.

112 *B. Mitigation measure shortlisting process*

113 Mitigation measures were shortlisted through three stages (which are further detailed in
114 Supplementary Table S9). The process began with a review of literature to consider
115 options for cattle production systems to improve productivity and reduce E_i . Measures
116 were included based on options that: a) avoided high costs, b) improved system
117 productivity, c) maintained or reduced absolute emissions, and d) had evidence of
118 feasibility for application in SSA. Inevitably, there was a bias towards shortlisting
119 mitigation measures that could have their application modelled. Secondly, consultation
120 with experts with experience working in animal nutrition, genetics and health
121 management in SSA, removed further measures and saw the addition of others, based
122 largely on feasibility and effectiveness. A final stage of shortlisting involved focus group
123 discussions with study livestock keepers (Salmon *et al.* 2016); this further shortlisted
124 based on likelihood of uptake.

125 The shortlist of mitigation measures is summarised in Table 2. Feed related measures
126 are dominant due to: a) focus group discussions identifying feed interventions as having
127 the greatest immediate feasibility; and b) the low nutritional value of 'baseline' rations,
128 and the availability of higher nutritional value feed materials.

129 *<Insert Table 2 here>*

130 *C. Defining parameter changes to model application of shortlisted mitigation measures*

131 'Baseline' systems had model input parameters for GLEAM altered to represent the
132 expected changes to the system when each mitigation measure is applied; these are
133 detailed in Table 3. Specific parameter changes were based on available relevant
134 literature. In the first instance measures were applied stand-alone, i.e. assuming no
135 interaction and comparison always to the 'baseline' systems. Following an assessment
136 of the CE of measures with no interaction, they were then applied as packages with
137 interactions between them considered. Abatement potential (tonnes of CO₂eq abated
138 per herd, per year) was calculated by multiplying the difference in E_i between 'baseline'
139 and 'mitigation measure applied' systems by the 'baseline' system protein yield.

140 <Insert Table 3 here>

141 *D. Economic analysis and cost-effectiveness*

142 Economic analysis and CE results were based on a typical herd with eight breeding
143 cows, on an annual basis. The CE of each mitigation measure was calculated by
144 dividing the cost of implementing the mitigation measure by the change in E_i (see below
145 equation). Only the private costs of implementation were considered (Note: the cost of
146 tsetse removal, to remove the burden of trypanosomiasis (**Tryps**), was covered by the
147 government, but included at herd level); social costs (e.g. economic welfare,
148 environmental impacts beyond GHGs, human health and animal welfare) would require
149 further quantification to be included. The cost of implementing each mitigation measure
150 is the change in herd gross margin arising from the implementation of the measure.

$$CE \text{ (\$/tCO}_2\text{eq)} = \frac{\text{Gross margin with measure applied} - \text{Gross margin without measure applied}}{(\text{E}_i \text{ without measure} - \text{E}_i \text{ with measure}) \times \text{Baseline protein yield}}$$

151 *Cost assumptions*

152 Revenue and cost assumptions are detailed in the Supplementary Table S10. The cost
153 of implementing feed mitigation measures represents an annual reoccurring cost to
154 maintain an improved ration. It was assumed that no additional fixed costs or capital
155 investments are required to improve rations and that any additional costs are included in
156 the price of the feed materials. The cost of implementing measures to remove the
157 burden of foot and mouth disease (**FMD**) and lumpy skin disease (**LSD**) also represent
158 an annual reoccurring cost, with control based on the implementation of effective
159 vaccination. It was assumed that any additional costs are included in the price of the
160 treatment. The costs of Tryps burden removal were based on a project within Senegal to
161 remove the tsetse fly vector (Bouyer *et al.* 2014). Due to the isolation of the tsetse
162 population in Senegal from the rest of the African tsetse belt, an assumption was made
163 that once the initial project cost of eradicating the tsetse is applied, the eradication will
164 be sustainable without additional costs. Therefore, to consider net present value, the
165 costs and benefits of the tsetse vector eradication were discounted. A discount rate of
166 10%, suggested by Shaw *et al.* (2013) to be acceptable for livestock projects, was
167 applied over 30 years.

168 **Results**

169 *<Insert Figure 2 here>*

170 *<Insert Table 4 here>*

171 *'Baseline' emission intensity of produce*

172 The Ei for protein, emission categories and protein yields for 'baseline' systems are
173 illustrated in Figure 2. Key emission categories are enteric methane, feed nitrous oxide
174 (largely from organic nitrogen in urine and manure both deposited directly by animals
175 whilst grazing and collected then spread), and carbon dioxide from energy use in the
176 production of groundnut meal and compound feed. Figure 2 shows the variation in Ei
177 between 'baseline' systems and suggests a relationship to productivity (protein yield).
178 The sensitivity analysis (Supplementary Figures S2 to S8) revealed that the Ei result is
179 most affected by the ration digestibility, milk yield, body weight and fertility rate;
180 therefore the 'baseline' values for these parameters are presented in Table 4.

181 *<Insert Table 5 here>*

182 *Mitigation measure abatement potential and cost-effectiveness*

183 The CE and GHG abatement potential of the shortlisted mitigation measures applied to
184 typical herds (with eight adult females) of the 'baseline' systems are detailed numerically
185 in Table 5. An example marginal abatement cost curve (**MACC**) for the indigenous zebu
186 x taurine cross (IZ x BT) better management herds is shown in Figure 3 (MACCs for
187 other systems are shown in Supplementary Figures S11 to S16); this system is chosen
188 as an example as at 'baseline' it shows greatest productivity (Figure 2) and provides the
189 highest household profit (Marshall *et al.* 2016). The MACC indicates: a) the CE of
190 emission abatement (y-axis), b) the GHG abatement potential for each measure (x-axis),
191 and c) the total cost of each measure (the area of each bar). The MACC displays a
192 reference line to show a shadow price of carbon of \$31/tCO₂eq, representing the
193 economic cost to society caused by an additional ton of carbon dioxide emitted. Each

194 MACC suggests measures which are: a) "win-win", with potential to abate emissions and
195 provide a private benefit (below the x-axis), b) economically efficient, with potential to
196 abate emissions at a cost less than the social cost of carbon reference line (above the x-
197 axis, but below the reference line), and c) economically inefficient, with potential to abate
198 emissions, but with a cost per tonne of carbon currently greater than the social cost of
199 carbon reference line (above both the x-axis and the reference line).

200 <Insert Figure 3 here>

201 **Discussion**

202 *'Baseline' emission intensity*

203 The Ei results for milk production (4 kgCO₂eq/kg to 13 kgCO₂eq/kg) (Table 4) are similar
204 to those in Opio *et al.* (2013) (9 kgCO₂eq/kg for SSA), but greater than those in Weiler *et*
205 *al.* and Udo *et al.* (around 2 kgCO₂eq/kg for Kenyan systems). Contrast with Weiler *et*
206 *al.* (2014) and Udo *et al.* (2016) is likely due to differences in levels of productivity.
207 Specifically in relation to the milk yields for the lower producing Senegal systems (Weiler
208 *et al.* (2014) and Udo *et al.* (2016) consider yields from 1 500 to >3 000 kg/cow/year);
209 and herd structure for all systems, with productive cows making up 30% to 40% of
210 Senegal study herds, whilst cows were 45% to 60% of herds in Weiler *et al.* (2014) and
211 Udo *et al.* (2016). The Ei results for meat production (16 kgCO₂eq/kg to 44 kgCO₂eq/kg)
212 (Table 4) are less than Opio *et al.* (2013) (70 kgCO₂eq per kg beef). Contrast here is
213 likely due to Senegal study systems having animals of a greater body weight (adult cows
214 weighed between 294 kg and 433 kg in comparison to 271 kg in Opio *et al.* (2013)), and
215 a higher cow replacement rate (17% to 21% in comparison to 11% in Opio *et al.* (2013)).

216 The results demonstrate that for the effective assessment of any development or
217 productivity improvement plans the 'baseline' should be considered in detail.

218 Within the Senegalese systems there is substantial variation in Ei of protein
219 produced from 'baseline' systems (Figure 2). Indigenous zebu x taurine cross (IZ x BT)
220 and taurine (BT) herds with 'better' management have lower Ei (113 kgCO₂eq/kg protein
221 and 111 kgCO₂eq/kg protein, respectively) than other 'baseline' systems (averaging 239
222 kgCO₂eq/kg protein). The sensitivity analysis (Supplementary Figures S2 to S8)
223 demonstrated this variation is likely to be due to productivity (milk yields, body weights,
224 fertility, and age at maturity etc.) and ration digestibility differences. Indigenous zebu x
225 taurine cross (IZ x BT) and taurine (BT) herds with 'better' management are fed rations
226 of a higher digestible energy (59 DE% and 62 DE% respectively) compared to other
227 systems (averaging 56 DE%) (Table 4) (DE%: digestible energy expressed as a
228 percentage of gross energy). Indigenous zebu x taurine cross (IZ x BT) and taurine (BT)
229 herds with 'better' management also have a higher level of productivity, for instance
230 higher annual milk yields (2 032 kg and 2 197 kg, respectively, compared to other
231 systems averaging 707 kg). Figure 2 shows both 'better' managed indigenous zebu (IZ)
232 and indigenous x Guzerat zebu cross (IZ x GZ) herds have Ei lower than 'poorer'
233 managed herds with breed groups of likely higher genetic potential for productivity
234 (indigenous x Guzerat zebu cross (IZ x GZ) and indigenous zebu x taurine cross (IZ x
235 BT) respectively) (Table 1). This demonstrates the importance of suitable management,
236 and that breeds of high genetic potential are not always optimal under challenging
237 conditions with limited inputs. Cross bred animals that introduce some productivity

238 potential but retain some of the resilience of indigenous breeds are often more
239 appropriate (Marshall *et al.* 2016).

240 *Key emission categories*

241 Enteric methane and feed nitrous oxide are expected as key emission categories, and
242 consistent with Opio *et al.* (2013). Through their digestive process ruminants produce
243 methane and production is increased when ration digestibility decreases (Gerber *et al.*
244 2013). Cattle in these systems spend considerable time grazing pasture, depositing
245 organic nitrogen in manure and urine, and any collected manure is stored solid
246 promoting the release of nitrous oxide. Carbon dioxide from feed production is due to
247 the presence of processed feed components (groundnut meal and purchased
248 concentrate compound feeds) in the rations.

249 *Abatement potential and cost-effectiveness*

250 The CE (\$ per tonne of CO₂eq abated) and abatement potential (tonnes of CO₂eq
251 abated per herd, per year) of the shortlisted mitigation measures for each of the
252 production systems are presented in Table 5 and Figure 3. The results suggest that
253 across the 'baseline' systems there is potential to abate between 4.7 tCO₂eq
254 (indigenous x Guzerat zebu cross (IZ x GZ) herds with 'better' management) and 6.8
255 tCO₂eq (taurine (BT) herds) per herd per year through 'win-win' measures. This
256 represents a respective reduction of 10% and 13% to annual total herd GHG emissions.
257 Mitigation measures were modelled as packages, applied in order of their CE when
258 applied in isolation. Consequently, interactions between measures are considered and
259 double counting of abatement potential was avoided.

260 The effective control through vaccination of LSD and FMD, and the removal of
261 Tryps burden through tsetse vector control are consistent 'win-win' interventions for the
262 various systems. The cost of additional vaccinations to fully protect herds is assumed to
263 be outweighed by the expected increases in productivity. For example, the assumed
264 burden of 27% and 22% on milk yield for individual cows with LSD and FMD burdens
265 respectively, which translates through prevalence to 2% and 1.5% respective increase
266 for herd average milk yields, will increase herd revenue from milk sales. The cost-
267 effectiveness of LSD and FMD removal, although always below \$0/tCO₂eq, varies
268 between systems depending on the 'baseline' milk yields. The higher yielding breed
269 groups (Indigenous zebu x taurine cross (IZ x BT) and taurine (BT) herds) will
270 experience a greater absolute volume increase in milk yield. For instance, the removal
271 of FMD from indigenous zebu herds (IZ) with 'poorer' management changes the herd
272 average milk offtake from 323 kg to 328 kg per lactating cow per year (an extra 5kg per
273 cow), whilst for taurine (BT) herds there is a change from 2 197 kg to 2 230 kg (an extra
274 33 kg per cow). The removal of Tryps burden through the project explained by Bouyer *et*
275 *al.* (2014), has an initial project cost, but then is followed by reoccurring annual
276 productivity benefits (Table 3), for example a 7% increase in herd milk yields.
277 Discounting these revenue benefits over a period of 30 years still provides a net present
278 value that outweighs the project costs. A further refinement could be to allocate some of
279 the cost to other benefits of removing the tsetse vector, such as expected health and
280 production benefits for other livestock species and a reduction in grazing pressure
281 (Bouyer *et al.* 2014), this may increase the CE further.

282 The improvement of hay nutritional value by timing the hay harvest for optimal
283 nutritional value is also suggested as a 'win-win' option for all systems. The improved
284 nutritional value of the hay improves the overall quality of the ration, and means less
285 volume is required to meet the energy requirements of the cattle, representing a saving.
286 It is assumed that the improved hay will not increase in cost and will not require any
287 additional labour. The cost-effectiveness, although always below \$0/tCO₂eq, varies
288 between systems depending on the proportion of hay in the ration. The indigenous zebu
289 x taurine cross (IZ x BT) and taurine (BT) herds spend more time housed, so hay is a
290 larger proportion of their ration (30% and 18% respectively); therefore this measure is
291 most cost-effective when applied to these systems. Both indigenous zebu x taurine
292 cross (IZ x BT) with 'better' management and taurine (BT) herds also have a higher
293 proportion of millet stover in their ration, making the urea treatment of stover a 'win-win'
294 measure for these systems only. For all other systems urea treatment of stover has a
295 positive cost; this is generally close to the social cost of carbon, suggesting this maybe
296 economically efficient from a social perspective.

297 The measures involving the use of groundnut cake or purchased compound feed
298 are suggested to be expensive, both have significant purchase costs. The improvement
299 of rations using these materials greatly improves digestibility, reducing enteric methane
300 emissions and the volume of total ration required to meet the energy demands of cattle.
301 Measures are applied in packages, groundnut cake with a better CE is applied first and
302 has abatement potential of between 1.6 and 2.2 tCO₂eq per herd per year. The
303 subsequent application of purchased compound feed, will also increase digestibility.
304 However, the response of enteric methane emissions decreases with each unit

305 improvement of ration digestibility, therefore following the further package improvements
306 reduces the power of the measure for abatement. For indigenous zebu x taurine cross
307 (IZ x BT) and taurine (BT) herds the increased emissions from the processing of
308 purchased compound feed increase absolute emissions, so would not be applied as part
309 of the package of measures (Table 5). This highlights a limitation of this study and an
310 opportunity for future refinement in that productivity changes are likely following changes
311 in nutrition (Bryan *et al.* 2013) and these are not fully captured in the current approach.
312 This means that the net costs of the feed measures are likely to be overestimated and
313 abatement potential underestimated.

314 It is encouraging that the results identify that ‘win-win’ measures are available,
315 these are important for engagement and increased uptake of measures by livestock
316 keepers. However, their presence raises the question as to why ‘win-win’ measures,
317 such as the removal of FMD and LSD, are not currently adopted. Focus group
318 discussions with over 200 of the study livestock keepers carried out by the authors
319 suggest barriers include: a lack of initial financial means to invest, a lack of regular
320 access to resources, and system characteristics and traditions (Salmon *et al.* 2016).

321 **Conclusion**

322 The results of this study suggest that the emissions intensity of meat and milk from our
323 study systems can be significantly reduced through measures that also maintain or
324 increase protein production. A portion of this emission abatement could be achieved
325 with apparent ‘win-win’ measures, improving the likelihood of essential engagement with
326 livestock keepers. However, it is suggested that benefits from some of the measures

327 applied to study systems are likely to be underestimated (and the costs overestimated)
328 because the full impacts of the measures on livestock productivity are difficult to
329 quantify. This is particularly true of measures that improve the nutritional value of
330 rations. The use of modelling to identify and quantify cost-effective measures of
331 productivity improvement, as demonstrated by this study, should be an important
332 primary step in effective sustainable development efforts.

333 **Acknowledgements**

334 The authors would like to thank experts from ILRI, Alan Duncan, Augustine Ayantunde,
335 and Ben Lukuyu, field staff in Senegal, and CIRAD staff in Dakar for their advice and
336 assistance during the mitigation measure shortlisting process. This study is part of a
337 wider PhD project funded by the International Livestock Research Institute under
338 CCAFS, the CGIAR Climate Change, Agriculture and Food Security Research Program.
339 The Senegal Dairy Genetics project was funded by the Finnish Ministry of Foreign
340 Affairs under the FoodAfrica program, and the CGIAR Livestock and Fish Research
341 Program.

342 **References**

343 Abutarbush SM, Ababneh MM, Al Zoubi IG, Al Sheyab OM, Al Zoubi MG, Alekish MO
344 and Al Gharabat RJ 2015. Lumpy skin disease in Jordan: Disease emergence, clinical
345 signs, complications and preliminary-associated economic losses. *Transboundary and*
346 *Emerging Diseases* 62, 549–554.

347 Ayelet G, Abate Y, Sisay T, Nigussie H, Gelaye E, Jemberie S and Asmare K 2013.
348 Lumpy skin disease: Preliminary vaccine efficacy assessment and overview on outbreak
349 impact in dairy cattle at Debre Zeit, central Ethiopia. *Antiviral Research* 98, 261–265.

350 Bayissa B, Ayelet G, Kyule M, Jibril Y and Gelaye E 2011. Study on seroprevalence, risk
351 factors, and economic impact of foot-and-mouth disease in Borena pastoral and agro-
352 pastoral system, southern Ethiopia. *Tropical Animal Health and Production* 43, 759–766.

353 Blowey R and Weaver A 2003. *Color Atlas of Diseases and Disorders of Cattle*. 2nd ed.
354 Mosby Elsevier Science Ltd. Edinburgh, UK.

355 Bouyer F, Seck MT, Dicko AH, Sall B, Lo M, Vreysen MJB, Chia E, Bouyer J and Wane
356 A 2014. Ex-ante benefit-cost analysis of the elimination of a *Glossina palpalis*
357 *gambiensis* population in the Niayes of Senegal. *PLoS Neglected Tropical Diseases* 8,
358 1–12.

359 Bryan E, Ringler C, Okoba B, Koo J, Herrero M and Silvestri S 2013. Can agriculture
360 support climate change adaptation, greenhouse gas mitigation and rural livelihoods?
361 insights from Kenya. *Climatic Change* 118, 151–165.

362 Chenost M and Kayouli C 1997. Urea Treatment: Roughage utilization in warm climates.
363 Retrieved on 22 September 2016, from
364 <http://www.fao.org/docrep/003/w4988e/w4988e04.htm>

365 Daher I 1994. La maladie nodulaire cutanee des bovins et ses incidences economiques
366 dans les elevages laitiers des Niayes (Senegal). Diploma thesis, Inter-State School of
367 Veterinary Science and Medicine (EISMV), Dakar, Senegal.

368 Gari G, Bonnet P, Roger F and Waret-Szkuta A 2011. Epidemiological aspects and
369 financial impact of lumpy skin disease in Ethiopia. *Preventive Veterinary Medicine* 102,
370 274–283.

371 Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A and
372 Tempio G 2013. *Tackling Climate through Livestock: A Global Assessment of Emissions*
373 *and Mitigation Opportunities*. Food and Agriculture Organization of the United Nations
374 (FAO), Rome, Italy.

375 Hailu B, Gari G, Tolosa T, Beyene B and Teklue T 2015. Study on the epidemiological
376 and financial impacts of clinical lumpy skin disease in selected districts of Tigray and
377 Afar regional states, North Eastern Ethiopia. *International Journal of Current Research*
378 7, 17415–17425.

379 Intergovernmental Panel on Climate Change (IPCC). 2006. *IPCC Guidelines for*
380 *National Greenhouse Gas Inventories*, Volume 4, Chapter 10 Emissions from livestock
381 and manure management. Retrieved on 20 September 2016, from [http://www.ipcc-](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)
382 [nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

383 Jarrige R 1989. *Ruminant nutrition: recommended allowances and feed tables*. INRA,
384 Paris, France.

385 Jemberu WT, Mourits MCM, Woldehanna T and Hogeveen H 2014. Economic impact of
386 foot and mouth disease outbreaks on smallholder farmers in Ethiopia. *Preventive*
387 *Veterinary Medicine* 116, 26–36.

388 Knight-Jones TJD and Rushton J 2013. The economic impacts of foot and mouth
389 disease - What are they, how big are they and where do they occur? Preventive
390 Veterinary Medicine 112, 162–173.

391 Lukuyu B, Gachuri CK, Lukuyu M, Lusweti C, Mwendia S 2012. Feeding dairy cattle in
392 East Africa. East Africa Dairy Development Project, Nairobi, Kenya.

393 Lyons NA, Alexander N, Stärk KDC, Dulu TD, Sumption KJ, James AD, Rushton J and
394 Fine PEM 2015. Impact of foot-and-mouth disease on milk production on a large-scale
395 dairy farm in Kenya. Preventive Veterinary Medicine 120, 177–186.

396 Marshall K, Tebug S, Juga J, Tapio M and Missohou A 2016. Better dairy cattle breeds
397 and better management can improve the livelihoods of the rural poor in Senegal. ILRI
398 Research Brief 65. Retrieved on 04 April 2017, from
399 <https://cgspace.cgiar.org/handle/10568/72865>

400 Ministère de l'élevage (MEPA) 2013. Rapport annuel d'activites 2012. Dakar, Senegal.
401 Retrieved on 16 September 2016, from <http://www.elevage.gouv.sn/RA2013.pdf>

402 Ministère de l'élevage et des productions animales (MEPA) 2014. Rapport d'activites
403 2014. Dakar, Senegal. Retrieved on 04 April 2017, from
404 <http://www.elevage.gouv.sn/RA2014.pdf>

405 Ministère du Commerce, Senegal 2013. Commercialisation du Lait Local—Restructurer
406 les chaînes d'approvisionnement. Retrieved on 8 February 2017, from
407 [http://www.commerce.gouv.sn/article.php3?id_article=285#sthash.qzA8ID8Z.
408 qg4D7rA9.dpbs](http://www.commerce.gouv.sn/article.php3?id_article=285#sthash.qzA8ID8Z.qg4D7rA9.dpbs)

409 Onono JO, Wieland B and Rushton J 2013. Constraints to cattle production in a
410 semiarid pastoral system in Kenya. *Tropical Animal Health and Production* 45, 1415–
411 1422

412 Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod M, Vellinga T, Henderson
413 B and Steinfeld H 2013. Greenhouse gas emissions from ruminant supply chains - A
414 global life cycle assessment. Food and Agriculture Organization of the United Nations
415 (FAO), Rome, Italy.

416 Roland-Holst D and Otte J 2007. Livestock and livelihoods : Development goals and
417 indicators applied to Senegal. *African Journal of Agricultural Research* 2, 240–251.

418 Rufael T, Catley A, Bogale A, Sahle M and Shiferaw Y 2008. Foot and mouth disease in
419 the Borana pastoral system, southern Ethiopia and implications for livelihoods and
420 international trade. *Tropical Animal Health and Production* 40, 29–38.

421 Salib FA and Osman AH 2011. Incidence of lumpy skin disease among Egyptian cattle
422 in Giza Governorate, Egypt. *Veterinary World* 4, 162–167.

423 Salmon GR, Marshall K, Tebug SF, Missohou A, Sabi SS and MacLeod M 2016. Farmer
424 attitudes to the improvement of productivity in Senegalese low input cattle systems.
425 LEES Working Papers 2016. SRUC, Edinburgh, UK. Retrieved on 04 April 2017, from
426 [https://www.sruc.ac.uk/downloads/file/3240/90_farmer_attitudes_to_the_improvement_o](https://www.sruc.ac.uk/downloads/file/3240/90_farmer_attitudes_to_the_improvement_of_productivity_in_senegalese_low_input_cattle_systems)
427 [f_productivity_in_senegalese_low_input_cattle_systems](https://www.sruc.ac.uk/downloads/file/3240/90_farmer_attitudes_to_the_improvement_of_productivity_in_senegalese_low_input_cattle_systems)

428 Şentürk B and Yalçın C 2008. Production losses due to endemic foot-and-mouth
429 disease in cattle in Turkey. *Turkish Journal of Veterinary and Animal Sciences* 32, 433–
430 440.

431 Shaw A, Hendrick G, Gilbert M, Mattioli R, Codjia V, Dao B, Diall O, Mahama C, Sidibé I
432 and Wint W 2006. Mapping the benefits: a new decision tool for tsetse and
433 trypanosomiasis interventions. Department for International Development, Animal Health
434 Programme, Centre for Tropical Veterinary Medicine, University of Edinburgh, UK and
435 Programme Against African Trypanosomiasis, Food and Agriculture Organization of the
436 United Nations, Rome, Italy.

437 Shaw A, Torr S, Waiswa C, Cecchi G, Wint W, Mattioli R and Robinson T 2013.
438 Estimating the costs of tsetse control options: An example for Uganda. *Preventive
439 Veterinary Medicine* 110, 290–303.

440 Tebug SF, Kamga-Waladjo AR, Ema PJN, Muyeneza C, Kane O, Seck A, Ly MT and Lo
441 M 2015. Cattle farmer awareness and behavior regarding prevention of zoonotic disease
442 transmission in Senegal. *Journal of Agromedicine* 20, 217–224.

443 Thior Y 2015. Estimation de la variabilite de la digestibilite et des emissions de methane
444 des regimes des ruminants en fonction de la saison sur parcours Sahelien. Masters
445 thesis, Inter-State School of Veterinary Science and Medicine (EISMV), Dakar, Senegal.

446 Udo H, Weiler V, Modupeore O, Viets T and Oosting S 2016. Intensification to reduce
447 the carbon footprint of smallholder milk production: Fact or fiction? *Outlook on
448 Agriculture* 45, 33–38.

449 Weiler V, Udo HM, Viets T, Crane T and De Boer IJ 2014. Handling multi-functionality of
450 livestock in a life cycle assessment: the case of smallholder dairying in Kenya. *Current
451 Opinion in Environmental Sustainability* 8, 29–38.

452 Young JR, Suon S, Andrews CJ, Henry LA and Windsor PA 2013. Assessment of
453 financial impact of foot and mouth disease on smallholder cattle farmers in Southern
454 Cambodia. *Transboundary and Emerging Diseases* 60, 166–174.

455

456

457

458

459

460

461

462

463

464

465

466

467

468

469

470 **Tables**

471 **Table 1** *Breed groups, into which households are categorised based on herd dominant*
 472 *breed*

Breed group	Description	Number of households
IZ	100% Zebu Gobra or Maure Low productivity, high resilience to local environment	120
IZ x GZ	25% to 50% Guzerat Guzerat recently introduced from Brazil, improved meat productivity.	40
IZ x BT	25% to 50% Montbeliarde or Holstein – Friesian Bos Taurus, high milk productivity, low resilience to local environment	46
BT	75% to 100% Montbeliarde or Holstein – Friesian	14

473 IZ = indigenous zebu; IZ x GZ = indigenous x Guzerat zebu cross; IZ x BT = indigenous zebu x taurine
 474 cross; BT = taurine

475 **Table 2** *Details of shortlisted mitigation measures*

MM	MM identification	Further description
Improved ration supplementation with GNC	GNC +5% (Increase GNC by 5%)	High protein feed resource, locally available as an agro-industrial by-product and present in 'baseline' rations at varying levels
Improved ration supplementation with PC	PC 30 / PC 40% (PC altered to 30 or 40% of the ration) PC +5 (Increase PC by 5%)	High energy feed resource, improves utilisation of poor quality roughages, likely to reduce enteric methane and increase animal productivity ¹ , present in 'baseline' rations at varying levels
Improvement to timing of hay making	Hay	Hay provides a feed resource for when there are shortages. Effective timing of haymaking can maximise protein content and digestibility ¹
Urea treat crop stovers in the ration	Urea treatment	Treating stovers with urea improves digestibility and protein content ¹
Remove LSD burden	LSD	<i>A capripoxvirus</i> , symptoms include skin nodules and fever, which limits animal productivity, vaccination possible ²
Remove FMD burden	FMD	Highly contagious virus, symptoms include fever and vesicular eruptions on feet and mouth, limits animal productivity, vaccination possible ²
Remove Tryps burden	Tryps	Tsetse fly transmitted parasite, causing substantial reduction to productivity ² , options for control available ³

476 MM = mitigation measure; GNC = groundnut cake; PC = purchased compound feed; LSD = lumpy skin disease; FMD = foot and mouth disease;

477 Tryps = trypanosomiasis

478 ¹See Lukuyu *et al.* (2012)

479 ²Blowey and Weaver (2003)

480 ³Bouyer *et al.* (2014)

481

482

483

484

485

486

487

488

489

490

491

492

493

494

495 **Table 3** Details of model parameter changes assumed for the application of each mitigation measure. Disease burdens for
 496 lumpy skin disease and foot and mouth disease are for infected individuals, whereas trypanosomiasis burdens are for a
 497 population

Details of model parameter changes										
DR (%)										
MM	Pop %	Milk yield	BW (%)	at birth	calves		young and adult years			FR (%)
		(%)			female	male	1-2	2-3	3+	
LSD	7.1 ¹	27.0 ²	17.0 ²	10.0 ²	10.0 ²	10.0 ²	10.0 ²	9.0 ²	9.0 ²	100.0 ³
FMD	6.9 ¹	22.0 ⁴	31.0 ⁴	9.00 ⁴	9.00 ⁴	9.00 ⁴	6.00 ⁴	5.0 ⁴	4.0 ⁴	100.0 ³
Tryps	na ⁵	7.1 ⁵	1.1 ⁵	17.3 ⁵	18.8 ⁵	15.8 ⁵	25.0 ⁵	20.0 ⁵	28.6 ⁵	6.0 ⁵
GNC	The proportion of groundnut cake is altered, other ration components change on a <i>pro rata</i> basis									
PC	The proportion of purchased concentrate feed is altered, other ration components change on a pro rata basis									
Hay	Natural pasture varies in nutritional value seasonally, as does the hay harvested. 'Baseline' hay nutritional value is assumed an average, and is improved to the optimum nutritional value of hay. 'Baseline': DE% = 43.6% ⁶ gN/kg DM = 15.4 ⁶ Optimum: DE% = 46.5% ⁷ gN/kg/DM = 16.1 ⁷									
Urea treatment	Urea treatment increases both the digestibility (+29%) and nitrogen content (+126%) of millet stover ⁸ 'Baseline': DE% = 33.2% ⁶ gN/kg DM = 9.6 ⁶ Improved: DE% = 42.8% ⁸ gN/kg/DM = 21.7 ⁸									

498 MM = mitigation measure; Pop % = prevalence of disease in population; BW = impact of disease on body weight; DR = impact of disease on death
499 rate; FR = impact of disease on fertility rate; LSD = lumpy skin disease; FMD = foot and mouth disease; Tryps = trypanosomiasis; GNC =
500 groundnut cake; PC = purchased compound feed; DE% = ration digestibility (expressed as percentage of gross energy); gN/kg/DM = grams of
501 nitrogen per kg of dry matter.

502 ¹See MEPA (2014; 2013)

503 ²Derived from: Daher (1994), Abutarbush *et al.* (2015), Ayelet *et al.* (2013), Hailu *et al.* (2015), Gari *et al.* (2011), Salib and Osman (2011)

504 ³Assumed if animal had LSD or FMD it would not be fertile, fertility burden equal to respective disease prevalence (Knight-Jones and Rushton
505 2013; Gari *et al.* 2011)

506 ⁴Derived from: Bayissa *et al.* (2011), Lyons *et al.* (2015), Rufael *et al.* (2008), Young *et al.* (2013), Şentürk and Yalçın (2008), Jemberu *et al.*
507 (2014), Onono *et al.* (2013)

508 ⁵data taken from Shaw *et al.* (2006) details burden for a herd/population with trypanosomiasis

509 ⁶See Jarrige (1989)

510 ⁷See Thior (2015)

511 ⁸See Chenost and Kayouli (1997)

512 **Table 4** *Details of parameters identified by the sensitivity analysis to have most influence on emission intensity (Ei)*
 513 *(kgCO₂eq/kg product) result*

Breed group	Mgt	Ei milk	Ei meat	DE%	Milk yield (kg/cow/year)	BW (kg)	FR (%)
IZ	poorer	12.9	44.4	55.0	323.4	294.4	57.1
	better	7.0	25.7	56.5	876.9	316.8	63.2
IZ x GZ	poorer	11.6	40.7	55.2	411.0	301.7	54.5
	better	6.1	22.9	55.3	988.8	309.2	70.6
IZ x BT	poorer	6.7	25.6	57.2	937.1	333.3	54.5
	better	3.8	17.5	58.6	2032.1	413.6	70.6
BT	better	4.1	16.3	62.5	2197.8	432.8	63.2

514 IZ = indigenous zebu; IZ x GZ = indigenous x Guzerat zebu cross; IZ x BT = indigenous zebu x taurine cross; BT = taurine;

515 Mgt = Level of management; DE% = ration digestibility (expressed as percentage of gross energy); BW = adult cow body weight; FR = adult cow
 516 fertility rate

517

518

519

520

521

522 **Table 5** Abatement potential (AP) (tCO₂eq/herd/year), percentage reduction to 'baseline' emissions (%), and cost-
523 effectiveness (CE) (\$/tCO₂eq) for mitigation measures applied to typical herds with eight cows; '-' represents where
524 measures were not applicable to the respective system or the application increased absolute emissions.

Breed group	Mgt	Result	Mitigation measure ¹								
			LSD	FMD	Hay	Tryps	Urea treatment	GNC +5%	PC 30%	PC 40%	PC +5%
IZ	poorer	AP	2.2	1.6	0.2	1.3	1.0	1.9	0.6	-	-
		%	4.8	3.7	0.4	2.9	2.1	4.2	1.2	-	-
		CE	-100.2	-113.7	-31.5	-23.6	61.1	248.6	4060.4	-	-
	better	AP	2.0	1.4	0.5	1.2	0.9	1.9	0.3	-	-
		%	4.1	3.0	1.0	2.6	1.9	3.9	0.7	-	-
		CE	-149.0	-175.2	-76.5	-42.9	40.5	258.0	6809.2	-	-
IZ x GZ	poorer	AP	2.0	1.5	0.4	1.2	0.9	1.6	0.5	-	-
		%	5.1	3.8	0.9	3.1	2.2	4.0	1.2	-	-
		CE	-111.4	-130.4	-45.4	-39.8	43.3	199.3	3056.6	-	-
	better	AP	1.6	1.5	0.5	1.1	1.1	2.0	-	-	0.1
		%	3.4	3.2	1.0	2.3	2.2	4.2	-	-	0.3
		CE	-254.7	-232.6	-79.6	-83.1	62.7	378.1	-	-	6439.4
IZ x BT	poorer	AP	1.5	1.5	0.7	1.0	0.6	1.6	-	-0.3	-
		%	3.5	3.4	1.6	2.3	1.3	3.7	-	-0.8	-
		CE	-245.7	-218.3	-82.6	-84.0	34.4	247.2	-	-	-
	better	AP	1.8	1.6	1.6	1.2	0.3	2.2	-	-0.9	-
		%	2.9	2.6	2.6	1.9	0.5	3.5	-	-1.5	-
		CE	-383.7	-360.5	-125.0	-129.3	-16.2	215.4	-	-	-
BT	better	AP	1.4	2.1	0.9	1.1	1.3	1.8	-	-0.1	-
		%	2.4	3.5	1.6	2.0	2.2	3.1	-	-0.2	-
		CE	-300.2	-260.4	-207.0	-142.6	-112.8	51.4	-	-	-

525 IZ = indigenous zebu; IZ x GZ = indigenous x Guzerat zebu cross; IZ x BT = indigenous zebu x taurine cross; BT = taurine; Mgt = Level of
526 management; LSD = lumpy skin disease; FMD = foot and mouth disease; Tryps = trypanosomiasis; GNC = groundnut cake; PC = purchased
527 compound feed.

528 ¹See Table 2 and Table 3

529

530

531 **Figure captions**

532 **Figure 1** *Overview of methodology*

533

534 **Figure 2** *Emission intensity (kgCO₂eq/kg protein) (bars, left y-axis) and herd protein production (diamonds, right y-axis) by*
535 *breed group and management level, based on calculations for a typical herd with eight cows.*

536

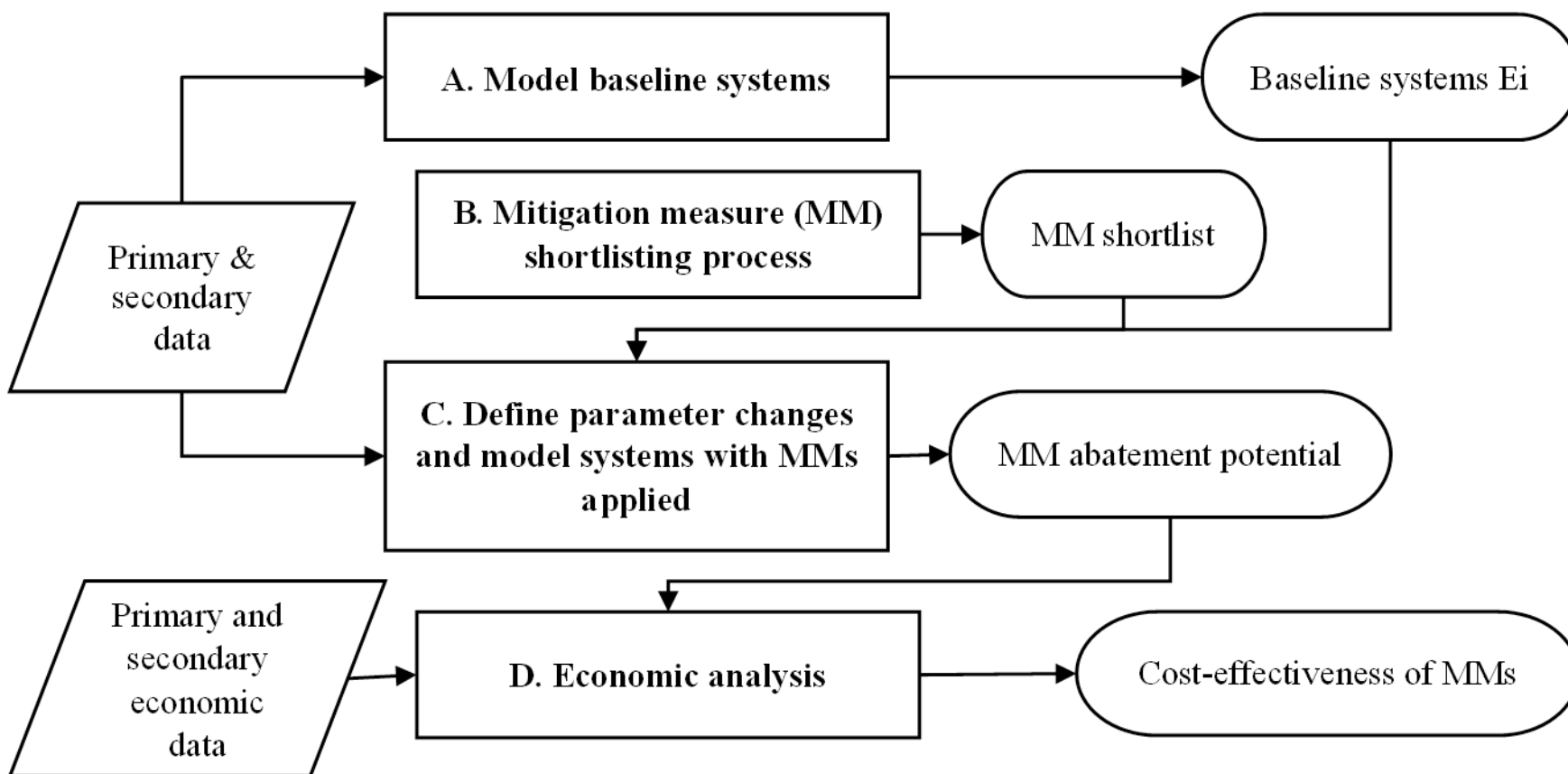
537 **Figure 3** *Annual marginal abatement cost curve (MACC) for a typical herd (with eight adult cows), of indigenous zebu x*
538 *taurine cross breed group with a better level of management. Measures are applied as a package in order from left to right,*
539 *with interactions between measures considered. The dashed reference line illustrates a social cost of carbon of*
540 *\$31/tCO₂eq. 1 tonne of CO₂eq is equal to approximately 2% of total herd GHG emissions. Measures appear to not be*
541 *applied in order of cost-effectiveness (CE); however, they are applied as a package from left to right, with the order*
542 *defined by their CE when modelled in isolation.*

543

544 Figure 1

545

546

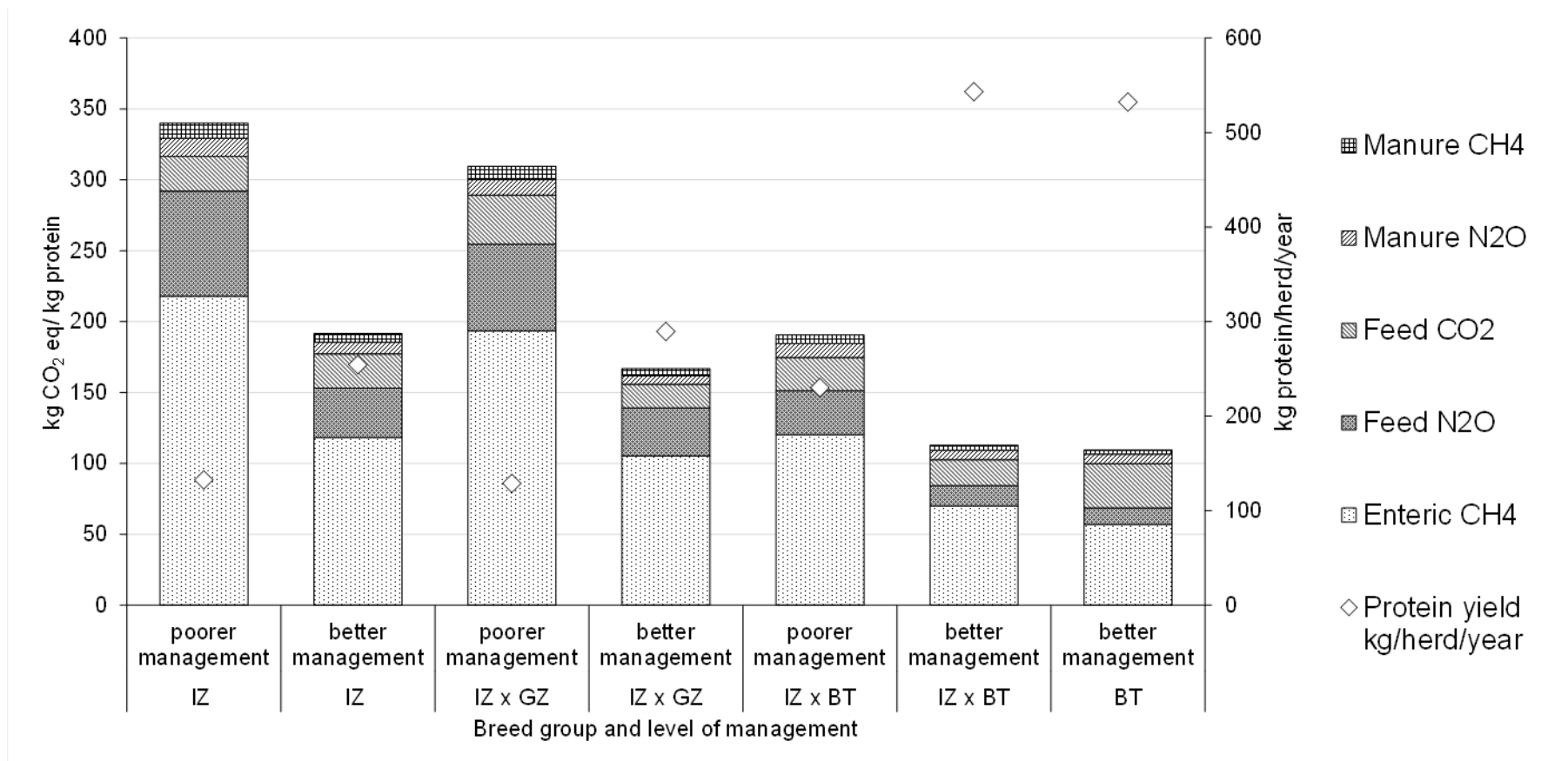


547

548

549

550 Figure 2



551

552

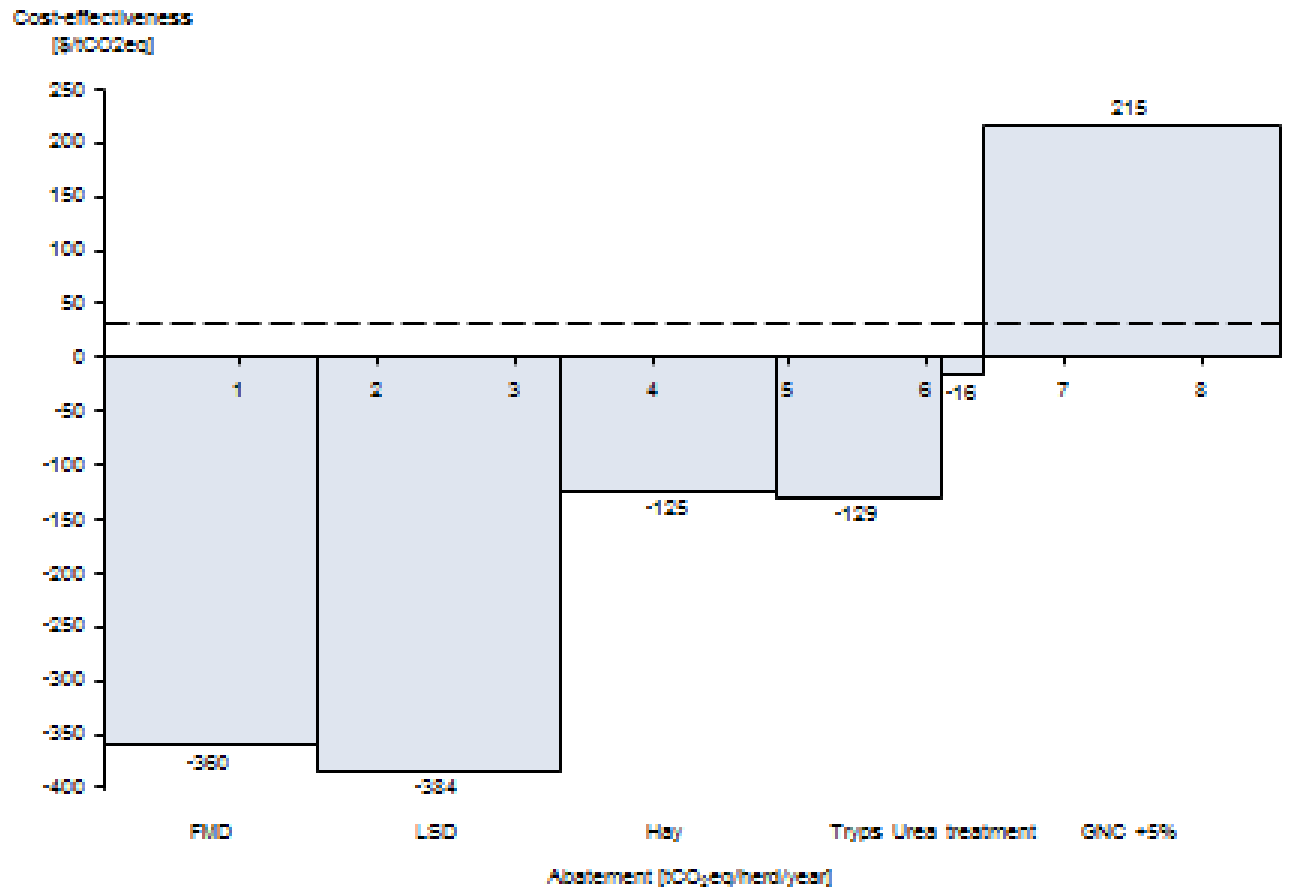
553

554

555

556

557 Figure 3



558

559

560

561

562

563

564

565