Life-cycle impact assessment of organic and non-organic grass-fed beef production in Japan

メタデータ	言語: eng
	出版者:
	公開日: 2019-05-14
	キーワード (Ja):
	キーワード (En):
	作成者: 堤, 道生
	メールアドレス:
	所属:
URL	https://repository.naro.go.jp/records/2533

1

1
2
3
4
5
6
7 Life-cycle impact assessment of organic and non-organic grass-fed beef production in Japan

8
9
10
11
12
13
14
15

16 Michio Tsutsumi [a],[*], Yutaka Ono [b], Hideki Ogasawara [b], Masayuki Hojito [b]

17
18
19 [a] *Division of Japanese Black Cattle Production and Wildlife Management Research, Western*
20 *Region Agricultural Research Center, National Agriculture and Food Research Organization*
21 *(NARO), 60 Yoshinaga, Kawai-cho, Ohda, 694-0013, Shimane, Japan*
22 [b] *Field Science Center, School of Veterinary Medicine, Kitasato University, 35-1, 23-Bancho,*
23 *Towada, Aomori 034-9628, Japan*

24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44 * Corresponding author.
45 *E-mail address: mcot@affrc.go.jp (M. Tsutsumi).*

46 **Abstract**

47   Beef production, especially when based on the calves from suckler cows, typically has the

48 greatest environmental impacts among various livestock production systems. Conventional beef

49 production in Japan uses a large amount of imported concentrate feed, which results in

50 substantial environmental impacts. Yakumo Farm, located in northern Japan, produces grass-fed

51 beef using only farm-grown feed. Pesticides and chemical fertilizer were used in the past, but

52 organic management was introduced at the farm more recently. We assessed the environmental

53 impacts of grass-fed beef production at Yakumo Farm before and after the introduction of

54 organic management (hereafter, non-organic and organic, respectively), and a conventional

55 Japanese (hereafter, conventional) system using life-cycle assessment (LCA). We constructed the

56 LCA models based on data collected at Yakumo Farm, from the literature and from LCA

57 databases. The LCA system boundaries included feed production, transportation, processing,

58 animal management, enteric fermentation, and manure and its management. The functional unit

59 was defined as 1 kg of cold carcass weight of beef steers. The impact of each system was

60 determined regarding its potential contribution to global warming, acidification, and

61 eutrophication, as well as its energy consumption. Both the organic and non-organic systems had

62 much smaller impacts on acidification, eutrophication, and energy consumption than the

63 conventional system. The impact on global warming associated with the organic system was

64 equivalent to the conventional system, whereas for the non-organic system it was greater than for

65 the conventional system. Generally, the exclusion of the process of feed transportation reduced

66 the environmental impacts. The use of chemical fertilizer increased the global warming-related

67 impact in the non-organic system. Therefore, we concluded that introducing organic management

68 to Yakumo Farm mitigated its environmental impacts. Our results provide implications for

69   mitigating the environmental impacts caused by beef or other livestock production not only in

70   Japan, but also in other countries depending upon imported feed.

71

72   *Keywords:*   Beef production, Environmental impact, Feed transportation, Life-cycle assessment,

73   Livestock production, Organic farming

74

1. Introduction

Sustainability of food production has attracted much attention in recent decades. In general, livestock products bear greater environmental burdens than food of plant origin (excluding greenhouse crop production, for example) (Mogensen et al., 2009; Schmidinger and Stehfest, 2012). de Vries and de Boer (2010) compared the environmental impacts of several livestock products, and reported that beef production used the most land and energy, and had the greatest global warming potential (GWP). It was also found that beef production systems based on the calves from suckler cows had greater environmental impacts than those based on dairy calves (de Vries et al., 2015). Nguyen et al. (2010) evaluated the environmental impacts of the EU suckler-based beef production system and compared them with those of the conventional Japanese system (Ogino et al., 2004, 2007). They reported that these systems had similar levels of GWP, but that the Japanese system had greater acidification and eutrophication potentials, and used much more energy. Peters et al. (2010) compared the GWP and energy use among beef production systems in Australia and other countries including Japan. According to their comparisons, Japanese beef production had the greatest GWP and used, by far, the most energy. Other research also indicated the considerable GWP (Stackhouse-Lawson et al., 2012) and energy consumption (Ogino et al., 2016) of Japanese beef production. Thus, beef produced in Japan can be regarded as a food with a great environmental load.

Suckler-based beef production in Japan is divided into the cow-calf and fattening (backgrounding and finishing) stages. In the conventional beef production system in Japan, the fattening stage has greater GWP than the cow-calf stage (Ogino et al., 2004, 2007), which contrasts with systems in the USA (Lupo et al., 2013; Pelletier et al., 2010; Stackhouse-Lawson et al., 2012), Canada (Beauchemin et al., 2011), and Uruguay (Picasso et al., 2014). Japanese

98   beef production typically uses a non-grazing housing system that relies largely on concentrate

99   feed especially during the fattening stage. Most concentrate feed used in Japanese livestock

100   production (88% in 2013, based on total digestible nutrient) is imported from other countries,

101   mainly the USA, although most roughage (77%) is produced within Japan. Hence, the

102   environmental impacts of Japanese beef production are enhanced not only by production of a

103   large amount of concentrate feed but also by feed transportation.

104   Life-cycle assessment (LCA) is a widely accepted method for evaluating and comparing the

105   environmental impacts of livestock production systems (de Vries and de Boer, 2010). Numerous

106   comparative LCAs among different beef production systems have been conducted to assess the

107   mitigation of environmental impacts (reviewed by de Vries et al., 2015). de Vries et al. (2015)

108   compared the environmental impacts of beef produced in contrasting systems in terms of the type

109   of diet fed to fattening calves (roughage- or concentrate-based) and the type of production

110   (organic or non-organic). They reported smaller GWP and energy consumption for concentrate-

111   based systems compared with roughage-based systems, whereas no clear patterns were found in

112   their acidification and eutrophication potentials. In addition to this, GWP and energy

113   consumption were smaller in organic systems than in non-organic systems, but organic systems

114   had greater acidification and eutrophication potentials.

115   Yakumo Experimental Farm, Field Science Center, Kitasato University School of Veterinary

116   Medicine (Yakumo Farm, hereafter) is located in southwest Hokkaido in northern Japan

117   (42°15'N, 140°8'E). Yakumo Farm produces grass-fed beef using only farm-grown feed, which is

118   distributed as "Kitasato Yakumo Beef" (hereafter, Yakumo Beef). Yakumo Farm had used

119   pesticides and chemical fertilizer until 2002 and 2004, respectively. Since 2005, the farm has

120   been managed organically. Subsequently, Yakumo Beef was certified as Japan's first organic

121   beef. Yakumo Beef has few environmental impacts from feed transportation (only within the

122   farm), in contrast to beef produced using the conventional Japanese system, which is based on

123   concentrate feed that is transported long distances, such as from the USA to Japan. Large

124   amounts of carbon dioxide, sulfur oxides and nitrogen oxides are emitted and energy is used to a

125   large degree in the process of feed transportation (Table S1). Therefore, it is hypothesized that

126   Yakumo Beef has smaller GWP, acidification and eutrophication potentials, as well as less

127   energy consumption than conventionally produced beef, in contrast to the conclusions derived by

128   de Vries et al. (2015). However, like other grass-fed beef production systems (Capper, 2012;

129   Lupo et al., 2013; Pelletier et al., 2010), production efficiency (body weight gain) at Yakumo

130   Farm is lower than that of the conventional system (Table 1), which might enhance the

131   environmental impacts per product weight, as reported in previous studies (Beauchemin et al.,

132   2011; Lupo et al., 2013; Pelletier et al., 2010).

133   In this study, we used LCA to evaluate the environmental impacts of grass-fed beef produced

134   at Yakumo Farm before and after the introduction of organic management (hereafter, non-organic

135   and organic, respectively), and compared the results with those for the conventional Japanese

136   (hereafter, conventional) system.

137

138   **2. Materials and methods**

139   *2.1. Goal and scope definition*

140   The targets of this analysis were steers. The varieties of cattle were Japanese Shorthorn and

141   its crossbreeds at Yakumo Farm, and Japanese Brown in the conventional system whose market

142   weight has been similar to that of Yakumo Beef in recent years. Note that the targeted varieties of

143   cattle are different from the Japanese Black variety. The environmental impacts of Japanese

144 Black beef production have already been assessed in several studies (Ogino et al., 2004, 2007;

145 Oishi et al., 2013; Tsutsumi et al., 2014). Although the environmental impacts of conventional

146 production of Japanese Brown beef were assessed by Tsutsumi et al. (2017), the methods of

147 calculation are slightly different from those employed in this study. In the current study, the

148 functional unit was defined as 1 kg of cold carcass steer weight.

149   The data for the production systems (including the cattle growth curve, grazing schedule,

150 resources used for pasturing, forage nutrient values and reproductive performance) of Yakumo

151 Farm were obtained for 1997–2004 for the non-organic system and 2006–2013 for the organic

152 system. The data for the conventional system were obtained from Nihon Akaushi Touroku

153 Kyoukai (2000), NARO (2009, 2010) and the Agriculture and Livestock Industries Corporation

154 (2016). The system boundaries included feed production, feed processing, feed transportation,

155 animal management, enteric fermentation, and excreta and its management. All resources used in

156 the system were considered, such as the energy used to produce the chemical fertilizer; however,

157 capital goods, such as barns and machinery, were not considered.

158 *2.2. Production systems of Yakumo Farm*

159   In the organic and non-organic systems at Yakumo Farm, the following issues were common.

160 All cattle were grazed on pastures from mid-May to mid-October without supplemental feed, and

161 managed in barns during the remaining period (Tables 1 and 2). In the barns, the cattle were fed

162 farm-grown roughage. The lactating period was six months.

163   There were no differences in age at first calving and calving interval between the organic and

164 non-organic systems, whereas calving occurrences per cow in the non-organic system were

165 higher than those in the organic system. Both grass silage and hay were used as roughage in the

166 non-organic system, but only grass silage was used in the organic system. The fattening period

167 was longer and both live weight at slaughter and carcass weight were heavier in the organic

168 system than the non-organic system. The fattening period has been gradually extended since 2003

169 based on a management decision.

170   In the non-organic system, chemical fertilizer was applied onto the pastures used for both

171 harvesting (Table S2) and grazing (Table S3). To obtain 1 t of dry matter (DM) of roughage, 12.4

172 kg of nitrogen (N), 10.0 kg of phosphate (P_2O_5), and 18.3 kg of potassium (K_2O) were used. In

173 addition, 8.7 kg of magnesium (MgO), 12.7 kg of fused magnesium phosphate, 44.3 kg of

174 magnesia lime, 3170 kg of manure and 89.9 kg of other organic fertilizer were applied. To

175 produce 1 t DM of roughage in the organic system, 3007 kg of manure and 21.7 kg of other

176 organic fertilizer were applied.

177   We estimated the herbage intake based on the required total digestible nutrients (TDN)

178 (NARO, 2009). NARO (2009) stated that the energy needed for the maintenance of cattle on a

179 sloping pasture is 25% higher than their maintenance energy in a feedlot. We determined the

180 required TDN based on this assumption. We estimated the milk intake by calves based on NARO

181 (2009).

182 *2.3. Conventional beef production system*

183   In the conventional system, all cattle were managed in barns during all seasons. The cattle

184 were fed concentrate mixture, grass hay and rice straw (Table 2). The lactating period was three

185 months. Compared with Yakumo Farm, the age of first calving was earlier but the calving

186 interval was longer in the conventional system. The steers were fattened to 761 days of age (722

187 kg in body weight and 465 kg in cold carcass weight). The milk intake by calves was estimated

188 based on NARO (2009).

189 *2.4. Life-cycle inventories*

190   In the following analysis, we used MiLCA software, which was specifically designed to

191   conduct LCA by the Japan Environmental Management Association for Industry (JEMAI, 2012).

192   We took into account the energy consumption and emissions of carbon dioxide (CO_2), methane

193   (CH_4), nitrous oxide (N_2O), ammonia (NH_3), nitrogen dioxide (NO_2), nitrogen oxide (NO_x),

194   sulfur dioxide (SO_2) and sulfur oxide (SO_x). To construct the life-cycle inventories, we used the

195   Inventory Database for Environmental Analysis (IDEA) via MiLCA.

196   Resource consumption data for feed production and processing were based on the records of

197   Yakumo Farm and previous studies (Kim et al., 2014; Kobayashi and Yuyama, 2006; NIAES,

198   2003; Pelletier et al., 2010; Pradhan et al., 2011). In the conventional system, all concentrate feed

199   and grass hay for calves was produced in the USA, whereas the other roughage used was farm-

200   grown (Table 2). Evaluations of the direct emissions from soil were carried out based on the

201   literature listed in Table 3 (Bouwman et al., 2002; GIO, 2016; Hayashi et al., 2011, 2009, 2008;

202   IPCC, 2006; Shimizu et al., 2013). Tables S3–S5 provide the life cycle inventories for all feed

203   production used in our analysis.

204   The enteric CH_4 emissions were estimated according to age for calves under five months

205   (Sekine et al., 1986), or DM intake for other cattle (Shibata et al., 1993), as described in Table 4.

206   Both in Yakumo Farm and the conventional systems, composting was carried out by piling

207   without forced aeration, a method employed at most Japanese beef farms (GIO, 2016). The

208   amounts of excreted organic matter and N were estimated according to IPCC (2006) and Terada

209   et al. (1998), respectively. Based on these sources and the literature listed in Table 4 (Bouwman

210   et al., 2002; GIO, 2016; Groot Koerkamp et al., 1998; Shiraishi et al., 2004), the emissions of

211   CH_4, NH_3, and N_2O from excreta and its treatment were estimated.

212   We also accounted for the environmental loads associated with animal management

213   including lighting of the cattle barn, feed preparation, and carrying manure within the farm

214   according to the Agriculture, Forestry and Fisheries Technology Information Society (AFFTIS,

215   2000).

216   *2.6. Allocation of environmental impacts*

217   We allocated the environmental impacts of by-product feeds according to their prices, where

218   the ratio of allocated environmental impacts per unit weight was the same as the ratio of their

219   prices. We conducted this allocation assuming that (1) unhulled rice and rice straw yielded 600

220   and 750 kg/ha, respectively, and the ratio of prices was 25:2 for unhulled rice to rice straw; (2)

221   780 kg of flour and 220 kg of bran were made from 1000 kg of wheat, and the ratio of prices was

222   81:19 for flour to bran; and (3) 205 kg of soybean oil and 795 kg of soybean meal were made

223   from 1000 kg of soybean, and the ratio of prices was 72:28 for soybean oil to soybean meal.

224   *2.7. Transportation*

225   We calculated the environmental loads of transporting the feed produced in the USA as

226   follows (see Table S1). Grass hay, alfalfa hay, maize and soybean meal were transported to the

227   port of New Orleans by truck (50 km) and by freighter ship along the Mississippi River (1385

228   km). Wheat bran was transported to the port of Portland by truck (50 km) and rail (2765 km).

229   The marine transportation distances from New Orleans and Portland to Japan (the port of

230   Tomakomai) were 18053 and 8997 km, respectively (Japan Coast Guard, 2011). The land

231   transportation distance by truck within Japan was 210 km.

232   *2.8. Life-cycle impact assessment*

233   Four impact categories (global warming, acidification, eutrophication and energy

234   consumption) were adopted for the impact assessment of this study. We calculated the GWP for

235   a 100-year time horizon (for CO_2: 1, CH_4: 25 and N_2O: 298; IPCC, 2007), the acidification

236   potential (AP for SO_2 and SO_x: 1.00, NH_3: 1.88, and NO_2 and NO_x: 0.70; Heijungs et al., 1992)

237   and the eutrophication potential (EP for NH_3: 0.35, and NO_2 and NO_x: 0.13; Heijungs et al.,

238   1992).

239

240   **3. Results**

241   *3.1 Global warming potential*

242   The non-organic systems had the greatest GWP, and there was little difference between

243   GWPs for the conventional and organic systems (Table 5). The top contributor to the total GWP

244   for all three systems was enteric fermentation, but the subsequent contributors differed among the

245   systems. Excreta (including composting) was the second strongest contributor in the organic

246   system, whereas in the non-organic system it was roughage production. Feed transportation was

247   the second largest contributor in the conventional system, followed by concentrate production.

248   The GWPs caused by each process of animal management, enteric fermentation and excreta in

249   the non-organic system were equivalent to those in the organic system. However, the GWPs

250   caused by feed production were different between the organic and non-organic systems, which

251   was reflected in the difference between the total GWPs. Because a large amount of CO_2 is

252   emitted during the production of chemical fertilizers (Tables S3 and S4), the use of chemical

253   fertilizer increased GWP in the non-organic system.

254   *3.2 Acidification and eutrophication potentials*

255   The conventional system had the greatest AP, which was about three times as high as the

256   corresponding values in the organic and non-organic systems (Table 6). In the conventional

257   system, the top contributor was feed transportation followed by excreta and concentrate feed

258 production. Excreta contributed the most to total AP in the organic and non-organic systems. AP

259 caused by feed production was smaller in the organic than in the non-organic system, whereas

260 AP caused by excreta was smaller in the latter, resulting in smaller AP in the non-organic system

261 than in the organic system. The EP results were similar to those of the AP results (Table 7). The

262 conventional system had the greatest EP, with values about twice those of the organic and non-

263 organic systems. The top and subsequent contributors to EP in each production system were the

264 same as those for AP. The EP was smaller in the non-organic system than in the organic system

265 for the same reason as mentioned above for AP.

266 *3.3 Energy consumption*

267 The conventional system had by far the greatest energy consumption, which was 553% and

268 61% greater than the values for the organic and non-organic systems, respectively (Table 8). In

269 the conventional system, feed transportation was the top contributor followed by concentrate

270 production. Roughage production contributed the most to total energy consumption in the non-

271 organic and organic systems. Energy consumption of feed production in the non-organic system

272 was 365% greater than that of the organic system. This difference was caused by the use or non-

273 use of chemical fertilizer (see Tables S3 and S4) and, similar to GWP, it was reflected in the

274 difference in total energy consumption.

275

276 **4.   Discussion**

277 *4.1. Testing the hypothesis*

278 The organic and non-organic systems had smaller AP, EP, and energy consumption than the

279 conventional system (Tables 6–8). Although the organic system exhibited a slightly greater GWP

280 than the conventional system (Table 5), the difference was insignificant as the order could be

281 changed depending on the methodological choices. For example, we recalculated the GWP for

282 the feed transportation process except for transportation within Japan using other emission

283 factors (EPA, 2014). Consequently, the GWP for feed transportation in the conventional system

284 was estimated as 7.5 kg CO_2e per carcass weight, and then the total GWP was calculated as 29.4

285 kg CO_2e whereas it was 29.3 kg CO_2e in the organic system. The non-organic system had a

286 greater GWP than the conventional system. Overall, these results support the hypothesis that

287 Yakumo Beef has smaller environmental impacts than conventionally produced Japanese beef. In

288 the conventional system, the process of feed transportation was the top contributor to all the

289 environmental categories assessed. Without the process of feed transportation, GWP in the

290 conventional system would be the smallest, and its AP and EP would lie between those of the

291 organic and non-organic systems. Therefore, if the environmental impacts caused from feed

292 transportation are not taken into account, a comparison of the results for GWP, AP and EP

293 between Yakumo Farm and the conventional system would support the conclusions of de Vries

294 et al. (2015). However, in the present circumstances, it is not feasible to increase production of

295 concentrate feed within Japan.

296 　　Even if the process of feed transportation is ignored, the conventional system has a greater

297 energy consumption than the organic system, in contrast to the result by de Vries et al. (2015).

298 This is because of the large amount of concentrate used in conventional Japanese beef production

299 (cf. production in the EU; Nguyen et al., 2010, for example). The process of concentrate

300 production accounted for 33% of the energy used in the conventional system and, similarly, feed

301 transportation accounted for 51% (Table 8). Chemical fertilizer production was the top

302 contributor to the energy consumption in the process of concentrate production (Table S5).

303 Therefore, to reduce the energy consumption in Japanese beef production, it is necessary to

304 reduce not only the amount of imported feed but also the amount of chemical fertilizer used for

305 feed production. To mitigate the environmental impacts, introduction of a beef production system

306 based on roughage without chemical fertilizer use, such as that at Yakumo Farm in recent years,

307 or with a reduced usage level, is a feasible option in Japan or other countries that depend on

308 imported concentrate feed such as South Korea or the United Arab Emirates.

309

310 *4.2. Effects of the introduction of organic management*

311   The GWP and energy consumption were smaller in the organic system than in the non-

312 organic system (Tables 5 and 8). Only in the process of feed production were GWP and energy

313 consumption different between the organic and non-organic systems. The fattening period was

314 longer in the organic system than in the non-organic system, which enhanced emissions of CH_4

315 from enteric fermentation and N_2O from excreta for production of one steer although these

316 differences were not reflected in the emissions per carcass weight. The non-organic system used

317 chemical fertilizer (Tables S2 and S3), which raised the productivity of feed per unit area, when

318 compared with the organic system. However, its livestock productivity (reproduction rate and

319 weight gain) was not much higher than that of the organic system (Table 1), which led to greater

320 GWP and energy consumption per unit of beef in the non-organic system. The AP and EP were

321 slightly greater in the organic than in the non-organic system (Tables 6 and 7). This was mainly

322 because of the extension of the fattening period, which increased NH_3 emissions from excreta

323 and composting (Table 1; see Ogino et al., 2004), rather than the introduction of organic

324 management.

325   Masuda and Yamamoto (2013) performed LCA for organic and conventional roughage

326 production in Japan, and reported that organic grass production had smaller GWP, AP and EP

327   but greater energy consumption. Their conclusion for energy consumption is contrary to our

328   analysis (Table S2). In our study, energy consumption of grass production (harvesting) in the

329   organic system was 1.21 GJ per 1 t DM, whereas it was 5.32 GJ per 1 t DM in the non-organic

330   system. The inconsistency was presumably because they used an input-output analysis to

331   calculate the indirect energy consumption, whereas we used a process analysis.

332   It has been reported that the effects of introducing organic management into beef production

333   on the environmental impacts differ depending on the environmental categories and production

334   systems assessed (de Vries et al., 2015; Meier et al., 2015). The previous comparisons were made

335   among farms with organic or non-organic management. This study is the first work to assess the

336   environmental impacts of beef production for the same farm before and after the introduction of

337   organic management. Our analysis has the advantage of having little dependence on the

338   variability in land productivity and livestock performance of the farm.

339   The results indicate that introducing organic management at Yakumo Farm has yielded

340   beneficial effects on the environment. Hojito et al. (2016) assessed N flow at Yakumo Farm

341   under organic management. They showed that the soil N stock increased gradually and N export

342   was low, and concluded that it is possible to balance N inputs with N outputs in beef production

343   without the need for feed or fertilizer imports. Currently, Yakumo Beef trades at prices as high as

344   premium beef from Japanese Black, which is known for its highly marbled meat. This high price

345   might be attributed to not only the quality of the meat, but also its environmental performance.

346   Therefore, beef production at Yakumo Farm under organic management can be considered

347   economically and environmentally sustainable.

348   Land use is also a crucial determiner of the sustainability of livestock production (de Vries

349   and de Boer, 2010). At Yakumo Farm, grass yield decreased after the introduction of organic

350   management from 5.3 to 3.5 t DM/ha/year (in pasture for harvesting only), and the number of

351   cattle slightly decreased from 263 to 256 head. Therefore, organic beef production at Yakumo

352   Farm may utilize more land per unit of beef than non-organic production, consistent with the

353   results of de Vries et al. (2015). In Japan, the area of abandoned cultivated land has been

354   increasing annually. It had reached 4230 km^2 by 2015, while the area of land still under

355   cultivation was 44700 km^2. The Japanese national and local governments have been promoting

356   the reuse of abandoned lands through the use of such land for cattle grazing (see Tsutsumi et al.,

357   2014, 2016, 2012). By reusing abandoned lands, it may be possible to expand organic beef

358   production in Japan.

359   *4.3. Comparison of our results with previous reports*

360   Environmental impacts in contrasting beef production systems have been assessed, and it is

361   well known that they vary largely among systems (de Vries et al., 2015). de Vries et al. (2015)

362   found that environmental impacts of beef could vary depending on the type of diet, origin of

363   calves and type of production; for example, systems using culled dairy calves had smaller

364   environmental impacts per unit of beef produced than suckler-based systems.

365   We compared the results of LCAs for suckler- and roughage-based (following the definition

366   of de Vries et al. (2015)) beef production systems including grass-fed and organic systems

367   (Beauchemin et al., 2011; Capper, 2012; Cardoso et al., 2016; Edwards-Jones et al., 2009; Lupo

368   et al., 2013; Mogensen et al., 2015; Nguyen et al., 2010; Nguyen et al., 2012; Ogino et al., 2016;

369   Pelletier et al., 2010; Ruviaro et al., 2015; Stackhouse-Lawson et al., 2012; Tsutsumi et al., 2017)

370   with our results for Yakumo Farm (Table 9). For the cases that used live weight as the functional

371   unit, we converted the live weight to carcass weight assuming the dressing percentage as 56%.

372   Among the listed cases, GWP in the organic system was at the intermediate level, but that in the

373   non-organic system was slightly greater. Similar results were found by comparing Yakumo Farm

374   and the listed grass-fed systems. The AP and EP values in both the organic and non-organic

375   systems were the lowest to third lowest of the listed cases, although only a small number of

376   studies assessed both AP and EP. This was partly because of differences in methodological

377   choices among the studies, such as the emission factors used for NH_3 from excreta and its

378   management. For example, Nguyen et al. (2012) assumed that 12% of excreted N in barns was

379   directly emitted as NH_3, and 6 % of the remaining N was also emitted as NH_3 through manure

380   management, whereas we assumed values of 6.39 and 2.38%, respectively (Table 4). Energy

381   consumption in the organic system was smaller than that of the listed cases, and was the greatest

382   in the non-organic system. Accordingly, based on the comparisons above, the introduction of

383   organic management at Yakumo Farm mitigated the GWP and energy consumption, leading to

384   their positions in the intermediate and smaller ranges, respectively. The GWP and energy

385   consumption largely varied among the listed cases for non-organic grass-fed beef production.

386   Pelletier et al. (2010) estimated GWP and energy consumption in grass-fed beef production

387   ("pasture" in Table 9) at 34.3 kg CO_2 equivalent (CO_2e) and 86.4 MJ per carcass weight (kg)

388   respectively, which were similar to the values in the non-organic system in our analysis.

389   However, Capper (2012) estimated them at 26.8 kg CO_2e and 12.3 MJ, respectively. These

390   differences might stem from the intensity of fertilization in grass production. In the grass

391   production system assumed by Pelletier et al. (2010), 112 to 168 kg of N fertilizer per hectare

392   was applied annually, whereas less than 1 kg was applied in Capper (2012). Under non-organic

393   management at Yakumo Farm, 55 kg of N fertilizer per hectare per year was applied to pastures

394   for harvesting. These results suggest that grass-fed beef production with intensive chemical

395   fertilizer application can increase GWP and energy consumption.

396

5. Conclusions

397

398   We performed a comparative LCA for grass-fed beef production at Yakumo Farm before

399   and after the introduction of organic management, and the conventional Japanese system, which

400   depends on imported concentrate feed. Both the organic and non-organic systems had much

401   smaller AP, EP and energy consumption than the conventional system. Generally, the exclusion

402   of feed transportation resulted in a reduction of these environmental impacts. The organic system

403   had an equivalent GWP, but the non-organic system had a greater GWP than the conventional

404   system. The use of chemical fertilizer increased the GWP in the non-organic system. The

405   comparison of environmental impacts for Yakumo Farm and other previously reported beef

406   production systems based on calves from suckler cows that are predominantly fed roughage

407   indicated that: (1) the non-organic system had a slightly greater GWP and the greatest energy

408   consumption; and (2) the organic system had an intermediate GWP and smaller energy

409   consumption. Therefore, we conclude that introducing organic management at Yakumo Farm

410   mitigated its environmental impacts. Our results provide implications for mitigating the

411   environmental impacts caused by beef or other livestock production not only in Japan, but also in

412   other countries depending upon imported feed.

413

421

422   **References**

423   AFFTIS, 2000. Investigation of Energy-Managing Agricultural Production System Development,

424   Tokyo.

425   Akaushi Touroku Kyoukai, 2000. Data for improving Japanese Brown Cattle.

426   http://www.akaushi.or.jp/kairyou_seika/kairyo_top.html (accessed 12.04.17).

427   Agriculture and Livestock Industries Corporation, 2016. Livestock and livestock product:

428   statistical data. Agriculture and Livestock Industries Corporation.

429   http://lin.alic.go.jp/alic/statis/dome/data2/e_nstatis.htm (accessed 12.04.17).

430   Beauchemin, K.A., Janzen, H.H., Little, S.M., McAllister, T.A., McGinn, S.M., 2011. Mitigation

431   of greenhouse gas emissions from beef production in western Canada: evaluation using farm-

432   based life cycle assessment. Anim. Feed Sci. Technol. 166, 663-677.

433   Bouwman, A.F., Boumans, L.J.M., Batjes, N.H., 2002. Estimation of global NH_3 volatilization

434   loss from synthetic fertilizers and animal manure applied to arable lands and grasslands. Global

435   Biogeochem. Cycles 16 (2) (art. no. 1024).

436   Capper, J.L., 2012. Is the grass always greener?: comparing the environmental impact of

437   conventional, natural and grass-fed beef production systems. Animals 2, 127-143.

438   Cardoso, A.S., Berndt, A., Leytem, A., Alves, B.J.R., de Carvalho, I.N.O., de Barros Soares,

439   L.H., Urquiaga, S., Boddey, R.M., 2016. Impact of the intensification of beef production in

440   Brazil on greenhouse gas emissions and land use. Agric. Syst. 143, 86-96.

441   de Vries, M., de Boer, I.J.M., 2010. Comparing environmental impacts for livestock products: a

442   review of life cycle assessments. Livest. Sci. 128, 1-11.

443   de Vries, M., van Middelaar, C.E., de Boer, I.J.M., 2015. Comparing environmental impacts of

444   beef production systems: a review of life cycle assessments. Livest. Sci. 178, 279-288.

445   Edwards-Jones, G., Plassmann, K., Harris, I.M., 2009. Carbon footprinting of lamb and beef

446   production systems: insights from an empirical analysis of farms in Wales, UK. J. Agric. Sci.

447   147, 707-719.

448   EPA (United States Environmental Protection Agency), 2014. Emission Factors for Greenhouse

449   Gas   Inventories.   https://www.epa.gov/sites/production/files/2015-07/documents/emission-

450   factors_2014.pdf (accessed 12.10.17).

451   GIO (Greenhouse Gas Inventory Office of Japan), Center for Global Environmental Research,

452   National Institute for Environmental Studies, 2016. National Greenhouse Gas Inventory Report

453   of Japan. Center for Global Environmental Research, National Institute for Environmental

454   Studies, Tsukuba, Japan.

455   Groot Koerkamp, P.W.G., Metz, J.H.M., Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath,

456   R.W., Short, J.L., White, R.P.P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K.H.,

457   Pedersen, S., Takai, H., Johnsen, J.O., Wathes, C.M., 1998. Concentrations and Emissions of

458   Ammonia in Livestock Buildings in Northern Europe. J. Agric. Eng. Res. 70, 79-95.

459   Hayashi, K., Koga, N., Fueki, N., 2011. Limited ammonia volatilization loss from upland fields

460   of Andosols following fertilizer applications. Agric. Ecosyst. Environ. 140, 534-538.

461   Hayashi, K., Koga, N., Yanai, Y., 2009. Effects of field-applied composted cattle manure and

462   chemical fertilizer on ammonia and particulate ammonium exchanges at an upland field.

463   Atmos. Environ. 43, 5702-5707.

464   Hayashi, K., Nishimura, S., Yagi, K., 2008. Ammonia volatilization from a paddy field following

465   applications of urea: rice plants are both an absorber and an emitter for atmospheric ammonia.

466   Sci. Total Environ. 390, 485-494.

467   Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener

468   Sleeswijk, A., Ansems, A.M.M., Eggels, P.G., van Duin, R., de Goede, H.P., 1992.

469   Environmental life cycle assessment of products: guide and backgrounds (Part 1). CML,

470   Leiden.

471   Hojito, M., Adachi, Y., Ono, Y., Ogasawara, H., 2016. Nitrogen flow on an organically managed

472   beef farm in Hokkaido, Japan. Soil Sci. Plant Nutr. 62, 545-552.

473   IPCC, 2006. 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National

474   Greenhouse Gas Inventories. Institute for Global Environmental Strategies, Hayama, Japan.

475   IPCC, 2007. Climate Change 2007: the Physical Science Basis. IPCC, Geneva, Switzerland.

476   Japan Coast Guard, 2011. Distance Table. Japan Hydrographic Association, Tokyo.

477   JEMAI, 2011. LCA Software MiLCA. JEMAI, Tokyo.

478   Kim, S.D., Dale, B.E., Keck, P., 2014. Energy requirements and greenhouse gas emissions of

479   maize production in the USA. BioEnergy Res. 7, 753-764.

480   Kobayashi, H., Yuyama, Y., 2006. An estimation of lifecycle energy consumption and GHG

481   emission for imported forage supply to Japan by district. J. Environ. Inf. Sci. 35(3), 45-53.

482   Lupo, C.D., Clay, D.E., Benning, J.L., Stone, J.J., 2013. Life-cycle assessment of the beef cattle

483   production system for the Northern Great Plains, USA. J. Environ. Qual. 42, 1386-1394.

484   Masuda, K., Yamamoto, Y., 2013. Comparison of environmental performance between

485   conventional and organic roughage production: grass and silage maize. Agroecol. Sust. Food

486   Syst. 37, 1120-1143.

487 Meier, M.S., Stoessel, F., Jungbluth, N., Juraske, R., Schader, C., Stolze, M., 2015.

488   Environmental impacts of organic and conventional agricultural products: are the differences

489   captured by life cycle assessment? J. Environ. Manage. 149, 193-208.

490 Mogensen, L., Hermansen, J.E., Halberg, N., Dalgaard, R., Vis, J.C., Smith, B.G., 2009. Life

491   cycle assessment across the food supply chain, in: Baldwin, C.J. (Ed.), Sustainability in the

492   Food Industry. Wiley-Blackwell, Ames, pp. 115-144.

493 Mogensen, L., Kristensen, T., Nielsen, N.I., Spleth, P., Henriksson, M., Swensson, C., Hessle,

494   A., Vestergaard, M., 2015. Greenhouse gas emissions from beef production systems in

495   Denmark and Sweden. Livest. Sci. 174, 126-143.

496 NARO (National Agriculture and Food Research Organization), 2009. Japanese Feeding

497   Standard for Beef Cattle (2008). Japan Livestock Industry Association, Tokyo.

498 NARO, 2010. Standard Tables of Feed Composition in Japan (2009). Japan Livestock Industry

499   Association, Tokyo.

500 Nguyen, T.L.T., Hermansen, J.E., Mogensen, L., 2010. Environmental consequences of different

501   beef production systems in the EU. J. Clean. Prod. 18, 756-766.

502 Nguyen, T.T.H., van der Werf, H.M.G., Eugène, M., Veysset, P., Devun, J., Chesneau, G.,

503   Doreau, M., 2012. Effects of type of ration and allocation methods on the environmental

504   impacts of beef-production systems. Livest. Sci. 145, 239-251.

505 NIAES (National Institute for Agro-Environmental Sciences), 2003. Life Cycle Assessment for

506   Environmentally Sustainable Agriculture, NIAES, Tsukuba, Japan.

507 Ogino, A., Kaku, K., Osada, T., Shimada, K., 2004. Environmental impacts of the Japanese beef-

508   fattening system with different feeding lengths as evaluated by a life-cycle assessment method.

509   J. Anim. Sci. 82, 2115-2122.

510   Ogino, A., Orito, H., Shimada, K., Hirooka, H., 2007. Evaluating environmental impacts of the

511   Japanese beef cow-calf system by the life cycle assessment method. Anim. Sci. J. 78, 424-432.

512   Ogino, A., Sommart, K., Subepang, S., Mitsumori, M., Hayashi, K., Yamashita, T., Tanaka, Y.,

513   2016. Environmental impacts of extensive and intensive beef production systems in Thailand

514   evaluated by life cycle assessment. J. Clean. Prod. 112, 22-31.

515   Oishi, K., Kato, Y., Ogino, A., Hirooka, H., 2013. Economic and environmental impacts of

516   changes in culling parity of cows and diet composition in Japanese beef cow-calf production

517   systems. Agric. Syst. 115, 95-103.Pelletier, N., Pirog, R., Rasmussen, R., 2010. Comparative

518   life cycle environmental impacts of three beef production strategies in the Upper Midwestern

519   United States. Agric. Syst. 103, 380-389.

520   Peters, G.M., Rowley, H.V., Wiedemann, S., Tucker, R., Short, M.D., Schulz, M., 2010. Red

521   meat production in Australia: life cycle assessment and comparison with overseas studies.

522   Environ. Sci. Technol. 44, 1327-1332.

523   Picasso, V.D., Modernel, P.D., Becoña, G., Salvo, L., Gutiérrez, L., Astigarraga, L., 2014.

524   Sustainability of meat production beyond carbon footprint: a synthesis of case studies from

525   grazing systems in Uruguay. Meat Sci. 98, 346-354.

526   Pradhan, A., Shrestha, D.S., McAloon, A., Yee, W., Haas, M., Duffield, J.A., 2011. Energy life-

527   cycle assessment of soybean biodiesel revisited. Trans. ASABE 54, 1031-1039.

528   Ruviaro, C.F., de Léis, C.M., Lampert, V.d.N., Barcellos, J.O.J., Dewes, H., 2015. Carbon

529   footprint in different beef production systems on a southern Brazilian farm: a case study. J.

530   Clean. Prod. 96, 435-443.

531   Schmidinger, K., Stehfest, E., 2012. Including CO_2 implications of land occupation in LCAs:

532   method and example for livestock products. Int. J. LCA 17, 962-972.

533   Sekine, J., Kondo, S., Okubo, M., Asahida, Y., 1986. Estimation of methane production in 6-

534   week-weaned calves up to 25 weeks of age. Jpn. J. Zootech. Sci. 57, 300-304.

535   Shibata, M., Terada, F., Kurihara, M., Nishida, T., Iwasaki, K., 1993. Estimation of methane

536   production in ruminants. Anim. Sci. Technol. 64, 790-796.

537   Shimizu, M., Hatano, R., Arita, T., Kouda, Y., Mori, A., Matsuura, S., Niimi, M., Jin, T.,

538   Desyatkin, A.R., Kawamura, O., Hojito, M., Miyata, A., 2013. The effect of fertilizer and

539   manure application on CH_4 and N_2O emissions from managed grasslands in Japan. Soil Sci.

540   Plant Nutr. 59, 69-86.

541   Shiraishi, M., Osada, T., Takimoto, E., Wakimoto, N., Kitamura, N., Okuda, K., 2004. Method

542   of controlling generation of nitrous oxide and methane. Bull. Okayama Prefect. Cent. Anim.

543   Husb. Res. 15, 70-75.

544   Stackhouse-Lawson, K.R., Rotz, C.A., Oltjen, J.W., Mitloehner, F.M., 2012. Carbon footprint

545   and ammonia emissions of California beef production systems. J. Anim. Sci. 90, 4641-4655.

546   Terada, F., Abe, H., Nishida, T., Shibata, M., 1998. Prediction of nitrogen excretion in finishing

547   steers. Anim. Sci. Technol. 69, 697-701.

548   Tsutsumi, M., Hikita, K., Takahashi, Y., Yamamoto, N., 2014. Life cycle assessment of beef

549   cow-calf systems with and without grazing on abandoned cultivated lands in Japan. Grassl. Sci.

550   60, 150-159.

551   Tsutsumi, M., Nakamura, Y.-N., Kaneko, M., Hayashi, Y., Tsubomi, H., Yamada, A.,

552   Kobayashi, R., 2017. Life cycle impact assessment of the year-round grazing system for

553   fattening Japanese Brown beef steers. J. Warm Reg. Soc. Anim. Sci. Jpn. 60, 27-35.

554   Tsutsumi, M., Takahashi, Y., Emoto, S., Ito, N., Otani, I., Matsumoto, K., 2016. Component-

555   based quantification and prediction of diet selection by cattle grazing on multi-species

556   communities. Grassl. Sci. 62, 12-20.

557   Tsutsumi, M., Takahashi, Y., Emoto, S., Ito, N., Sahara, S., Yoshimura, T., Watanabe, T., 2012.

558   Simple prediction of crude protein content in vegetation growing on abandoned cultivated land.

559   Grass Forage Sci. 67, 55-63.

560

561   Table 1

562   Description of the three beef production systems
563
564

	Yakumo Farm		Conventional
	Organic	Non-organic	
All cattle			
Grazing period per year (days)	168	168	0
Cow-calf			
Age at first calving (days)	779	779	757
Calving interval (days)	395	395	417
Calving occurrences per cow	7	9	9
Lactation period (months)	6	6	3
Steer			
Daily weight gain (kg)	0.63	0.65	0.95
Age at slaughter (days)	1089	885	761
Live weight at slaughter (kg)	724	615	722
Cold carcass weight (kg)	410	339	465

565

566 Table 2
567 Feed composition for producing one marketed steer including cow-calf, backgrounding and
568 finishing stages in the three beef production systems
569
570

	Yakumo Farm		Conventional
	Organic	Non-organic	
Feed produced in Yakumo Farm (kg dry matter)			
Grass (harvesting)	8157 [a]	6719 [b]	
Grass (grazing)	6785	5931	
Other farm-grown feed (kg)			
Italian ryegrass hay			2266
Rice straw			1437
Wild grass hay			515
Imported feed (kg)			
Maize			3098
Wheat bran			1330
Alfalfa hay			956
Soybean meal			833
Timothy hay			569

571
572 [a] Only silage.
573 [b] Silage and hay.
574

575 Table 3
576 Environmental loads associated with direct emissions of ammonia (NH_3), nitrous oxide (N_2O) and
577 methane (CH_4) from soil in feed production, emission factors and referenced literature
578
579

	Unit	Emission factor	Reference
In Japan			
Rice paddy			
NH_3	% NH_3-N	8.1	Hayashi et al. (2008)
N_2O	% N_2O-N	0.31	GIO (2016)
CH_4	kg CH_4/ha/year	439	GIO (2016)
Other arable systems			
NH_3 (chemical fertilizer)	% NH_3-N	0.08	Hayashi et al. (2011)
NH_3 (manure)	% NH_3-N	0.8	Hayashi et al. (2009)
N_2O (chemical fertilizer)	% N_2O-N	1.39	Shimizu et al. (2013)
N_2O (manure)	% N_2O-N	0.46	Shimizu et al. (2013)
In the USA			
NH_3	% NH_3-N	7	Bouwman et al. (2002)
N_2O	% N_2O-N	1	IPCC (2006)

580
581 [1] The units, % NH_3-N and % N_2O-N, indicate the proportion of N emitted as NH_3 and N_2O,
582 respectively, relative to the applied amount of N.

583   Table 4
584   Environmental loads associated with enteric emission, excreta and composting for ammonia (NH_3),
585   nitrous oxide (N_2O) and methane (CH_4), emission factors or estimation equations, and referenced
586   literature
587
588

Source	Unit	Emission factor or estimation equation	Reference
Enteric emission			
CH_4 (<5 months of age)	g/day	$-1.2 + 3.4 \times W$	Sekine et al. (1986)
CH_4 (others)	L/day	$-17.766 + 42.793 \times DMI - 0.849 \times DMI^2$	Shibata et al. (1993)
Excreta			
CH_4 (on pasture)	kg	$VS \times 0.095\%$	GIO (2016)
CH_4 (in barn)	kg	$VS \times 0.13\%$	GIO (2016)
NH_3 (on pasture)	% NH_3-N	3.8	Bouwman et al. (2002)
NH_3 (in barn)	% NH_3-N	6.39	Groot Koerkamp et al. (1998)
N_2O (on pasture)	% N_2O-N	0.684	GIO (2016)
Composting			
NH_3	% NH_3-N	2.38	Shiraishi et al. (2004)
N_2O	% N_2O-N	1.6	GIO (2016)

589
590   [1] W: age in weeks.
591   [2] DMI: dry matter intake per day (kg).
592   [3] VS: volatile solid (kg), estimated according to IPCC (2006).
593   [4] Amount of excreted nitrogen was estimated according to Terada et al. (1998).
594   [5] The units, % NH_3-N and % N_2O-N, indicate the proportion of N emitted as NH_3 and N_2O,
595   respectively, compared with the N contained in excreta.
596

597 Table 5
598 Global warming potential of the three beef production systems, and the contribution of each process
599 and substance (kg carbon dioxide equivalent per kg of cold carcass steer weight)
600
601

	Yakumo Farm		Conventional
	Organic	Non-organic	
Total	29.3	35.1	28.9
Process			
Roughage production (farm-grown)	2.8	8.4	1.9
Roughage production (USA)			0.3
Concentrate production (USA)			3.8
Feed transportation			7.0
Animal management	0.3	0.3	0.4
Enteric fermentation	21.7	22.1	12.3
Excreta and composting	4.5	4.4	3.2
Substance			
Methane (CH_4)	22.2	22.7	13.3
Carbon dioxide (CO_2)	2.0	5.6	11.2
Nitrous oxide (N_2O)	5.1	6.8	4.3

602

603 Table 6
604 Acidification potential of the three beef production systems, and the contribution of each process
605 and substance (g sulfur dioxide equivalent per kg of cold carcass steer weight)
606
607

	Yakumo Farm		Conventional
	Organic	Non-organic	
Total	115.9	103.5	325.7
Process			
Roughage production (farm-grown)	10.0	13.1	1.6
Roughage production (USA)			4.3
Concentrate production (USA)			24.4
Feed transportation			218.2
Animal management	0.1	0.1	0.2
Excreta and composting	105.9	90.3	77.0
Substance [a]			
Ammonia (NH_3)	115.1	99.9	103.6
Nitrogen oxide (NO_x)	0.6	1.7	104.0
Sulfur dioxide (SO_2)	0.2	1.6	2.0
Sulfur oxide (SO_x)	0.1	0.4	116.1

608
609 [a] The values contributed by nitrogen dioxide (NO_2) were lower than 0.01 in all systems.
610

611　Table 7
612　Eutrophication potential of the three beef production systems, and the contribution of each process
613　and substance (g phosphate equivalent per kg of cold carcass steer weight)
614
615

	Yakumo Farm		Conventional
	Organic	Non-organic	
Total	20.31	17.84	37.50
Process			
Roughage production (farm-grown)	1.71	1.97	0.23
Roughage production (USA)			0.74
Concentrate production (USA)			4.06
Feed transportation			18.94
Animal management	0.02	0.02	0.02
Excreta and composting	18.58	15.85	13.52
Substance [a]			
Ammonia (NH_3)	20.20	17.53	18.19
Nitrogen oxide (NO_x)	0.10	0.31	19.31

616
617　[a] The values contributed by NO_2 were lower than 0.01 in all systems.
618

619 Table 8
620 Energy consumption of the three beef production systems and the contribution of each process (MJ
621 per kg of cold carcass steer weight)
622
623

	Yakumo Farm		Conventional
	Organic	Non-organic	
Total	29.1	117.9	190.1
Process			
Roughage production (farm-grown)	24.3	113.3	18.2
Roughage production (USA)			6.5
Concentrate production (USA)			62.8
Feed transportation			97.1
Animal management	4.8	4.6	5.6

624 Table 9

625 Comparison of environmental impacts of suckler- and roughage-based beef production systems (per kg of cold carcass weight)

626

Reference	Country	Description	Grass-fed	Organic	GWP (kg CO$_2$e)	AP (g SO$_2$e)	EP (g PO$_4$e)	Energy (MJ)
This study	Japan	Organic	Yes	Yes	29.3	115.9	20.3	29.1
	Japan	Non-organic	Yes	No	35.1	103.5	17.8	117.9
Edwards-Jones et al. (2009) [a]	UK	Conventional	No	No	27.7			
	UK	Extensive	No	No	85.0			
Pelletier et al. (2010) [a]	USA	Pasture	Yes	No	34.3		253.6	86.4
	USA	Backgrounding/Feedlot	No	No	28.9		212.5	80.4
Nguyen et al. (2010)	EU	Suckler cow-calf	No	No	27.3	210.0		59.2
Beauchemin et al. (2011)	Canada	Increased use of forages	No	No	23.1			
Capper (2012)	USA	Grass-fed	Yes	No	26.8			12.3
Nguyen et al. (2012)	France	Standard	No	No	27.8	169.0	98.0	64.8
	France	With omega-3 and linseeds	No	No	27.7	173.0	98.0	68.4
Stackhouse-Lawson et al. (2012)	USA	With stocker phase	No	No	22.6			
Lupo et al. (2013)	USA	Grassfed	Yes	No	31.5	299.1	35.1	
Ruviaro et al. (2015) [a]	Brazil	Natural grass	Yes	Yes	76.1			
	Brazil	Improved	Yes	No	41.6			
	Brazil	Supplemented	No	No	50.6			
Mogensen et al. (2015)	Denmark	Beef breed intensive, DK	No	No	23.1			
	Denmark	Beef breed extensive, DK	No	No	29.7			
	Sweden	Beef breed intensive, SE	No	No	25.4			
Cardoso et al. (2016)	Brazil	Pasture forage	Yes	Yes	49.6			
	Brazil	With protein and/or energetic supplements	No	No	31.0			
Ogino et al. (2016) [a]	Thailand	Extensive	Yes	No	25.0	83.9	53.6	6.3
Tsutsumi et al. (2017)	Japan	Grazing	No	No	27.8	153.2	20.3	134.2

627

628 [a] Because live weight was used as functional unit in these studies, we converted the live weight to carcass weight assuming the dressing

629 percentage as 56%.

630 [1] GWP: global warming potential; AP: acidification potential; EP: eutrophication potential; CO$_2$e: carbon dioxide equivalent; SO$_2$e: sulfur

631 dioxide equivalent; PO$_4$e: phosphate equivalent.