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ORIGINAL ARTICLE

Assessment and Mitigation of Methane Emissions from Livestock Sector in Pakistan

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Abstract
The study examined Pakistan's livestock sector to assess the scale of GHG emissions and identified feasible technical interventions through which GHG particularly methane can potentially be reduced. Life Cycle Assessment of emissions from livestock production supply chain for the year 2014 was performed using Global Livestock Environment Assessment Model (GLEAM-i, version 2) developed by FAO. Annual emissions from the livestock sector were estimated at 404.2 million ton CO_2 eq., representing carbon dioxide 6.6%, methane 70.6% and nitrous oxide 22.8%. Enteric methane averaged 63.4% of total emissions. Feed production and processing, manure management and energy use contributed 25%, 11% and 1%, respectively to the total sector emissions. Carbon footprint of milk from cows and buffalo was 184.9 against global average of 110.0 kg CO_2-eq/kg milk protein and that of beef and mutton was 606.4 against the global average of 235 CO_2-eq/kg meat protein. The emission intensity of chicken meat and eggs were lowest 49.6 and 20.8 kg CO_2-eq/kg protein, respectively and compared to global averages. Buffaloes produced maximum GHG followed by cattle, goats, sheep and poultry. Mitigation interventions in the form of improved fodder, herd heath and genetics reduced methane intensity ranging from 14.6 to 43.2% compared to baseline. This was associated with 25–100% increase in milk yield and 10–65% in meat supply above baseline scenarios. The strong inverse correlation between methane intensity and milk yield suggested that efforts to enhance productivity reduce carbon footprint of the livestock products thus achieving the dual goals of protecting environment and food security.

Keywords GHG emissions · Methane · Mitigation · Livestock production systems · Pakistan

1 Introduction

The role of livestock in achieving food security and rural poverty reduction is well recognized (FAO, 2009; Hristov et al. 2013). However, in the face of 70% rise in demand for animal source food to the year 2050 and that most of this increase shall require to enhance livestock yield by 60–80% (Alexandratos and Bruinsma 2012; FAO 2016) poses a key issue for sustainable development of the livestock sector. The situation is more challenging in developing countries including Pakistan where the natural resources are limited and adverse impact of climate change on agricultural productivity is getting pronounced. Livestock is regarded both as culprit and victim of climate change. Globally this sector contributes to 14.5% of total human-induced GHG emissions (IPCC 2014b) and represents over 80% of the total emission from agriculture sector (Tubiello et al. 2013) highlighting the fact that emissions related to direct human consumption of food crops is 20% compared to 80% from livestock.

Methane which is 21 times more potent than carbon dioxide is the single most abundant emission from ruminant animals and share 90% of the net sector emission. Methane accounted for about 16 percent of global greenhouse gas emissions in 2015 and during last decade has risen sharply in rapidly developing regions of Asia (IPCC 2014a). More recent revised calculation show that methane emission from livestock is 11% higher than was estimated previously (Wolf et al. 2017) posing an additional challenge in the struggle to restrain global warming.

Pakistan holds livestock number over 186 millions growing at unchecked average rate of 3.3% annually. The predominant smallholder system where more than 80% of the livestock is fragmented in small units of less than five in number poses a big challenge in implementation of

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development activities. Based on the assessment performed elsewhere under similar farming systems (FAO 2017), the increasing number with poor productivity of livestock in Pakistan is supposed to emit large amount of GHG than normally perceived. There has been no focused study conducted in Pakistan on assessment of emissions from livestock supply chain. The information published in various international and national reports appear superficial and incomplete and estimated with simple approach without recognizing the complex multilateral aspects of livestock farming in Pakistan. This questions the validity of national emission data for agriculture which is at the fore front of the country's INDCS as part of the global commitment to lessening of global warming. Although livestock as subsector of agriculture is blamed for large emissions, these can be reduced varying from 18 to 63% through efficiency improvement interventions related to genetics, feeds and health as the fundamental biological pillar of livestock production systems (Jabbar and Ahuja 2017; Habib et al. 2016; Gerber et al. 2013a). The responses, however, vary among regions and countries depending on the livestock species, their numbers, productivity, farming systems and several other factors. Therefore, each country has to perform own investigations starting from the assessment of baseline emissions covering the whole livestock production supply chain. Livestock professionals in Pakistan have not yet generated such country level data. The present study was performed to quantify GHG emissions from livestock production supply chain at farm level with the objective to set a baseline of reference year 2014 for the country which could be further refined and updated periodically. The study also explored potential of various mitigation interventions as part of the future development plan. The ultimate aim is to provide evidence based information to concerned departments, ministry and policy makers in the country for helping formulating effective mitigation action plan for combating emissions from the agriculture sector.

2 Materials and Methods

Total GHG emissions from national livestock and poultry sector of Pakistan for the year 2014 were estimated from cradle to farm gate using the downloadable version-2 of Global Livestock Environmental Assessment Model (GLEAM-i 2016) developed by FAO. The system boundary of cradle to farm gate encompasses all backend processes in livestock and poultry production chain up to the farm gate where the animals or products leave the farm and include production and supply of farm inputs and on-farm production activities. GLEAM is a spatially explicit model that represents biophysical processes and activities along livestock supply chains using a life cycle assessment approach. The model quantifies GHG emissions resulting from production of the main livestock commodities such as milk and meat from cattle, buffalo, sheep and goats and eggs and meat from chicken in different production systems. The model estimate main sources of emissions such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) from feed production to enteric methane, manure emissions and embedded energy. The emissions are expressed in mass based CO_2-equivalents (CO_2-eq). The model calculates emission per unit of commodity protein referred as emission intensity. It considers typology of farming system. In case of ruminant livestock emissions from grazing system and mixed systems are assessed and for poultry the systems are differentiated into backyard and commercial broiler and layers. Detail particulars and principles of the GLEAM are described by Gerber et al. (2013a) and Opio et al. (2013). The full description of GLEAM including variables and equations is also available from http://www.fao.org/gleam/resources.

Primary data on country's animal numbers for the year 2014 were estimated from the inter-census growth of livestock during 1996 and 2006 (GOP 1996, 2006). The data on herd structure, distribution of animals between the grazing and mixed production systems, feed resources and feeding practices were extracted from the country report (FAO 2013, Unpublished). Data on reproduction parameters, per animal milk yield, body weight, mortality and ration composition were obtained from various national reports and literature and further verified through consultation with local subject experts. The assessment does not include land use change related to pasture expansion because of non-availability of local specific data. All milk was converted to fat and protein corrected milk (FPCM) with 4.0% fat and 3.3% protein, using the following formula (FAO 2010);

$$\text{FPCM kg} = (\text{raw milk kg} \times (0.337 + 0.116 \times \text{fat contents\%} + 0.06 \times \text{protein contents\%})$$

For investigating potential of mitigation options, three interventions pertaining to feed, health and breed were selected and evaluated individually and in combination as a "package" in dairy cows and buffaloes. Data and information on the impact of selected interventions on productive, reproductive and health performance of dairy animals were extracted from literature, reports and through personal communication with the local experts. Separate calculations on GLEAM were performed for the baseline scenario and then for each mitigation intervention. Carbon footprint of milk and meat and changes in their yield were compared to the baseline scenario. The criteria used for selecting interventions included the potential for improving production efficiency, feasibility of adoption by local farmers and the potential to reduce total GHG and enteric methane emission intensities under current farm condition in the country.

3 Results and Discussion

3.1 Quantification of GHG Emissions

Total GHG emission from the livestock and poultry sector in Pakistan during the year 2014 was estimated at 404.2 million ton and composed of CO_2 6.6%, N_2O 22.8% and CH_4 70.6%. Methane and N_2O, as the dominant emissions, have more powerful global warming impact compared to CO_2 (IPCC 2014b).The major sources that contributed to livestock emissions on CO_2-eq basis were enteric CH_4 63%, feed related emission 25%, manure management 11% and energy use 1% (Fig. 1). The present estimate of net emissions from country's livestock is much higher than reported by Kaleem and Ijaz (2016) and the difference is due to methodology used. Kaleem and Ijaz (2016) used Tier one approach by multiplying livestock numbers with fixed emission factors according to guidelines of IPCC (1997). While in the present study a Tier two simulation tool GLEAM developed by FAO specifically for livestock was used. The inventories calculated with Tier one method provide crude estimate of livestock emissions. Tier two based inventories use information on the animal's feed intake or gross energy intake to estimate emissions and closely reflect country's farming system and productivity (GRA 2016).

In line with the present findings, globally CH_4 is considered as the principal GHG produced by livestock (Gerber et al. 2013a, Opio et al. 2013). Two major sources of CH_4 in livestock farming include that arising from feed digestion and generated during manure storage. These together were estimated at 285.3 million ton or 71% of sector total emission with a 90% share coming from enteric fermentation. These findings closely agree with Gerber et al. (2013a) who reported that globally about 90% of the CH_4 was produced by digestive fermentation in the ruminant livestock and 10% sourced from the management of stored manure. Garg et al. (2016) estimated enteric CH_4 from dairy cattle and buffalo in India ranged from 66.8 to 78.7% of total emission. Enteric CH_4 represents losses of energy to animals (Hristov et al. 2013) and add to lowering productivity. Wide variation in CH_4 emission experienced with current livestock raising systems in the country suggests large opportunity for mitigation achievable through improved feeding. Both CH_4 and N_2O emissions from manure can be reduced through proper storage and processing techniques but such end of the pipe mitigations may not be a priority at present where culminating sources of these GHG deserve the primary focus. Feed processing and transportation generated significant emission and accounted for 25% of the sector net emissions. Because of large number of ruminant livestock and greater volume of land based feed they consume, the feed processing and transportation related emissions were double of that associated with poultry production. The carbon footprint of direct and indirect energy use was minimal to the extent of 1% of total emissions and about two-third was sourced from dairy production. In contrast, energy use contributed 20% to the total sector emission at global level (Gerber et al. 2013a) and may explain the high energy use in industrialized livestock systems of developed countries included in the assessment.

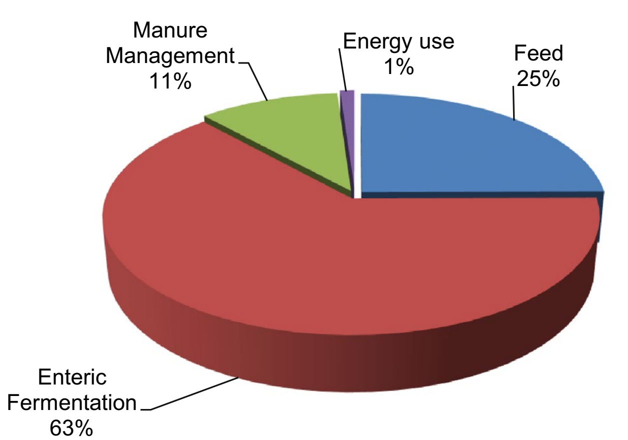


Fig. 1 GHG emission (CO_2-eq.) by source from livestock sector of Pakistan

Results in Table 1 summarize CH_4 emission by production systems. Cattle and buffalo in the mixed crop-livestock system while sheep and goats in the grazing system were responsible for higher CH_4 emission.

The higher emission in mixed system was associated with better productivity while poor feed supply in the grazing system attributed to elevated CH_4 emission. Overall species comparison revealed that buffaloes were responsible for producing major part (51%) of the net CH_4 emission followed by cattle. Sheep and goats produced to a minimum extent and shared 3.3–12.6% while contribution by poultry production was negligible (0.02%). This trend was parallel to absolute annual GHG emission per animal calculated as 3.9, 5.6, 0.3, 0.7 and 0.1 1000 ton CO_2-eq, in cattle, buffaloes, sheep, goats and poultry, respectively. Garg et al. (2016) also found that total GHG and CH_4 emissions from buffaloes were higher than cattle in Indian dairy system.

Table 1 Methane emissions (million ton CO_2-eq) from livestock in grazing and mixed systems

	Grazing system	Mixed system	Total	Share %
Cattle	25.41	56.97	82.38	32.2
Buffalo	13.05	119.94	132.99	51.9
Sheep	7.30	1.09	8.39	3.3
Goats	22.34	9.97	32.31	12.6
Total	68.10	187.97	256.07	100.0

3.2 Productivity and Emission Intensities

Annual yield of milk and meat is reported in Table 2. Fat and protein corrected milk (FPCM) was estimated at 65.5 million ton. Meat was supplied from both dairy and non-dairy systems estimated at 2.6 million ton annually.

These national estimates are close to the values reported officially for the same year 2014 (GOP 2014-15). Meat in the dairy system is a co-product and sourced from surplus adult and growing cattle and buffaloes and culled animals while in the non-dairy system the herds are primarily managed for meat production. Due to relatively large number of livestock and better feeding and reproductive management, annual meat supply of 1.6 million ton from dairy system exceeded that of non-dairy herd (1.1 million ton). Several reasons contributed to low performance of animals in the non-dairy systems and included inadequate feed from poor grazing lands, high morbidity and mortality and poor fertility. In the nondairy system large herd sizes of unproductive animals are generally maintained for sale at need and serve as financial security for the farmers. As such number of heads rather than production output remains farmer's choice in this system.

Emission intensity (EI) is the amount of GHG emissions generated per unit of commodity produced by the animals and explain carbon footprint of the product. As shown in Table 2, average EI of meat from dairy herds was 10 times lower than that of non-dairy herd (175.5 vs.1037.1 kg CO_2-eq/kg meat protein). This suggests that currently livestock in the nondairy system as meat producer are inefficient with high carbon footprint and marked as hotspot for mitigation. This may require shift from subsistence to specialized feedlot farming supported by access to market. The present estimate of EI of meat supply from both the systems was higher than global averages. Gerber et al. (2013a) reported average EI of beef and mutton was 290 and 180 kg CO_2-eq/kg meat protein, respectively, while EI of milk from cows and small ruminants averaged 90 and 130 kg CO_2-eq/kg milk protein, respectively. The overall carbon footprint of mutton from small ruminants in both the systems was less than beef and supports the regional findings of Opio et al. (2013).The comparison explains high carbon footprint of producing milk and meat in Pakistan and warrant mitigation. The analysis also indicates that dairy system is more efficient than pure meat (non-dairy) system because dairy herds produce both milk and meat while non-dairy herd primarily supply meat.

Table 2 Annual production of milk and meat, total GHG emission and emission intensity in different species managed in two distinct production systems

Production systems	Species	Production (× 1000 Tonnes)		Total emissions CO_2-eq. × 1000 ton	Average emission intensity (kg CO_2-eq/kg protein)	
		[a]Milk	[b]Meat		Milk	Meat
Dairy	Cattle	24,799	687	109,523	156.2	197.4
	Buffalo	39,444	687	128,248	205.6	173.9
	Sheep	58	6	1027	190.1	130.1
	Goats	1157	172	18,681	188.0	201.3
	Total/Avg.	65,458	1552	257,479	184.9	175.7
Non- dairy	Cattle	–	161	30,196	–	1749.9
	Buffalo	–	364	70,415	–	1339.2
	Sheep	–	87	11,774	–	565.1
	Goats	–	401	31,619	–	494.1
	Total/Avg.	–	1014	144,004	–	1037.1

[a]Fat and protein corrected milk (FPCM)

[b]Meat as carcass weight

Table 3 Annual production and emission intensities of eggs and chicken meat production

	Backyard	Commercial broilers	Commercial layers	Total
Production eggs (× 1000 ton)	161	0	386	547
Production meat (× 1000 ton)	10	420	27	474
Total emissions CO_2-eq. (× 1000 ton)	614	945	1203	2762
Emission intensity egg (kg CO_2-eq/kg protein)	18.8	0	22.9	20.8
Emission intensity meat (kg CO_2-eq/kg protein)	82.4	24.8	41.6	49.6

Poultry production contributed little (0.68%) to the total GHG emission and annually produced 474,000 ton chicken meat which accounted for 16% of total meat produced at country level. The average EI of poultry meat and eggs were 49.6 and 20.8 kg CO_2-eq/kg commodity protein, respectively (Table 3) and compared close to global average EI of 40 and 30 kg CO_2-eq/kg protein, respectively (Gerber et al. 2013a).

3.3 Mitigation Options

Methane from enteric fermentation is the single largest emission produced by ruminant livestock as discussed earlier and has been the focus of applying mitigation options by several workers (Garg et al. 2016; Gerber et al. 2013a; Pryce and Veerkamp 2010; Hristov et al. 2013; Knapp et al. 2014; Opio 2017; Wolf et al. 2017). In the present study, three different mitigation interventions were investigated for their potential to reduce CH_4 emission in dairy cows and buffaloes in mixed crop-livestock system. These were identified as improved fodder supply, vaccination for preventive health care and breed improvement. A combination of all three interventions in the form of a single package was also evaluated. The criteria for selecting the above options were based on relevancy to current dairy farming, adoptability and that these were included in the government action plan for dairy development. Changes in enteric CH_4 emission intensity in response to the selected interventions are illustrated in Fig. 2. Associated increase in milk and meat yields is shown in Fig. 3. Improving feed quality is considered as one of the most effective ways of mitigating enteric CH_4 emissions (Hristov et al. 2013, Opio 2017). According to Gerber et al. (2013a) an increase of 1% in digestibility due to improved feeding leads to a 4% increase in weight gain in young stock, 5% increase in milk yields and 4% decrease in age at first parturition. Based on this assumption a 40% increase in fodder supply in dairy rations reduced CH_4 intensity (kg CO_2-eq/

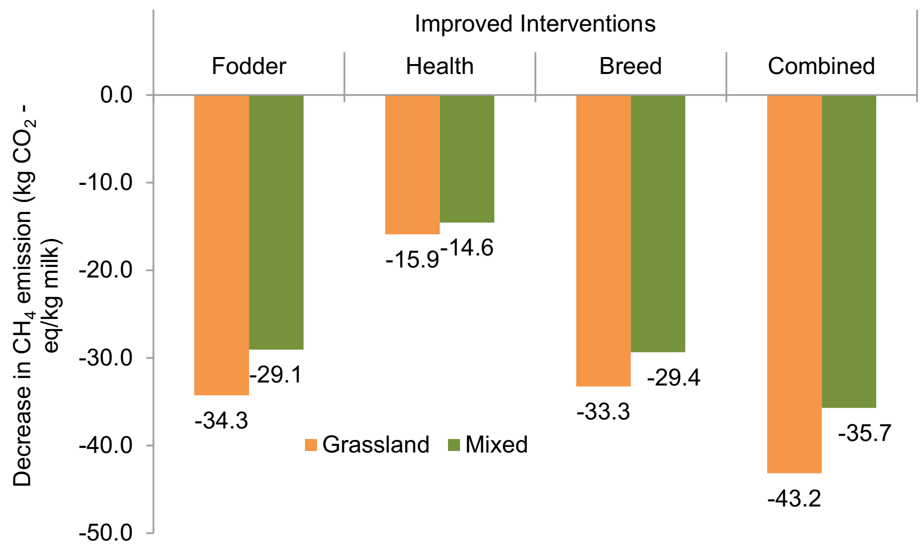


Fig. 2 Decrease in enteric methane emission intensity of fat-protein corrected milk (FPCM) in dairy cows and buffaloes compared to baseline in response to selected farm interventions in grazing and mixed crop-livestock systems

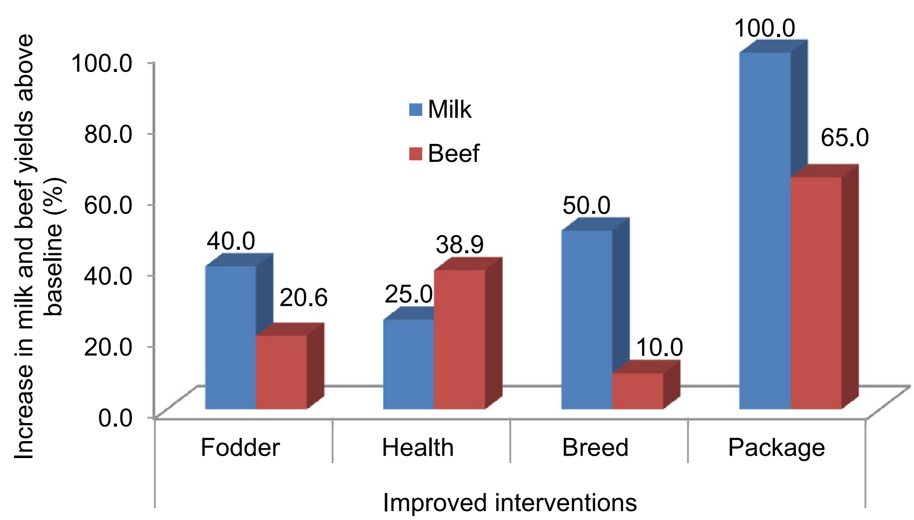


Fig. 3 Increase in average fat-protein corrected milk (FPCM) and beef production above baseline in cattle and buffaloes in response to selected farm interventions

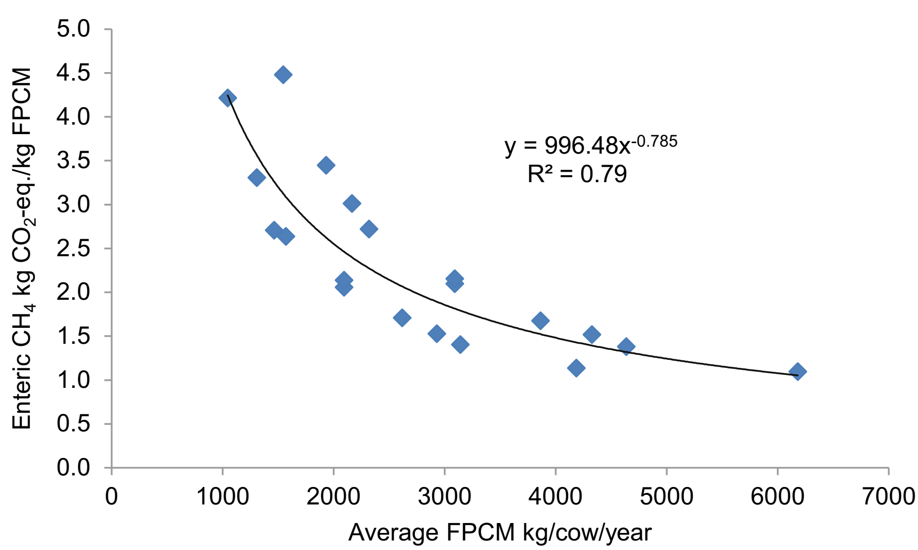
kg milk protein) between 29.4 and 39.1% and was associated with 40% increase in milk yield compared to baseline. Garg et al. (2016) found that enteric CH_4 emissions (g/kg milk yield) was reduced by 15–20% in lactating cows when offered feed that was more digestible. Digestibility of poor quality feed can be improved through various chemical and biological treatments, but due to low farm compatibility, these were not adopted in past by local farmers. Enhancing fodder supply vertically using improved seeds is a viable and proven option to fill the wide yield gap (Dost 2003).

Adequate health care increases herd productivity and reduce GHG emission by reducing mortality, morbidity, production losses and unproductive emissions from animals (FAO 2013; Hristov et al. 2013). We estimated that with preventive health care CH_4 intensity could be reduced by approximately 15% compared to baseline and would support 25% increase in milk yield. Enhancing genetic potential is universally considered most critical to dairy development because it improves fertility, reduces puberty age and increases productivity. Assuming breed improvement would cause 50% increase in milk yield (Pryce and Veerkamp 2010), the abatement in emission intensity of enteric CH_4 in the present case ranged from 29.4 to 33.3% compared to baseline and was close the mitigation response obtained with improved fodder (Fig. 3). The findings indicate that enhancing the genetic potential of the animal has large scope as a mitigating strategy but it is equally important not to import high genetic potential animals into our local climates and management environments of smallholder system in rural areas where high-producing imported cows cannot attain their potential due to heat stress, health issues and inadequate feed supply. Cross breeding of local with exotic genetics and selective breeding among native dairy breeds such as Sahiwal, Red Sindhi and Cholistani are more appropriate to breed improvement program because of their better adaptability to local harsh conditions and diseases. Farmers opting for keeping cows of improved genetic will always enhance feed quality and will resort to better health care for achieving the desired milk production. We, therefore, tested a combination of all the above three interventions as a single "package" with intention to achieve the breed potential. In response to package intervention, CH_4 emission per unit of milk reduced between 35.7 and 43.2% compared to baseline with associated 100% increase in milk yield.

Abatement in CH_4 intensity in response to all four mitigation interventions was more pronounced in grazing system compared to mixed system. This was apparently due to lower baseline performance of animals in the former system caused by poor feed supply from grazing lands. In all cases increase in milk production was associated with decrease in CH_4 intensity. A strong inverse relationship of average milk yield per animal and intensity of CH_4 emission per unit of milk protein was found and illustrated in Fig. 4. The high coefficient of correlation 0.71 means that 71% variation in emissions intensity is explained by milk production per cow. According to the trend line, increasing per cow annual milk production from 1000 to 3000 L would decrease the emissions intensity from 4.6 to 1.9 kg CO_2-eq/kg milk corresponding to a drop off 58%. The relationship in Fig. 4 is based on limited range of data on milk production and the trend is in close conformity to Gerber et al. (2013a) and Garg et al. (2016). Based on the data reported by Gerber et al. (2013a) it is assumed that no further reduction in methane emission intensity would occur with FPCM above 4000 kg in cows.

Notably considerable increase in beef yield varying from 10 to 65% above the baseline was also found in response to above mitigation interventions in the dairy herds across both the systems. This occurred because beef is a co-product of dairy herds and any intervention that increases performance

Fig. 4 Correlation between methane intensity and annual fat-protein corrected milk (FPCM) yield per cow



of animal for enhanced milk yield will also simultaneously improve growth rate and other parameters for improved carcass weight. These findings strongly emphasize the scope to reduce carbon footprint of dairy production in the country by implementing mitigation strategies such as improved fodder supply, preventive health care and better genetics applied individually or in combination. The strong indication that emission intensities are reduced with productivity gain emphasizes that the dual goal of food security and climate change can be addressed with such mitigation approaches. There is need to consider how these interventions would behave on ground at farm level and shall require understanding barriers in adoption such as farmer's capacity and awareness, access to inputs, market and services (Kebebe et al. 2017). Realizing the economic benefits of mitigation practices would be important to farmers in the adaptation process and decision making. Supportive policy of government is critical for creating an enabling environment to facilitate adoption of improved technologies.

4 Conclusions and Recommendations

The present analysis concludes that GHG emissions from livestock sector in Pakistan is much higher than thought previously, which are produced at high emission intensities due to low productivity and large numbers of animals. When compared to global averages, the carbon footprint of milk was slightly and that of meat was threefolds higher. Methane was identified as the major emission from livestock caused by poor feeding and management practices and offer large potential for mitigation. Poultry keeping contributed least to total sector emission and had lower environment tag of producing human food. Large ruminants shared most of the emission and per animal emission of methane and total GHG remained higher than small ruminants. The much higher carbon footprint of beef and mutton production from non-dairy herds is viewed inefficient and deserve priority for mitigation. The analysis of current mitigation options suggest that technical interventions which increase milk yield per cow will reduce its emission intensity and will concomitantly increase beef production in dairy herds. This approach to mitigation appears most promising in achieving the overall national objective of increasing milk and meat for food security and protecting the environment. The present assessment provides guidelines. Adoption on farm level shall require removing the barriers on ground. Other mitigation strategies such as reducing the herd size and enhancing the carrying capacity of rangelands need investigation. The present findings will help knowing the scale of emission from livestock sector in Pakistan, sensitizing the livestock departments and stakeholders for evolving mitigation strategies and informing policy makers for legislation and supportive environment.

Compliance with Ethical Standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Alexandratos N and Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision. Agricultural development economics division, Food and Agriculture Organization of the United Nations, Rome. http://large.stanford.edu/courses/2014/ph240/yuan2/docs/ap106e.pdf. Accessed 08 May 2018

Dost M (2003) Fodder production for peri-urban dairies in Pakistan. Country Pasture/Forage Resource Profiles, FAO, Rome. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Pakistan/Pakistan.htm. Accessed 02 May 2018

FAO (2009) The state of food and agriculture; livestock in balance food and agriculture organization of the united nations, Rome. http://www.fao.org/docrep/012/i0680e/i0680e.pdf. Accessed 19 Apr 2018

FAO (2010) Greenhouse Gas Emissions from the dairy sector; a life cycle assessment. Animal Production and Health Division. FAO, Rome. http://www.fao.org/docrep/012/k7930e/k7930e00.pdf. Accessed 10 Apr 2018

FAO (2013) Greenhouse gas emissions from ruminant supply chains—a global life cycle assessment. FAO, Rome. http://www.fao.org/docrep/018/i3461e/i3461e.pdf. Accessed 10 Apr 2018

FAO (2016) The state of food and agriculture; climate change, agriculture and food security. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/a-i6030e.pdf. Accessed 05 May 2018

FAO (2017) Supporting low emissions development in the Ethiopian dairy cattle sector—reducing enteric methane for food security and livelihoods. FAO and New Zealand Agricultural Greenhouse Gas Research Centre Rome. http://www.fao.org/3/a-i6821e.pdf. Accessed 12 April 2018

Garg MR, Phondba BT, Sherasia PL, Makkar HPS (2016) Carbon footprint of milk production under smallholder dairying in Anand district of Western India: a cradle-to-farm gate life cycle assessment. Animal Prod Sci 56:423–436. https://doi.org/10.1071/AN15464

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucc, Tempio AG (2013a) Tackling climate change through livestock- a global assessment of emissions and mitigation opportunities. FAO, Rome. http://www.fao.org/3/a-i3437e.pdf. Accessed 09 Apr 2018

GLEAM-i (2016) Global livestock environmental assessment model, version 1. FAO, Rome. http://www.fao.org/gleam/resources/en/. Accessed 02 Oct 2017

GOP (1996) Livestock Census Pakistan, Agricultural Census Organization,Statistical Division, Government od Pakistan, Gulberg Lahore, Pakistan

GOP (2006) Livestock census Pakistan, Government of Pakistan, Statistical division, Islamabad, Pakistan. http://www.pbs.gov.pk/content/pakistan-livestock-census-2006. Acceessed 04 May 2017

GOP (2014-15) Economic survey of pakistan. Government of Pakistan, Statistical division, Islamabad, Pakistan. http://www.finance.gov.pk/survey/chapters_15/02_Agricultre.pdf. Accessed 04 May 2017

GRA (2016) Livestock development and climate change: the benefits of advanced greenhouse gas inventories. https://cgspace.cgiar.org/rest/bitstreams/81212/retrieve. Accessed 24 May 2018

Habib G, Fatah Ullah KM, Javaid S, and Saleem M (2016) Assessment of feed supply and demand for livestock in Pakistan. J Agric Res

Technol, A 6: 191–202 http://www.davidpublisher.org/Public/uploads/Contribute/585744deb7133.pdf. Accessed 20 Nov 2017

Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, Waghorn G, Makkar HPS, Adesogan TT, Yang W, Lee C, Gerber PJ, Henderson B,Tricarico JM (2013) Special topics: mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J Anim Sci 91:5045–5069. https://doi.org/10.2527/jas2013-6583

IPCC (1997) In: Houghton J.T, Meira Filho L.G, Lim B, Treanton K, Mamaty I, Bonduki Y, Griggs D.J, Callander B.A (eds) Revised 1996 IPCC guidelines for national greenhouse gas inventories. Intergovernmental panel on climate change, IPCC/OECD/IEA, Paris, France

IPCC (2014a) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p 151

IPCC (2014b) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. In: Barros VR, Field CB, Dokken DJ Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p 1132

Jabbar MA and Ahuja V (2017) Dairy and climate change interface with a focus on the Asia-Pacific region: an exploratory review. working paper number: 2017-05, FAO Regional office for Asia and the Pacific, Bangkok, Thailand. http://www.dairyasia.org/file/WP5_Dairy_and_climate_change_interface.pdf. Accessed 20 Jan 2018

Kaleem AM and Ijaz M (2016) Greenhouse gas emission inventory of Pakistan for the year 2011–2012, GCISC Research Report-RR-19, Global Change Impact Studies Centre (GCISC) Ministry of Climate Change, Islamabad, Pakistan

Kebebe EG, Oosting SJ, Baltenweck I, Duncan AJ (2017) Characterization of adopters and non-adopters of dairy technologies in Ethiopia and Kenya. Trop Anim Health Prod 49(4):681–690. https://doi.org/10.1007/s11250-017-1241-8

Knapp JR, Laur GL, Vadas PA, Weiss WP, Tricarico JM (2014) Enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions- invited review. J Dairy Sci 97(6):3231–3261. https://doi.org/10.3168/jds.2013-7234

Opio C (2017) Feeding strategies to reduce methane and improve livestock productivity. Feedipedia, FAO, Rome. https://www.feedipedia.org/sites/default/files/public/BH_039_methane_productivity.pdf. Accessed 9 Apr 2018

Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod M, Vellinga T, Henderson B, Steinfeld H (2013) Greenhouse gas emissions from ruminant supply chains—a global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome. http://www.fao.org/docrep/018/i3461e/i3461e.pdf. Accessed 9 Apr 2018

Pryce JE, Veerkamp RF (2010) The incorporation of fertility indices in genetic improvement programmes. Fertility in the high producing dairy cow. BSAS Occ Publ 26:237–250. https://www.researchgate.net/publication/40147506. Accessed 10 Apr 2018

Tubiello FN, Salvatore M, Rossi S, Ferrara A, Fitton N, Smith P (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ. Res. Lett. 8:015009. https://doi.org/10.1088/1748-9326/8/1/015009

Wolf J, Asrar GR, Tristram O, West TO (2017) Revised methane emissions factors and spatially distributed annual carbon fluxes for global livestock. Carbon Balance Manage 12:16. https://doi.org/10.1186/s13021-017-0084-y