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Dairy and Climate Change Interface with a Focus on the Asia-Pacific Region: An Exploratory Review

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ABSTRACT

Livestock sector is often blamed for a significant contribution to global warming through emission of greenhouse gases (GHG)- carbon dioxide, methane and nitrous oxide. In the Asia-Pacific region, dairy is emerging as a major livestock activity as indicated by past trends and future projects of production, consumption and trade in dairy products. In this paper, available evidence on livestock sector contribution to greenhouse gas emissions and mitigation and adaptation measures being pursued are reviewed with a focus on dairy in order to help identify options for development of a sustainable dairy sector.

A review of the global level statistics generated by the IPCC on GHG emissions shows that the contribution of livestock to global GHG emissions got somewhat lost in the big picture. Based on IPCC guidelines, only non-CO2 emission have been considered yet due to aggregation and other methodological problems, a full account of the direct emissions from livestock activities was not available. Information about specific contribution from dairy sub-sector has not been presented in IPCC reports.

Review of studies on livestock sector including dairy, dairy sub-sector separately, and herd level experimental and survey based studies shows that rather than IPPC guideline, these studies have used life cycle assessment approach covering the entire supply chain from feed production to retail, hence assessed emissions of carbon dioxide, methane and nitrous oxide. The major findings from these studies are that at the global level, emission intensity for milk is several times higher in developing countries compared to developed countries mainly due to differences in yield. However, in national and sample based herd level studies, emission intensity is only marginally higher in developing countries. With ration balancing diets, the gap between developed and developing countries reduce even further. These findings suggest the need for revision of IPCC default emission factors taking cognizance of the diversity of breeds, production systems, feed resources and feed quality and other factors in the developing countries.

Mitigation efforts are targeted to methane and nitrous oxide because of their importance. Generally, there is an inverse relationship between milk yield and emission intensity over a wide range of yield. In the developed

countries, yield levels are already high so various mitigation options are tried at animal and farm/herd levels through manipulation of nutrition, genetics, health and management practices to reduce emission intensity with marginal or no yield increase. In the developing countries, dairy sector interventions are mostly focused on improving productivity through same types of interventions. Conscious efforts to mitigate GHG emissions are few if at all. Given low yield levels, developing countries have opportunities to increase yield and reduce emission intensity simultaneously. Because of ongoing mitigations efforts, developed countries are better prepared for development of adaptations strategies compared to developing countries.

Global livestock sector modelling with various mitigation options shows significant technical potential to mitigate different GHG emissions. However, economic potential of emission reduction appeared to be less than 10% of technical potential due to adoption constraints, costs and various trade-offs. Mitigation potentials and constraints specific to the dairy sector are not clearly known from the model results. However, appropriate policies and institutions need to be identified to remove constraints to enhance adoption of mitigation options in the livestock sector including dairy.

1 BACKGROUND AND OBJECTIVES

Livestock is a major component of the agriculture sector in the Asia-Pacific region generating income, employment, high quality food and livelihood. Across the region, as per capita income of a country increases, share of agriculture in GDP falls but share of livestock in agricultural GDP rise (see, World Development Indicators 2016 and FAOSTAT, accessed on 13 January 2017). This is a reflection of the fact that as a country develops and its income rise, sectoral structural change in the economy occurs and people's food habit change due to higher income and urbanisation: demand for higher quality nutritious foods like meat, milk and eggs increase.

Milk and meat feature among the top five agricultural commodities in terms of value in all the sub-regions of Asia and the Pacific. Milk is the top commodity in South Asia and Oceania, second highest in Central Asia and fifth in East Asia. Global milk output almost doubled from about 500 million tonnes in 1983 to 747 million tonnes in 2013. During the same period milk output in Asia increased from 80 to 270 million tonnes or by 3.34 times. In 2013, India, China, New Zealand and Pakistan respectively produced 18, 5, 3 and 2% of global milk output. While New Zealand and Australia are major net exporters of milk and milk products, the rest of the countries in the region except India are net importers (FAOStat, 2015). Global milk production is projected to increase by 175 million mt (23%) by 2024 compared to 2012-2014, the majority (75%) of which is anticipated to come developing countries, especially Asia.

Per capita availability of milk varies widely between the subregions of Asia-Pacific. In 2011, per capita availability in Australia-New Zealand was about 225 kg compared to about 150 kg in Central Asia, about 75 kg in South Asia and about 30-40 kg in East and South East Asia. A strong growing trend in dairy consumption has been observed throughout Asia over the last decade. From low consumption levels, South Asia has been experiencing major growth in demand but East and Southeast Asia, not having a strong tradition in milk consumption, has been also showing strong trend with the region emerging as a major importer of dairy products, especially from Australia and New Zealand. On the other hand, there is presence of a large number of undernourished people in the region, most of them children, especially in South Asia, who could have better nutrition and health from dairy consumption. Two thirds of the world's undernourished have home in the region and in some countries, incidence of child under-nutrition exceeds 40% (FAO, 2015a).

However, there are major concerns about the future shape of dairy in the region. First, while richer countries in the region, especially Australia and New Zealand, have advanced larger scale dairy production and processing industries, smallholder mixed farming systems still dominate the production and market share in the low and middle income countries especially in South Asia. In these systems there are diversities in species, breeds, production technology and systems, market and value chains, extension and research systems and capacities, and policy and regulatory environments. Yet with urbanization and income growth, demand for processed products and for quality and safety are emerging rapidly. In response, larger scale modern processing sector is also emerging. This dichotomy is induced by the fact that there are few economies of scale in production with labour intensive traditional technology while there are economies of scale in processing. Second, there are emerging concerns about economic, social and environmental sustainability of dairy production and marketing. The need for protection of the livelihoods of smallholder producers and poor consumers on the one hand and the need for production and productivity improvement in the face of scarcity of land, feed and water, emerging diseases and public health risks, and the interface with climate change create a complex matrix of issues and options posing challenges for making optimal choices.

In this context, the primary focus of this paper is dairy and climate change interface. Since the early 1990s, there has been a growing volume of criticism against livestock in general from environmentalists. Prominent among these criticisms were that livestock contributed to: water and environmental pollution through animal wastes; increased desertification through long term overgrazing particularly of semiarid rangelands; deforestation by lopping branches for use as fodder and felling trees to make way for pastures for commercial livestock production as in Latin America; global warming through emission of greenhouse gases (Steinfeld et al., 1997; de Haan et al., 1997).

However, during the 1990s and early 2000s, livestock impact on environment, especially its contribution to global warming remained conjectural and controversial due to lack of adequate empirical evidence. Several studies have documented inadequacy and contradictions in evidence, their possible reasons and alternative interpretations and explanations (see for example, Hecht, 1989; Dodd, 1991; Durning and Brough, 1991; 1992; Belk et al, 1992; Cleaver and Schreiber, 1992; ILCA, 1992; Winrock, 1992; Fitzhugh, 1993; Kaimowitz, 1994; Sansoucy et al., 1994).

Livestock contributes to global warming by emitting three major GHGs – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is emitted mainly through feed production and livestock induced land use changes such as deforestation. Methane emissions occur from enteric fermentation and both methane and nitrous oxide emissions occur through manure management systems. Evidence and statistics on global warming and its sources emerging in recent years suggest that livestock and dairy are significant sources of GHG emissions. However, the actual contributions of livestock and dairy to agriculture sector and global GHG emissions still remain highly controversial because of lack of clarity and consistency in the definition of what is included in agriculture, what are the pathways of GHG emission from livestock, especially dairy, methodology used in measuring emissions from various agricultural and livestock activities, and the time reference for various statistics presented. Herrero et al (2011) suggested that estimates of global greenhouse gas (GHG) emissions attributable to livestock range from 8 to 51% mainly due to methods and approaches used for estimation.

Such high variability in the estimates of livestock related emission highlights the importance of efforts required to generate more accurate data on emissions in order to more objectively contribute to the debate on the role of livestock in global GHG emission. In order to develop technology, policy and institutional arrangements for mitigation and adaption of livestock and dairy to climate change, efforts need to be made to make more objective assessment of livestock and dairy sector emissions.

Given this background, the main objective of this study is to conduct an exhaustive desk research on the topic with a view to bring together the current state of knowledge and the knowledge gaps (what we need to know and why?), including

a) Contribution of dairy sector to GHG emissions in the Asia-Pacific region disaggregated by sub-region, country and where available production systems and practices, and relate that to the global situation.
b) Adaptation and mitigation practices devised, tested and applied in the region disaggregated by sub-regional, country and where available production systems and practices, and the potential of the tested/applied practices for wide application.
c) Implications of dairy impact on climate change for nutrition, livelihoods/poverty reduction, in the region disaggregated by sub-region and country and production systems and practices.

The paper is organised as below. In section 2, evidence on dairy sector GHG emissions will be reviewed taking 'a view from above' perspective. Global trends in GHG emissions, sources of emission by type of gas and by sector will be reviewed to trace the share of dairy in global emissions. In section 3, 'a view from below' perspective will be taken to review estimates done for livestock sector emissions including dairy, dairy sub-sector emissions alone, and emission from sample dairy herds using experimental data.

In section 4, evidence from experimental and modelling studies on mitigation and adaptation options and practices will be reviewed and their implications of dairy sector emission for climate change and implications of climate change for the dairy sector will be discussed in relation to technical and economic feasibility of possible mitigation and adaptation options and practices. In section 5, a summary of the evidence on GHG emission from the dairy sector and options for mitigation and adaption will be presented.

2 DAIRY SECTOR CONTRIBUTION TO GHG EMISSION: A VIEW FROM ABOVE

2.1 Trend of global emissions and sources

Because of the extensive works of the Inter-Governmental Panel on Climate Change (IPCC), it is now generally accepted that the evidence for human influence on the climate system has grown rapidly as more than half of the observed increase in global average surface temperature from 1951 to 2010 was most likely caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (IPCC, 2014).

With better quality statistics, accuracy of the estimates is getting better, hence historical emission data are periodically revised. Take for example, the estimates of global emissions of GHGs from IPCC's assessment report 4 published in 2007 and assessment report 5 published in 2014 (Table 1). It is notable that for 1970, 1990 and 2000, AR5 estimates are 4 to 9% lower than the AR4 estimates. According to AR4, emission in 2004 was 49 $GtCO_2eq$ but according to AR5, that figure was reached only in 2010. Since GHG emission is a continuous process with varying rates over time, it is assumed that more recent estimates of both historical and current emission data are relatively more accurate.

Table 1: Estimated global emissions of greenhouse Gases in GtCO2eq per year for selected years by sources

Data Source	1970	1990	2000	2004	2005	2010
IPCC (2007)	28.7	39.4	44	49	na	na
IPCC (2014)	27	38	40	na	45	49
% change	-6	-4	-9.1	na	na	na
Index for IPCC (2014)	100	141	148		167	181

Source: IPCC (2007), p.5 and 36; IPCC (2014), p.5 and 46

It has been estimated that, despite a growing number of mitigation policies adopted, total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010 (Table 1). Anthropogenic GHG emissions increased from 27 $GtCO_2eq/yr$ in 1970 to 49 Gt CO_2eq/yr in 2010, an increase of 81%.[1] Total GHG emissions increased at the rate of 1.3% per year between 1970 and 2000, and by 2.2% per year between 2000 and 2010 (IPCC, 2014, p.5 and 46).

Along with increase in total GHG emission, share of different gases and the sources of emissions by sectors have also changed (Table 2). Before interpreting the pattern of change presented in Table 2, it will be useful to note that in the IPCC guidelines, it is recommended that net CO_2 emissions from agriculture including livestock should be considered zero or neutral due to balance of emission and sequestration in these domains. Hence emission from agriculture, forestry and other land use change (AFOLU) includes net CO_2 emission from forestry and other land use change (FOLU), and methane and nitrous oxide emissions from agricultural activities including livestock (see Box 1 for methodological notes of IPCC). However, when Life Cycle Assessment (LCA) approach is used, emissions arising from conception to retail are all covered. In case of livestock, it includes emissions from feed production and animal rearing, livestock induced land use change like deforestation and expansion of crop land into range land as well as from the processing and transportation of livestock commodities to markets. Further emissions occur after sale associated with transportation, storage, cooking and consumption or possible disposal. Some of these LCA emissions are reported in the GHG inventories of other sectors e.g. fossil fuels to transport products in the transport sector, energy used in processing in industry sector.

According to IPCC AR5, between 1970 and 2010, share of CO_2 from fossil fuel and industrial process, transportation and buildings in total global emissions increased from 55% to 65% while shares of CO_2 from FOLU and of methane and nitrous oxide from agriculture in total global emissions decreased in varying degrees. This has happened because CO_2 emission from fossil fuels, industrial processes, transportation and housing induced by economic and population growth accounted for about 78% of the total GHG emissions increase from 1970 to 2010. On the other hand, net carbon dioxide emission from FOLU, and methane and nitrous oxide emissions from agricultural and other activities increased at a slower rate compared to carbon emission from fossil fuel and industrial processes. Actually total GHG

[1] These estimates are sensitive to the assumptions made with respect to global warming potential of different gases. CO_2eq emissions in the IPCC report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP100) values from the Second Assessment Report. Using the most recent GWP100 values from the Assessment Report 5 would result in higher total annual GHG emissions (52 Gt CO_2eq/yr) in 2010 from an increased contribution of methane, but does not change the long-term trend significantly (IPCC, 2014). It may be noted that GWP100 for methane was assumed 23 in IPCC (2001), 25 in IPCC (2007) and 34 in IPCC (2014.)

emissions from AFOLU increased from 10 Gt CO_2eq in 1970 to 13 GtCO_2eq in 1990, then decreased to 12 GtCO_2eq in 2010.

Table 2: Changes in the composition of global anthropogenic GHG emissions and their sectoral sources, selected years

	1970	1990	2010
Total GHG emissions (GtCO_2eq/yr)	27	38	49
% share by type of gas			
Carbon dioxide from fossil fuel, industrial processes, transportation and buildings	55	59	65
Carbon dioxide from forestry and other land uses (deforestation, land clearing for agriculture, and degradation of soils)*	17	16	11
Methane (agricultural activities including livestock, waste management, energy use, and biomass burning)	19	18	16
Nitrous oxide (agricultural activities including manure management, fertilizer use, biomass burning)	7.9	7.4	6.2
Fluorinated gases (F-gases) (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) due to industrial processes, refrigeration, and the use of a variety of consumer products)	0.44	0.81	2
All gases	100	100	100
% share by sector			
Electricity and heat production (burning of coal, natural gas, and oil for electricity and heat)		26	25
Industry (fossil fuels burned on site at facilities for energy including emissions from chemical, metallurgical, and mineral transformation processes not associated with energy consumption and emissions from waste management activities)		19	21
Transportation		13	14
Buildings		8	6
Other energy		3	10
Agriculture, forestry, and other land use (crop, livestock, deforestation, biomass burning)*	37	31	24
All sectors		100	100

*A large portion of CO_2 is removed or sequestered through reforestation, improvement of soils, and other activities, so the net contribution is fairly small.
Source: IPCC (2014)

Box 1

Methodological notes by IPCC for estimation of GHG emissions from agriculture, forestry and other land use (AFOLU) sector

Several points have been noted about what has been included in the sector, data source and quality and what has been measured and what has been excluded.

First, Assessment Report 5 of the IPCC recognized that "estimating and reporting the anthropogenic component of gross and net AFOLU GHG fluxes to the atmosphere, globally, regionally, and at country level, is difficult compared to other sectors. First, it is not always possible to separate anthropogenic and natural GHG fluxes from land. Second, the input data necessary to estimate GHG emissions globally and regionally, often based on country-level statistics or on remote-sensing information, are very uncertain. Third, methods for estimating GHG emissions use a range of approaches, from simple default methodologies such as those specified in the IPCC GHG Guidelines [IPCC, 2006], to more complex estimates based on terrestrial carbon cycle modelling and / or remote sensing information" (Smith et al., 2014, p.819).

Second, IPCC further reported that only agricultural non- CO_2 sources are reported as anthropogenic GHG emissions because CO_2 emitted is considered neutral, being associated to annual cycles of carbon fixation and oxidation through photosynthesis. A large portion of CO_2 emitted by deforestation and other land use changes is removed or sequestered through reforestation, improvement of soils, and other activities elsewhere, So the net contribution of agricultural activities to carbon dioxide emission is fairly small or neutral due to balance of emission and sequestration (Smith et al., 2014, p.822 and 825).

Third, fluxes resulting directly from anthropogenic FOLU activity are dominated by CO_2 fluxes, primarily emissions due to deforestation, but also uptake due to reforestation / regrowth. Non- CO_2 greenhouse gas emissions from FOLU are small in comparison, and mainly arise from peat degradation through drainage and biomass fires (Smith et al., 2014, p.825).

Fourth, livestock induced CO_2 emissions are supposed to occur through feed production, feed processing, and land use change due to deforestation and expansion of crop cultivation into rangeland. But IPCC Guidelines for National Greenhouse Gas Inventories suggested that "CO_2 emissions from livestock are not estimated because annual net CO_2 emissions are assumed to be zero – the CO_2 photosynthesized by plants is returned to the atmosphere as respired CO_2. A portion of the C is returned as CH_4 and for this reason CH_4 requires separate consideration" (Dong et al., 2006, p.10.6).

Overall share of AFOLU sector in total emissions decreased from 37% in 1970 to 24% in 2010. Between these two years, agricultural non-CO_2 emissions grew by 0.9 % per year, with a slight increase in growth rates after 2005. Non-CO_2 emissions from agriculture sector in 2010 was estimated as 5.2 – 5.8 $GtCO_2eq$ and comprised 10-12% of global anthropogenic emissions. An additional 0.4-0.6 $GtCO_2eq$ CO_2 was emitted from use of fossil fuel on crop lands due to use of agricultural machinery like tractors and irrigation pumps but those were accounted for in the energy sector rather than in the AFOLU sector (FAO, 2013; Tubiello et al., 2013; Ceschia et al., 2010; quoted in Smith et al., 2014).

2.2 Changing regional pattern of global emissions

Although overall share of emissions from AFOLU decreased over time, changes in regional shares in AFOLU emissions showed uneven pattern. Asian share in AFOLU emission increased from 26% in 1970 to 39% in 2010 while shares of the other regions generally declined (Table 3). These changes were influenced by uneven regional changes in area of crop and pasture land, forest cover, N fertilizer application and livestock population growth. Compared to the other regions, application of N fertilizers increased at a much faster rate in Asia along with improved cereal production technologies, and the total number of livestock grew continuously in the developing regions, particularly in Asia, Middle East and Africa but decreased (except poultry) in the Economies in Transition and OECD-1990.

Table 3: Regional shares in total anthropogenic GHG emissions from agriculture, forestry and other land use changes, selected years

	1970	**1990**	**2010**
Total global emissions, $GtCO_2eq/yr$	27	38	49
Total emissions from agriculture, forestry and other land use changes (AFOLU), $GtCO_2eq/yr$	10	13	12
AFOLU share in global total (%)	37	34.2	24.5
Regional share in total AFOLU emission (%)			
Asia	26	31.5	39.2
Middle East and Africa	31	23.1	27.5
Latin America	18	16.9	15.8
Economies in Transition	12	11.5	5.2
OECD-1990	12	12.3	11.7

Source: IPCC (2014), Smith et al (2014)

2.3 Sources of emissions from agriculture including dairy

According to IPCC inventory guidelines, sources of GHG emissions from agriculture include rice cultivation, biomass burning, enteric fermentation, synthetic fertilizer application, crop residues, manure management systems, manure deposited on pasture, and manure applied to soils. However, for reporting purposes, IPCC recommended rice cultivation, biomass burning and enteric fermentation as independent categories while the others are aggregated into one category called 'agricultural soils'.

IPCC AR5 did not provide its own estimate of emission from agriculture sector rather presented estimates of non-CO_2 emissions from agriculture done by four independent studies for reference year 2005 (Smith et al., 2014, p.823-24). These are USEPA (2006 and 2011), FAOstat (2013), EDGAR (2013). These studies presented results for four categories – enteric fermentation, manure management systems, rice cultivation and agricultural soils (Table 4). So, these categories are somewhat different from those recommended by IPCC for reporting as mentioned above, especially with respect to manure related emissions.

Table 4: Non-CO2 GHG emissions from agriculture by sources in selected studies

Sources of emissions	**USEPA (2006)** $GtCO_2eq$	**USEPA (2011)** $GtCO_2eq$	**EDGAR (2013)** $GtCO_2eq$	**FAOStat (2013)** $GtCO_2eq$
'Agricultural soils'	2.2 (1.8-4.0)	2 (1.5-3.5)	1.5 (1.3-2.9	1.4 (1.2-2.8)
Enteric fermentation	1.9	1.8	2.0	1.9
Rice cultivation	0.6	0.7	0.8	0.5
Manure management systems	0.4	0.3	0.2	0.2
Total emissions	5.2 (4.8-7.0)	4.9 (4.5-6.5)	4.8 (4.2-6.0)	4.2 (3.9-5.5)

Note: Figures in the parentheses are 95% confidence intervals. For other categories, intervals are small hence not shown. These numbers have been derived from reading graphs; hence there may be minor margin of error in the numbers presented in the table.
Source: Smith et al, 2014, Figure 11.4, p. 822.

Comparison of the estimates shows that volume of total emissions decreased over time.[2] According to EDGAR and FAOSTAT, emission from enteric fermentation was the largest emission source, while USEPA listed emissions from 'agricultural soils' as the dominant source. Further, it has been noted that though these estimates are slightly different, they are

[2] Estimates over a longer time horizon also showed that total emission from milk and meat in 1960 was respectively over 1 and over 7 $GtCO_2eq$ which declined to respectively 0.7 and 5.5 $GtCO_2eq$ (Smith et al., 2014, p. 851)

statistically consistent given the large uncertainties in IPCC default methodologies (Tubiello et al., 2013, quoted in Smith et al., 2014).

However, such a conclusion seems highly questionable given the large spread of 95% confidence intervals of the estimates, especially in case of emissions from 'agricultural soils', which then influenced spread of total emissions.

Region specific estimates for all four sources of emissions from agriculture done by USEPA , FAO and EDGAR have been presented for reference year 2010 instead of year 2005 (Smith et al., 2014, Figure 11.5, p. 823) though no explanation has been given for choosing a different year for showing regional shares. The results show that 95% confidence intervals for region specific estimates of emissions for all the four categories for reference year 2010 are quite large, especially in case of Asia and other developing regions. Thus any conclusion about the extent of emissions from agriculture and its share in global and regional GHG emissions should be interpreted with utmost caution.

IPCC AR5 reported that from the livestock sub-sector, total emission of methane from enteric fermentation, and methane and nitrous oxide from various manure related activities increased from 2.22 to 3.45 $GtCO_2eq$ or by 55% between 1961 and 2010 (Table 5). Separate figures for methane and nitrous oxide emissions from manure have not been presented. Thus it appears that, livestock accounted for 7% of global total emissions of GHGs or 32% of global total methane and nitrous oxide emissions in 2010. It may be noted that based on IPCC guidelines, estimate of livestock sector emission excluded CO_2 emissions from feed production, processing and livestock induced land use change, and processing of products.

During 2000-2010, Asia and Latin America contributed the most of emission from enteric fermentation. In 2010 about 70% came from the developing countries. Cattle contributed about 75% followed by buffalo, sheep and goat.

Table 5: Methane and nitrous oxide emissions from livestock sub-sector, 1961 and 2010

	1961 $GtCO_2eq$	**2010** $GtCO_2eq$	**Growth rate/change**
Enteric fermentation	1.40	2.10	0.76% per year
Manure on pasture and as fertilizer	0.57	0.99	1.1% per year
Manure management systems	0.25	0.36	0.6% per year
Total	2.22	3.45	55%

Source: Smith et al. (2014), Figure 11.5 and pp. 823-24.

Manure on pasture and manure used as fertilizer had a larger share than manure management systems. During 2000-2010, about 80% of manure related emissions came from the developing countries of Asia, Latin America and Africa, and about 60% was contributed by grazing cattle, followed by sheep and goat. Largest share of emissions from manure management systems during 2000-2010 also came from Asia.

Region specific emissions for reference year 2010 for four categories – enteric fermentation, manure management systems, 'agricultural soils' and rice cultivation - with 95% confidence intervals show very large spread especially for developing regions (Smith et al., 2014, Figure 11.5)[3]. So the data needs to be interpreted with serious caution.

Thus, it appears that contribution of livestock in global GHG emissions got somewhat lost in the IPCC big picture about global emissions. Because of the use of IPCC guidelines, only direct non-CO_2 emissions have been considered yet due to aggregation of several manure related emission categories with other categories from agriculture sector into one category called 'agricultural soils', a full account of the direct emissions from livestock activities was not available. Information about specific contribution from dairy sub-sector has not been presented in IPCC reports.

[3] In the text of the IPCC AR5 report, figures for 2000-2010 are mentioned referring to Figure 11.5, but the figure only shows data for 2010, not for the period 2000-2010 (Smith et al., 2014, Figure 11.5).

3 DAIRY SECTOR CONTRIBUTION TO GHG EMISSION: A VIEW FROM BELOW

A review of the literature suggests that there are three types of studies that provided information on GHG emissions from the dairy sector. First, several studies estimated global emissions from the livestock sector and some of them have provided estimates for emissions from dairy. Second, a few studies focused exclusively on global dairy sector emissions. Third, a good number of studies have provided emissions data for national or a sample of dairy herds or specific dairy herds mostly from developed countries. Rather than following IPCC guidelines, all these studies used LCA approach taking the entire supply chain from cradle to farm gate, and in some cases up to retail, hence included CO_2 emissions due to feed production, land use change, feed and livestock products processing, transportation etc. A discussion on all three types of studies is in order.

3.1 Estimates of global livestock sector emissions

Alleged livestock contribution to global GHG emission remained conjectural in the 1990s and early 2000s due to lack of adequate empirical evidence. A major FAO study published in 2006 filled that gap but also raised alarm as it showed that livestock accounted for emissions of 4.6 to 7.1 $GtCO_2eq$ of GHGs per year or 14 to 18% of global anthropogenic emission of GHGs for the 2001-2004 reference period (Table 6).

Table 6: Livestock contribution to annual global carbon dioxide, methane and nitrous oxide emissions, 2001-2004

Type of gas and sources	Total global emissions, Gt CO_2eq*	Livestock sector emissions, $GtCO_2eq$	% share of livestock sector emissions	% share of livestock in global emissions
CO_2 (feed production and livestock induced land use change)	24 (~31)	~0.16 (~2.7)	38.9	9.0
CH_4	5.9	2.2	30.2	37.3
Enteric fermentation		1.80		
Manure management		0.37		
N2O	3.4	2.2	30.9	64.7
Manure management		0.33		
Manure application		0.84		
N fertilizer application and legume feed cropping		1.03		

Total	33 (~40)	~4.6 (~7.1)	100	14~18
Extensive systems		3.2 (~5.0)	70	10 (~13)
Intensive systems		1.4(~2.1)	30	4(~5)

* Global total was taken from CAIT, WRI, accessed on 02/06. Relatively imprecise estimates are preceded by a tilde.

Source: FAO (2006) Table 3.12, p.113

Of the total livestock sector emissions, CO_2 emissions from feed production and livestock induced land use change – deforestation, expansion of crop land into rangeland etcetera- accounted for 39%, methane emission mainly from enteric fermentation accounted for 30% and nitrous oxide emissions from manure management and manure applied to pasture and soils as fertilizer accounted for 31%. Livestock sector emissions accounted for 9% of global CO_2 emission, 37% of global CH_4 emissions and 65% of global N_2O emissions.

Seventy percent of the estimated livestock sector emissions occurred in extensive or mixed production systems and 30% in intensive systems. Cattle accounted for 65% of emissions. Beef, cattle milk, and buffalo milk and meat accounted for respectively 41, 20 and 8% of the sector emissions.

According to Table 6, volume of methane emission from enteric fermentation and manure management, and N_2O from manure deposited on pasture and applied as fertilizer was respectively 1.80, 0.37 and 1.17 $GtCO_2eq$ per year for reference period 2001-2004. But distribution of these gases by type of animal, production systems and region have been shown out of total emissions of respectively 85.62, 17.52 and 3.69 million tonnes of CO_2eq for year 2004 (see, FAO, 2006, Table 3.7, 3.8 and 3.11). Therefore, the usefulness of the estimates of shares of these gases by animal type, production systems and region is questionable.

The study raised substantial controversy and debate primarily on grounds of various methodological deficiencies and data limitations and the wide range and imprecision of the estimates. Some limitations of the study are as follows.

First, application of LCA approach instead of IPCC guidelines led to substantial uncertainty in the estimated volume of emissions from the sector due to uncertainty in the estimated emission of CO_2. Inclusion of CO_2 in the estimate most likely led to over estimation of the total volume of sectoral emission.

Second, even though a lower and an upper bound of the volume of sectoral emission have been shown, sectoral share in global emission has been estimated on the basis of the upper bound estimate. Moreover, total global emission has been derived from WRI perhaps because that was the best estimate available at that time. But WRI estimate also had a large range and the upper bound estimate has been used as the base to calculate livestock sector share in global emission. Consequently, livestock sector share in global emission has been most likely overestimated.

Third, IPCC estimates of global emissions released subsequent to the FAO study showed that WRI estimate of global emission was substantially low. IPCC AR4 published in 2007 reported global total emission in 2000 and 2004 as 40 and 44 $GtCO_2eq$ respectively. IPCC AR5 revised those estimates downward and reported 40 and 45 $GtCO_2eq$ respectively for 2000 and 2005. If it is assumed that FAO's upper bound estimate of livestock sector emission of 7.1 $GtCO_2eq$ was accurate, share of livestock in global emission would be lower than 18% if IPCC estimates of global emissions were available and used as the base in the FAO study.

Fourth, it has been suggested that the estimates might have been influenced by the use of IPCC default emission factors for different gases that are unrepresentative of the diverse species and breeds of animals, production and feeding systems, digestibility and productivity, manure disposal and management, and health and nutritional status of animals around the world.

A recent FAO study (Gerber et al., 2013) based on improved data sets and detailed analysis showed that the contribution of livestock supply chain to global anthropogenic GHG emission for reference year 2005 was 7.1 $GtCO_2eq$ which was equivalent to 14.5% of IPCC estimate of global total anthropogenic GHG emission of 49 $GtCO_2eq$ for the year 2004 (Table 7). If only methane and nitrous oxide emissions from enteric fermentation and manure were considered as per IPCC guidelines, total emissions of livestock sector in 2005 would be 5.1 $GtCO_2eq$ or 10.4% of global total emission of 49 $GtCO_2eq$ in 2004.

Table 7: Estimated livestock sector contribution in annual global greenhouse gas emissions in 2005

Type of gas and sources	Total global emissions, 2004* $GtCO_2eq$	Livestock sector emissions, 2005 $GtCO_2eq$	% share of livestock sector emissions, 2005	% share of livestock in global emissions in 2004
CO_2 (feed production and livestock induced land use change)	37.6	2.0	28.2	5.3
CH_4 (Enteric fermentation and manure management)	7.0	3.1	43.6	44.3
N_2O (manure management and	3.9	2.0	28.2	51.3

manure applied on pasture and soils and N fertilizer application for legume feed cropping)				
Total	49	7.1	100	14.5

* Based on IPCC AR4 (2007)

Source: Gerber et al. (2013)

Overall, livestock accounted for nearly 80% of GHG emissions from agriculture. Beef cattle, dairy cattle and buffalo accounted for respectively 35.1%, 30% and 8.7% of livestock sector emissions.

As for sources of emissions, methane emissions from enteric fermentation and manure management accounted for 44% of total emissions from the sector; nitrous oxide emissions from manure management, manure deposited on pasture and applied on soil accounted for 28%, and CO_2 emissions from feed production, processing and land use change accounted for 28%. The sector accounted for 5% of global CO_2 emission, 44% of CH_4 emission and 51% of N_2O emission. Cutting across all activities and all species, the consumption of fossil fuel along the supply chain accounted for about 20% of the livestock sector's emissions (Gerber et al., 2013).

Compared to the 2006 study, relative shares of CO_2 and N_2O in sectoral emissions decreased, and share of CH_4 increased. However, there are questions about accuracy of estimates of emissions from the sector as well its share in global total emission. For estimating share of the sector in 2005, global total emission in 2004 has been used as the base. Perhaps this has been done because at that time the most recent estimate of total global emission was available for 2004 (IPCC, 2007). But from IPCC AR5, it is observed that historical data on estimates of total global emissions have been revised up to 2010, and total emission in 2005 was 45 $GtCO_2eq$, which was lower than 49 $GtCO_2eq$ estimated for 2004 in AR4 (Table 2). In the revised estimate, emission of 49 $GtCO_2eq$ was reached only in 2010.

If for the sake of argument, both Gerber et al estimate of livestock sector emission of 7.1 $GtCO_2eq$ in 2005 and IPCC revised global total estimate of 45 $GtCO_2eq$ in 2005 are considered accurate, then livestock sector share in global total emissions in 2005 would be 15.8% rather than 14.5%. If only non-CO_2 categories were considered for the livestock sector, its share in total would be 11.3%. But realistically it has to be accepted that the downward estimates of historical global total emissions data in AR5 and declining share of agriculture in total emission also means that most likely estimated total emission from agriculture including livestock also decreased to some degree as indicated in Table 3. Hence livestock sector emission in 2005 was probably much less than 7.1 $GtCO_2eq$ if LCA approach was used or less than 5.1 $GtCO_2eq$ if only IPCC non-CO_2 categories were considered. But estimates of either total or source specific emissions from the livestock sector are not comprehensively presented in IPCC AR5, so it is not possible to directly compare Gerber et al. (2013) and IPCC AR5 estimates of livestock sector emissions of GHGs for reference year 2005.

Out of total emissions from all dairy animals, milk accounted for 66%, the rest was attributed to meat. Taking emissions from all ruminants including specialized beef production, milk accounted for 36% and meat for 64% (Table 8). Share of milk in mixed systems of production was higher than in grazing systems in case of dairy cattle and buffalo while opposite was the case for sheep and goats. Overall, share of milk in mixed systems was almost twice the share in grazing systems.

Table 8: Share of milk in total livestock sector emissions of greenhouse gases by species and system of production in 2005

Species	% share milk in total livestock sector emissions		
	Grazing systems	Mixed systems	All systems
Dairy cattle	69	74	73
Buffalo	64	67	67
Sheep	31	24	27
Goats	40	34	36
All dairy animals	58	67	66
All dairy and specialized beef	21	41	36

Source: Gerber et al. (2013)

Gerber et al. (2013) also provided estimates of emission intensity, i.e., amount of GHG emitted per unit of product or output, for meat and milk by species, production systems and regions (Table 9). Several common patterns emerge from the results.

First, emission intensity for meat is several times higher than that for milk from dairy herds in all species and production systems. Emission intensity for specialized beef is even larger than meat from dairy herds because dairy herds produce both milk and meat, so the emission is spread over a larger volume of output.

Second, emission intensity for milk is the lowest for cattle milk, followed by buffalo milk, then sheep milk and goat milk. For all species, intensity for milk is slightly higher in grazing systems than in mixed systems of production.

Third, emission intensity for meat is the lowest for cattle followed by sheep and goat at the same level, and then buffalo. Emission intensity for cattle is higher for grazing systems than mixed systems, about the same in case of sheep and goats but higher in mixed system in case of buffalo.

Table 9: Estimated emission intensities (kgCO2eq/kg product) for milk and meat from dairy and specialized beef herds by species and production systems, 2005

Species	Milk			Meat		
	Grazing	Mixed	All	Grazing	Mixed	All
Specialized beef				102.2	56.2	67.6
Dairy cattle	2.9	2.6	2.6	21.9	17.4	18.2
Buffalo	3.4	3.2	3.4	36.8	54.8	53.4
Sheep	9.8	7.5	8.4	23.8	23.2	23.4
Goats	6.1	4.9	5.2	24.2	23.1	23.3
All dairy	na	na	2.8	na	na	22.4
All dairy and specialized beef	na	na	2.8	na	na	42.6

Note: Milk measured as fat and protein corrected amount, meat as carcass weight, and neither includes post-harvest emissions

Source: Gerber et al. (2013)

Among the GHGs, CH_4 accounted for the highest share in all species for both milk and meat followed by N_2O and CO_2 (Table 10). Between species, CH_4 shares in both meat and milk were higher for buffalo and small ruminants but CO_2 and N_2O shares for both milk and meat were higher for cattle.

Among the regions, emission intensity for cattle milk is the highest in SSA followed by South Asia, NENA and LAC, and lowest in the developed countries (Table 11). For buffalo milk, emission intensity is the highest in East and South East Asia followed by NENA and South Asia. For small ruminant milk, emission intensity is the highest in East and South East Asia and NENA, followed by SSA, other regions.

In case of beef production, intensity is about 75 in South Asia, 70+ in LAC and SSA and <30 in the other regions while in case of buffalo meat, the order is East and South East Asia (70), South Asia (50), LAC (30+) and NENA (20).

A general pattern is that when emission intensity for a commodity or a region is high, share of methane from enteric fermentation in total emission of that commodity or region is also high compared to other gases. This is explained by the fact that in developing regions, emission intensity is high as yield is low due to poor quality feed, and in such cases rate of emission of methane is also high.

Herrero et al. (2016) provided a synthesis of several studies including the FAO studies reviewed above that estimated livestock sector emission of GHGs during the period 1995-2005 (Table 12). The summary shows that total emissions from the livestock sector was 5.6-7.5 $GtCO_2eq$ per year if Life

Cycle Assessment approach was used on the entire livestock supply chain or 2.0-3.6 $GtCO_2eq$ per year if only IPCC emission categories were considered. Thus IPCC categories represented 36-48% of total livestock sector emission if LCA approach was applied on the entire supply chain.

Table 10: Share of different gases in total emission per unit of milk and meat by species, 2005

Gases	Cattle (%)		Buffalo (%)		Small ruminants (%)	
	Milk	Meat	Milk	Meat	Milk	Meat
CH_4	50.3	44.0	60.6	63.8	59.1	56.9
Enteric fermentation	46.5	42.6	59.5	62.6	57.2	54.9
Manure management	3.8	1.4	1.1	1.2	1.9	2.0
N_2O	29.8	29.1	22.3	26.5	26.7	28.4
Manure management	5.4	3.6	4.9	5.7	3.8	2.0
Manure applied & deposited	17.0	18.1	10.1	13.8	15.6	17.6
Fertilizer and crop residues	7.4	7.4	7.3	7.0	7.3	8.8
CO_2	19.9	26.9	17.1	9.7	14.2	16.7
Feeds	10.9	10.0	10.3	9.2	12.3	11.1
Land use change and others	9.0	16.9	6.8	0.5	1.9	5.6

Source: Gerber et al. (2013)

Table 11: Emission intensity (kgCO2eq/unit of milk) by species and region, 2005

Region	Cattle	Buffalo	Small ruminants
South Asia	5.2	3.2	4.8
East and Southeast Asia	2.4	4.9	8.9
Sub-Saharan Africa	9.0		6.9
Near East and North Africa	4.3	3.6	8.8
Latin America and Caribbean	3.9		
Developed countries	<2		<5
World	2.6	3.3	6.5

Source: Gerber et al. (2013)

The synthesis showed that cattle production systems accounted for 64–78% of total emissions from the livestock sector. Studies that used LCA approach estimated that dairy cattle (producing both milk and meat) accounted for 46% of the total emission of 4.6 $GtCO_2eq$ per year from cattle from all sources.

The developing world contributed 70% of non-CO_2 emissions from ruminants and 53% from monogastrics. Mixed crop–livestock systems contributed 58% of total emissions whereas grazing-based systems contributed 19%, and industrial and other systems comprised 28%.

Taking an aggregate view of the sector, methane, N_2O and CO_2 respectively accounted for 43, 29 and 27% of total emissions. These estimates excluded carbon sequestered in grazing land (rangeland and pastures). There are varying degrees of uncertainty in the global estimates of CH_4 from enteric fermentation (CV= 18%), methane and N_2O from manure management (CV =27 and 46% respectively). National level estimates, mostly available from developed countries, show even larger degrees of uncertainty (Herrero et al., 2016).

Table 12: Estimated global greenhouse gas emissions from livestock (~1995–2005)

Emissions source	**Emissions ($GtCO_2eq$)**	**Source of data**
Feed N_2O	1.3–2.0‡	Bodirsky et al. (2012), Herrero et al. (2013), Gerber et al. (2013), FAO (2013a), FAO (2013b), EDGAR (2014)
Feed CO_2 (LUC excluded)	0.92	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Feed CO_2 (LUC)	0.23	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Pasture expansion CO_2 LUC	0.43	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Feed CH_4 rice	0.03	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Enteric fermentation CH_4*	1.6–2.7	US EPA (2006), Popp et al. (2010), Tubiello et al. (2013), Herrero et al. (2013), Gerber et al. (2013), FAO (2013a), EDGAR (2014)
Manure CH_4*	0.2–0.4	US EPA (2006), Popp et al (2010) Tubiello et al. (2013), Herrero et al. (2013), Gerber et al. (2013), FAO (2013a), EDGAR (2014)
Manure N_2O*	0.2–0.5	US EPA (2006), Popp et al. (2010)Bodirsky et al. (2012), Tubiello et al. (2013), Herrero et al. (2013), Gerber et al. (2013), FAO (2013a), FAO (2013b), EDGAR (2014),
Direct energy CO_2	0.11	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Embedded energy CO_2	0.02	Gerber et al. (2013), FAO (2013a), FAO (2013b)
Post-farm gate CO_2	0.023	Gerber et al. (2013), FAO (2013a), FAO (2013b)

Non- CO_2 emissions* (IPCC guidelines)	2.0–3.6	Herrero et al. (2016)
Total emissions (LCA approach)†	5.6–7.5	Herrero et al. (2016)

*Livestock emissions according to IPCC emissions guidelines (IPCC, 2006).

‡Range estimated using information from global analyses for key emissions source categories. LCA as implemented by FAO (Gerber et al., 2013).

† Includes N2O emissions from manures applied to pastures, and from fertilizers to croplands for both feed and pasture. Emissions from manure applied to pastures ranged from 0.42–0.95 GtCO_2eq.

Source: Herrero et al. (2016)

However, there are major problems of interpretation of these aggregated results. First of all, the synthesis recognized that the wide variation in the estimates arose because of differences in level of aggregation and methods used in estimation in different studies. Some of the estimates are based on Tier 1 approaches using default global or regional emission factors (USEPA, 2006; Popp et al., 2010. Bodirsky et al., 2012; Tubiello et al., 2013). Some used Tier 2 approaches (using estimated regional or local emission factors) for enteric fermentation (EDGAR, 2014). Some studies dis-aggregated emissions by country and region, species, production system and by product (milk, meat) (Herrero et al. 2013; Gerber et al., 2013). Some studies used Tier 2 methods for the IPCC emission categories and LCA methods for the other sources (Gerber et al., 2013; FAO, 2013a;   FAO, 2013b). One study (Herrero et al., 2013) used Tier 3 methods (application of a rumen kinetics model) for methane from enteric fermentation and Tier 2 methods for the other categories.

Second, even though LCA approach has been used in nearly all the studies, some studies covered cradle to farm gate while others covered up to processing yet others up to retail, hence sources of emission considered varied between studies. The degree of detail covered with respect to feed production and processing also varied between studies.

Third, emission is a continuous process, so its volume or rate varies over time. Consequently use of averages of aggregated data for different reference years over a decade to get an average yearly emission rate is conceptually problematic. For example, according to IPCC AR5, global total emission was 38, 40 and 45 GtCO_2eq respectively in 1990, 2000 and 2005 (IPCC, 2014). Thus without a specific reference year, estimation of livestock share in average total global emission over a decade is not very useful or accurate.

3.2 Estimates of global and regional dairy sector emissions

A study by FAO estimated dairy sector emissions of GHGs using LCA approach for reference year 2007 (FAO, 2010). The study focused only on cattle milk and related meat production. By dairy sector, the study meant all activities related to the feeding and rearing of dairy animals (milking cows, replacement stock and surplus calves from milked cows that are fattened for meat production), milk processing and the transportation of milk to dairy processing plants, and transportation of dairy products from dairy to retailers.

The study used four methodological innovations. First, it used GIS to store data and compute emissions for spatial resolutions consistent with geographically referenced data sources. Second, it used a dairy herd model that computes dairy related stock consisting of the number of cattle required to maintain a population of cows and surplus calves for meat production. Third, it included use of a feed basket computation model to link locally available feed resources, animal numbers and productivity. Fourth, it conducted sensitivity analysis with a range of values for various parameters of the model to see the stability of the results.

The aggregate emission estimates are summarized in Table 13. It appears that cattle milk and meat production contributed 1.969 $GtCO_2eq$ GHG accounting for 4% of global anthropogenic GHG emission in 2007. Milk production, processing and transportation accounted for 1.328 $GtCO_2eq$ or 67% of total emissions from the dairy sector or 2.7% of global total emissions of GHG; the remainder was attributed to meat production from the sector.

Table 13: Global dairy cattle milk and meat production and related GHG emissions, 2007

Commodity	Total production, Million tonnes	Total GHG emissions, $GtCO_2eq$*	Emission intensity, kg CO_2eq/kg product*	Share in global total emissions, %*
Milk (fat and protein corrected volume)	553	1.328	2.4	2.7
Meat from slaughtered dairy cows and bulls , carcass weight	10	0.151	15.6	0.3
Meat from fatted calves, carcass weight	24	0.490	20.2	1.0
Total		1.969		4.0

*Estimates are subject to ± 26% variation

Source: FAO (2010), p.33.

Emission intensity was 2.4 for milk and 17-20 for meat. The findings show that emission per kg of milk and meat are mostly affected by digestibility, milk yield per cow and manure management. The supporting uncertainty analysis, which assessed random variations in input parameters and emission factors, showed that emissions can range to plus and minus 26 % of the average emission per unit of milk. The results have been found comparable with findings of a number of studies conducted in the developed world using similar methodology. In some cases, emission intensities were found to be lower than the current study, which resulted from discrepancies in emission factors or allocation technique or the use of standard emission factor of Tier 2 in IPCC methodology in this study while use of country specific emission factors in others. The results are also comparable to intensities for cattle milk and meat reported in the Gerber et al. (2013) study for reference year 2005.

About 93% of the sectoral emissions occurred at the farm gate, and remaining 7% occurred in the post-farm segment of the dairy chain. The farm gate share was 90-99% in different developing regions and 78-83% in developed regions as a higher proportion of raw milk is sent to processing plants in the developed regions. For example, only about 62% of raw milk is processed in Asia while the ratio is 82-100% in the developed regions. Also end product of dairy processing varies between regions with implications for energy consumption and GHG emission.

Emission intensity ranged from 1.3 to 7.5 kgCO2eq per kg fat and protein corrected milk between regions as follows: developed countries 1.3 kg, North Africa and Near East 3.7 kg, South Asia 4.6 kg, and sub-Saharan Africa 7.5 kg. Comparison of the shares of global milk production and GHG emissions shows that in the developed countries, share of milk is much larger than the share in GHG emission while the opposite is the case in the developing countries. This is because of the differences in emission intensities between the regions. Higher productivity of cows in the developed countries means that emission per unit output is smaller than in the developing countries where productivity per cow is low due to the use of poor quality feed and other factors.

Emission intensity was 2.72 kg in grazing systems compared to 1.78 in mixed systems. But within each system, the intensity was lower in temperate ecozones compared to tropical/humid and arid zones.

In developed countries, methane, N_2O and CO_2 accounted for respectively 52, 27 and 21% of total sectoral emissions. The corresponding figures for the developing regions are 52, 38 and 10%. The higher share of N_2O in the developing regions is due to more manure being deposited on pasture and used as organic fertilizer.

Importance of methane is high especially in grassland systems of arid and humid climates, and in mixed temperate systems. The low digestibility of grass in the arid and, to a lower extent, humid regions is the main reason for the high methane emissions from grazing systems. N_2O accounted for 27-38% of emissions from milk production. Its share is relatively high for the arid zones and for grassland systems in humid environments mostly due to the deposition of manure on pasture and the use of dry lots for manure storage, combined with manure application to crops (mixed systems) in these climatic environments. The share of nitrous oxide in the temperate zones is substantially lower than in the arid and humid zones, because grazing time is limited and manure storage systems prevent high nitrous oxide emissions. Carbon dioxide accounted for on average 5 to 10 percent of the total emissions. Carbon dioxide emissions are highest in the temperate zones, most in industrialized countries, where milk production levels are highest and energy is used for feed production.

Two cautionary notes about the results of this study are as follows.
First, the study did not present global total emission figure for 2007 but mentioned that the sector contributed 4% of global total emission in 2007. On that basis, global total emission was 49.225 $GtCO_2eq$ in that year. But historical trend data on global total emissions presented in IPCC AR4 and AR5 (see Table 3 above) indicate that the actual total emissions in 2007 could not be 49 $GtCO_2eq$. Perhaps it would be around 47 $GtCO_2eq$. In that case, dairy cattle share in total global emission would be slightly higher at 4.2%. On the other hand, if actual emission from the dairy sector was lower than 1.969 $GtCO_2eq$ found in the study, dairy sector share in total global emission of 47$GtCO_2eq$ would be lower than 4%.

Second, the estimates are subject to 26% uncertainty with 95% confidence intervals. Even though the study claimed that the uncertainty coefficients are obtained from numerous model runs with changes in parameters, and the findings are consistent or comparable with other country specific studies on dairy sector emissions (FAO, 2010, p. 51), 26% uncertainty means a very large spread of the global averages.

So considering the high degree of uncertainty of the dairy sector emission estimates and uncertainty of the global total emission, the results should be interpreted with caution or reservation. These variations point to the need for more accurate estimate of both global livestock and dairy sector emissions.

Hagemann et al. (2011) quantified and compared GHG emissions of bovine milk production systems in 38 countries representing 70% of the world's bovine milk production. The analysis was based on the International Farm Comparison Network (IFCN) concept of typical dairy farms and the related globally standardized farms representing 45 dairy regions in the 38 countries. Various concepts and coefficients from the literature were used to estimate GHG emission from each farm, and the IFCN software TIPI-CAL was used to conduct a partial life cycle assessment of GHG emissions from dairy production. This approach was used in an attempt to make global comparison of GHG emissions from various dairy farming systems.

Results showed that emission intensity at the farm level varied from 0.8 to 3.1 kgCO_2eq per kg of energy corrected milk (ECM). The intensities were lower in the developed countries compared to the developing countries, the differences were mainly due to differences in milk yield/cow. Enteric CH_4 emission comprised the highest proportion of GHG emissions. Enteric and manure related emissions accounted for 70–95% of total emissions of farms depending on farming system. Comparison of various estimators for enteric CH_4 emissions suggested that these values might be underestimated. Therefore, the study recommended that in future research, dairy farms should be categorized into farming clusters based on their production intensity and feed usage, with equations to estimate enteric CH_4 emissions specific to cluster.

Lesschen et al.(2011) studied regional variations in dairy, beef, pork, poultry and egg production, and related GHG emissions in the 27 Member States of the European Union (EU-27), based on 2003–2005 data. Analyses were made with the MITERRA-Europe model which calculates annual nutrient flows and GHG emissions from agriculture in the EU-27. Main input data were derived from CAPRI (*i.e.,* crop areas, livestock distribution, feed inputs), GAINS (*i.e.,* animal numbers, excretion factors, NH_3 emission factors), FAO statistics (*i.e.,* crop yields, fertilizer consumption, animal production) and IPCC (*i.e.,* CH_4, N_2O, CO_2 emission factors). Sources of GHG emissions included were enteric fermentation, manure management, direct and indirect N_2O soil emissions, cultivation of organic soils, liming, fossil fuel use and fertilizer production.

The study found that the dairy sector had the highest GHG emission in the EU-27 followed by the beef sector. Enteric fermentation was the main source of GHG emissions in the European livestock sector (36%) followed by N_2O soil emissions (28%). Emission intensity was 22.6 kgCO_2eq/kg beef and 1.3 kg CO_2eq/kg milk. However large variations in emission intensity exist among EU countries, which are due to differences in animal production systems, feed types and nutrient use efficiencies. There are, however, substantial uncertainties in the base data and applied methodology such as assumptions surrounding allocation of feeds to livestock species. The study provided insight into differences in GHG sources and emissions among animal production sectors for the various regions of Europe.

Sevenster and DeJong (2007) reported emission intensity of 0.75-1.65 for developed countries while Opio et al. (2013) reported 1.6-1.7 for developed countries, and 2.0-9.0 for developing countries, with the highest intensity prevailing in sub-Saharan Africa.

3.3 National estimates of dairy sector emissions

The debate around livestock sector contribution to global GHG emission has attracted the attention of governments and researchers in some countries, especially in the developed world, to produce empirical evidence to develop strategy for mitigation and adaptation. Results on emission intensity from a number of such studies are summarized in Table 14.

Table 14: Emission intensity of milk production from sample dairy herds in selected countries

Data source	Study country	$kgCO_2eq/kg$ FPC milk
Foster et al., 2007	UK	1.14
Verge et al., 2007	Canada	1.0
Blonk et al., 2008	Netherlands	1.2
Thomassen et al., 2008	Nether lands	1.5-1.6
Basset-Mens et al., 2009	New Zealand	0.65- 0.75
Cappaer et al., 2009	USA	1.35
Thoma et al., 2013	USA	2.05
Cederberg et al., 2009	Sweden	1.0
Kristensen et al., 2011	Denmark	Organic 1.27 vs Conventional 1.20 0.9-1.10 after allocation to meat
Christie et al., 2011	Tasmania, Australia	1.4 (0.83-1.39)
Browne et al., 2011	SE Australia	8.5 - 9.4
Daneshi et al., 2014	Iran	1.57 at farm gate 1.73 at processing point
Weiler et al., 2014	Kenya	2.0 vs 1.6 *
Garg et al., 2016a	Gujarat, India	Cow 1.9 - 2.3 Buffalo 2.7-3.0 Both 2.2 vs 1.7*
Garg et al., 2016b	India (several states)	Cow 1.7 vs 1.2** Buffalo 2.4 vs 1.5**

* Without allocation to co-products vs when allocated to co-products to value multiple functions
** Emission with existing vs ration balancing diet

For interpretation and comparison of the estimates for different countries and years, several points need to be considered. Some studies are based on small samples of dairy herds from specific geographic areas while others are based on fairly large samples covering wider geographical areas with different breeds, feed resources, manure management systems and other production characteristics. In most cases LCA approach has been used to assess emissions of GHGs though the length of the dairy chain covered varied between studies as some used cradle to farm gate, others covered cradle to retail. Consequently sources of emissions considered were not the same. Methods of estimation varied especially as some studies were designed to test the efficacy of one or the other tools or methods for estimation of emissions, especially methane emission or assess emissions under different systems of production and manure management. Unlike global or livestock sector studies that mostly used IPCC default emission factors and Tier 1 methodology, these studies mostly used national data sources including national emission factors where available. Another major difference is that studies conducted in the developed countries considered only milk and meat as dairy herd output and used different allocation methods or ratios while in some developing country studies, alternative estimates have been made with and without consideration of multiple functions of smallholder herds including milk, meat, manure, finance and insurance functions.

Subject to these conceptual and methodological differences and limitations, the main feature of these estimates is that the emission intensities in the developing countries are only marginally higher than those in the developed countries. Intensities found in the developed countries are fairly similar to those found in the global and livestock sector studies by FAO but the intensities found for developing countries, especially in India, are over 60% lower than the intensities found for cattle in South Asia in the FAO studies (5.2 in Gerber et al., 2013 and 4.6 in FAO, 2010). The rates for buffalo are also slightly lower in the country level studies compared to the FAO studies.

A study in Denmark showed that emission intensity for milk was significantly higher in organic production system compared to conventional production system before any allocation was made to meat : 1.27 vs 1.20 kg CO_2eq/kg ECM ($p < 0.05$). But when allocation was made to meat using different methods and proportions, emission intensity for milk was 0.9 -1.10 CO_2eq/kg ECM and for meat was 3.41 - 7.33 kg CO_2eq per kg meat. The intensity for meat was highly sensitive to the method or proportion of allocation made to meat (Kristensen et al., 2011).

Share of CO_2 in total emission is much higher in the developed countries compared to the developing countries while opposite is the case for methane. Several studies reported that CH_4 contributes 45-70% of GHG emission intensity of milk in developed countries (e.g. Beukes *et al*., 2010; de Vries and de Boer, 2010; Bell *et al*. , 2011) and >75% of this is derived from enteric fermentation (Rotz *et al*., 2010). Studies in Kenya and India also showed that methane accounted for 68-76% of total emission intensity in milk production (Weiler et al., 2014; Garg et al., 2013; Garg et al., 2016a; Garg et al., 2016b).

Garg et al. (2013) studied 5019 cows and 7499 buffaloes from 327 villages in Andhra, Bihar, Uttar Pradesh, Rajasthan and Gujarat states in India to assess the effect of ration balancing diet on rumen function, feed conversion efficiency, milk yield and methane emission intensity. Results showed significantly higher milk yield and lower methane emission intensity with ration balancing diet compared to existing low quality diet. Ration balancing diet led to increased immunity and reduced parasitism due to better rumen function and feed conversion efficiency. An inverse relationship between milk yield and methane emission intensity was found.

Garg et al. (2016a) studied dairy animals on 60 smallholder farms in 12 villages in Anand district in Gujarat state in India using LCA approach to assess milk yield and emission intensity, and found mild inverse relationship between milk yield and emission intensity of GHG.

In another large study, 163,540 lactating cows and 163,550 buffaloes were monitored in northern, southern, eastern and western India where the National Dairy Development Board of India has been implementing a three year large-scale ration-balancing programme to increase milk yield of animals on smallholder farms (Garg et al., 2016b). These animals are managed with low quality feed resources and unbalanced diet resulting in productive and reproductive inefficiencies. The study used LCA approach taking cradle to farm gate as the dairy supply chain and feed production, enteric fermentation and manure management as system boundaries. The study explored effect of feeding balanced rations on milk yield and emission intensity using three allocation options: economic value, mass and digestibility. The results show that even with existing low quality feed resources and low milk yield, average emission intensities are comparable to those found in the developed countries. Feeding balanced rations significantly improved milk yield and reduced average emission intensity of milk on a lifetime basis by 31.2% and 34.7% in cows and buffaloes, respectively. Being based on a substantially large sample of dairy animals from ecologically different areas with animals of diverse characteristics, the results seem to be robust and representative of general South Asian situation.

4 MITIGATION AND ADAPTATION TO CLIMATE CHANGE

4.1 Options for mitigation of greenhouse gas emission

Within the framework of climate change, mitigation means a human intervention to reduce the sources or enhance the sinks of GHGs (IPCC, 2014). Within the ruminant livestock sector, methane from enteric fermentation, and methane and nitrous oxide from manure management are principal targets for mitigation in both developed and developing countries because of their dominant shares in total dairy sector emission. CO_2 emission at both ends of the supply chain – feed production and processing and post-farm gate transportation and processing - is more important in developed countries.

Many factors influence methane emissions from cattle including level of feed intake, type of carbohydrate and fat in the diet, size and growth rate, feed processing, addition of lipids or ionophores to the diet, milk production, and alterations in the ruminal microflora. Manipulation of these factors can reduce methane emissions from cattle (Johnson and Johnson, 1995; Jungbluth et al., 2001).

Most global studies predicted methane emissions from dairy cows based on their physiology and the animal's feed energy consumption. This may work better for systems with herds composed of fairly uniform animals in terms of breeds and size and feeding standards etc as found in the developed countries. But this approach may not give accurate emission prediction when herds are composed of animals with widely different traits and no uniform standards of feeding and management practices. Similarly, CH_4 and N2O emissions from manure may be predicted accurately if standard systems with minimal variation are in place. In developing countries, systems of manure management and disposal are widely different (Mitloehner et al., 2009; Hammond et al., 2015).

The basic premise for development of mitigation strategy and technology for CH4 is that feed conversion efficiency is the most important factor to be manipulated – more efficient feed conversion results in lower emission (Chase, 2009). However, 'one size fits all' strategy and technology will not work, rather mitigation options need to be tailored to local conditions and objectives. A major distinction needs to be made between large scale specialized systems with high milk yield and smallholder mixed farming systems with low milk yield. The significance of yield increase for reduction of methane emission intensity can be explained by the fact that in the US dairy sector, between 1944 and 2007, cow population decreased by 35.5%, milk output increased by 159%, milk/cow/day increased by 440%, total methane emission increased by 175% but methane emission per unit of milk decreased by 60% (Chase, 2009). Given that yield levels are already high in the developed countries, emission reduction may be possible along with marginal yield increase or without yield reduction (Grainger and Beauchemin, 2011).

In the developed countries, various options are being tried targeting both animal and farm or herd levels. At the animal level, the key objective is to optimize rumen fermentation and improve productivity through better feeds and feeding techniques including balanced ration (nitrogen and carbohydrate), addition of certain fat and other feed additives, and improved forage quality. At the farm level, herd management options considered include genetic selection, lower calving interval, lower age at first calving for heifers, lower culling rate, ration formulation, feedbunk management, increased feed efficiency and TMR's – total mixed rations. Another plausible option is improved breeding and animal health management to allow reduction of herd size with fewer high productive animals.

Where grazing based dairy is important, better management of grazing lands can improve productivity and create carbon sinks with the potential to help offset dairy sector emissions. Over a 30 year period, methane emission per kg output in Australia reduced by 30%, a significant part of that in the dairy sector, due to various interventions including better management of grazing and feed resources.

Some of the above strategies are likely to reduce CH_4 and N_2O emissions from manure due to better rumen degradation and digestion. Additional options for better manure management may be considered to ensure recovery and recycling of nutrients from manure, thereby increase its value. For example, treatment of manure in anaerobic digesters and biogas production may reduce CH_4 and N_2O emissions as well as improve the quality or value of manure as organic fertilizer.

Two examples are given below to illustrate real world application of some of the above options. Following USEPA guideline to improve livestock productivity to reduce methane emission per unit of product using cost effective technology, the Innovation Centre for US Dairy has been implementing the 'Cow for the Future' project since 2005 with a view to reduce methane emission from dairy cattle by 25% by 2020 (Knapp et al., 2011). The project envisaged that by 2015, 10-12% reduction in methane emission per unit milk would be possible by implementation of existing technologies and management practices. Additional 13-15% reduction by 2020 would be possible through investment in research to develop new strategies and technologies.

The project envisaged potential for reduction of methane through direct impact of five research areas as below:

Management practice	6-18%	Rumen function	5-10%
Herd structure	5-15%	Genetic selection	1-10%
Feed efficiency	6-8%		

Additional investment in research in microbial genomics and ecology, measurement technique, and mathematical modelling was envisaged to generate new strategies and technologies to significantly further reduce methane per unit of fluid milk.
The Canadian dairy industry has been testing several options with different timelines and potential for methane reduction (Table 15).

Table 15: Methods of reducing methane emissions from dairy cows and expected timeline

Timeline for development	Mitigation practice for the dairy industry	Expected reduction in methane
Immediate	Feeding oils and oilseeds	5 - 20%
	Higher grain diets	5 - 10%
	Using legumes rather than grasses	5 - 15%
	Using corn silage or small grain silage rather than grass silage or grass hay	5 - 10%
	Ionophores	5 - 10%
	Herd management to reduce animal numbers	5 - 20%
	Best management practices that increase milk production per cow	5 - 20%
5 years	Rumen modifiers (yeast, enzymes, directly fed microbials)	5 - 15%
	Plant extracts (tannins, saponins, oils)	5 - 20%
	Animal selection for increased feed conversion efficiency	10 - 20%
10 years	Vaccines	10 - 20%
	Strategies that alter rumen microbial populations	30 - 60%

Source: Adapted from Beauchemin and McGinn (undated)

In the developing countries, research, extension and development of technology for the dairy sector are usually focused on productivity improvement. Conscious testing and application of techniques for reduction of CH_4 and N_2O are rare. The principles behind various options being tried in the developed countries should be applicable in the smallholder mixed farming systems in Asia and other developing regions but the actual design or content of the interventions need to suit local situations. Because of existence of strong inverse relationship between milk yield and emission intensity over a wide yield range as found in a large Indian study (Garg et al., 2016), there is substantial latitude in low yielding smallholder mixed farming systems both for increasing yield and reducing emission. Studies in India also demonstrated that with ration balancing diets formulated for different states or ecological conditions based on currently used and available resources, emission intensity can be significantly reduced (Garg et al., 2016a, 2016b). In the same way, some of the other feeding and nutrition management strategies need to be developed based on assessment of existing local feed resources and types of improved feeds or supplements available locally. FAO (2013a) suggested that in South Asian mixed dairy farming systems, emission can potentially be reduced by 38% by improving feed and feeding practices, as well as animal health and husbandry compared to14 to 17% in mixed dairy systems in OECD countries through feed supplements, treatment of manure in anaerobic digesters and energy efficiency.

Some of the other options like reduction of herd size and genetic selection may also have limited applicability at the current state of dairy systems in developing countries. The aim of reduction of herd size is to keep fewer higher yielding animals. In smallholder systems, herd size, its composition and dynamic is a function of development and time. Smallholder farms maintain multifunctional animals for a reason but its importance declines with development. For example, once mechanization is adopted in the crop and transport sectors, redundant draft animals are usually replaced by dairy animals. Male calves to produce replacement draft animals are also replaced by female calves or cows, unless male claves are retained to raise as beef animals. As rural economies become more monetized and opportunities for saving and investment in formal financial institutions and instruments become easily accessible, importance of finance, store and insurance functions of livestock decline and gradually disappear. Unproductive animals previously maintained for non-economic reasons may also be culled in the face of intense feed constraints. Within this dynamic, reduction of herd size as a strategy can be applied opportunistically and its scope can be increased as systems change. For example, culling unproductive animals may be encouraged through provision of some kind of incentive as part of a genetic improvement programme.

Although genetics is fundamental for dairy development, the current poor and chaotic state of animal genetic resources and related programmes in most developing countries with few exceptions like China and Thailand, immediate application of genetic selection or manipulation as a tool for reducing methane emission has very limited scope. Even then, where genetic improvement through cross breeding or other means is pursued for increasing milk yield, opportunities for reducing emission intensity of CH_4

and N_2O through feeding and management options should be exploited. However, genetic selection should feature prominently in longterm strategy for adaptation to climate change (see more on this later).

FAO (2013a) suggested that there is 'emission intensity gap' (like 'yield gap') in various mixed livestock production systems in the developing countries i.e., there is wide variation in emission intensity between herds and farms within a system in an ecological area. Partially reducing this gap within existing production systems through promotion of appropriate mitigation options could potentially cut emissions by about 30%.

Choice of options for increasing yield and reducing emission of GHGs will depend on cost effectiveness as adoption of any option will depend on profitability. For example, types of fat and other feed additives suitable and cost effective for increasing yield and reducing methane emission intensity of high yielding cows in the developed countries may not be equally cost effective for low yielding cows in the developing countries because of poor yield response. A study on a sample of dairy farms in northern Germany showed that the farms were more GHG-efficient than cost-efficient – estimated potential cost savings was between 37.2% and 57.4% and potential savings in GHG emissions was between 24.9% and 41.3%. Cost and GHG emission reductions were complementary across a wide range: by moving from the status quo to cost-efficient production, at least 87.5% of the GHG saving potential would be tapped. Unlocking the remaining reduction potential would require a shadow price (abatement cost) of about €165/t CO_2 equivalent. From an input allocative point of view, a change from cost-efficient production to GHG-efficient production would require reductions in nitrogen use and an extension of diesel use. Compared to the sample average and the cost-efficient farms, GHG efficient dairy farms were characterized by a higher share of legumes and a longer effective lifetime of cows (Johannes et al., 2016).

The German study illustrated the kind of extension programme and policy support that might be needed to promote GHG reducing technology to dairy farms in a developed country situation. In non-standard smallholder mixed faming systems based on poor quality feed resources, such fine-tuned options would be difficult to diagnose yet the relevance of cost effectiveness and profitability of technical options can't be ignored in designing and promoting emission mitigation options for developing countries.

A global livestock system modelling exercise to assess outcomes of mitigation options for the livestock sector showed that there was large technical potential for reduction of GHG emissions (Table 16). But economic potential for reduction was less than 10% of technical potential because of adoption constraints, costs and numerous trade-offs. Whether economic potential for reduction of emissions in the dairy sub-sector and/or in the Asia region was any better than in the overall global livestock sector was unclear from the results (Herrero et al., 2016).

Table 16: Technical mitigation potentials of supply-side options for reducing emissions from the livestock sector – outcomes of a systems modelling exercise

Mitigation options	**Technical potential, $GtCO_2eq/yr$***
Improved feed digestibility, CH_4	0.68
Feed additives, CH_4	0.2 – 0.3
Manure management, CH_4, N_2O	<0.1
Genetics and herd management	0.1 - 0.25
CO_2 sequestration in grazing management	0.15 - 0.70
CO_2 sequestration in legume sowing	0.15
Rangeland rehabilitation	0.1 - 0.2
Avoid land use change due to ruminant production	0.25
Moderation of meat consumption	Large with high uncertainty

*Numbers have been derived from reading a figure, hence may contain small margin of error.

Source: Herrero et al., 2016 Figure 3, p.5

An interesting result of the model is that moderation of meat consumption has large technical potential (with high uncertainty in the estimate) for reduction of GHG because of possible dietary change towards more healthy food and accompanying changes in land use pattern. But its economic potential for adoption is unknown. This option is usually advocated by anti-livestock lobby in the developed countries where meat consumption level is high. In the poorer parts of the world, meat consumption levels are low so asking to limit meat consumption to reduce GHG emission in such situation is undesirable. Predictions are that with increased income, population and urban growth, consumption of livestock products will continue to increase rapidly for quite some time. However, as a general principle, efforts should be made to produce meat in the developing countries with reduced emission intensity.

Promotion of options for mitigation of GHG emissions will require policy support for research and development to generate and evaluate appropriate options; extension, advocacy and support services like communication, training, demonstration and network building to disseminate knowledge, increase awareness about the implications of GHG emission from livestock, and induce adoption. Financial incentives like soft loan and subsidy may be initially required in some cases to encourage adoption. Lessons learned from past resource conservation promotion projects and programmes in the agriculture sector may be useful in designing policy and support services for promotion of GHG mitigation options. One key lesson from conservation programmes is that technologies and management options with potential for increasing yield as well as reducing resource degradation have a higher potential for adoption than options that only reduce degradation.

Another lesson learning area is mitigation of industrial pollution (water pollution, land degradation, carbon emission) through regulations (prohibition and penalties) and financial instruments (polluter pay principle, incentives to reward self-control). Similar principles may be at least partially applied in case of pollution and emissions, especially in case of water pollution and smell, from manure because those are somewhat observable and measurable. But methane emission is neither directly observable nor easily measurable in developing country smallholder systems, hence finding appropriate instruments for promotion of options for mitigation of methane emission in such systems is likely to be more difficult.

4.2 Options for adaptation to climate change

Adaptation to climate change is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014).

Globally, crop-livestock systems produce over 90% of the world's milk supply and 80% of the meat from ruminants. Smallholder mixed crop-livestock systems are particularly important for livelihoods and food security of millions of poor people, especially in South Asia, some parts of Southeast Asia and sub-Saharan Africa, as they provide most of the staples consumed by poor people. Increased frequency and intensity of climate shocks such as drought, flooding and extreme temperatures are already occurring and they are likely to intensify. Increases in temperatures and changes in the amounts and patterns of rainfall are expected. These changes are likely to impact on smallholder livestock production systems through:

- change in production and productivity and quality of crops, crop byproducts and pastures,
- loss of animal productivity due to feed shortage and reduced feed quality, water stress and other physiological reasons,
- increased incidence of emerging diseases causing loss of livestock output due to increased morbidity and mortality, and rising health costs,
- change in seasonal water and feed availability,
- increase in prices of key resources like water, feed, and energy causing rise in production costs.

Several factors are at play so precise prediction of future climate scenarios is difficult. Consequently, the full range of climate change impacts on the mixed crop-livestock systems in the developing countries is not well understood, particularly in relation to impacts on food security and vulnerability of smallholder livestock keepers. On the other hand, these systems will be under considerable pressure in the coming decades to help satisfy the rapidly rising demand for crop and livestock products from rapidly increasing populations, particularly in South Asia and sub-Saharan Africa, where majority of the world's rural poor, hungry and malnourished people live (Thornton and Herrero, 2013).

These demands have to be met in the face of increased adverse effects of climate change, so options need to be designed for adaptation of livestock to, among others,

- increased heat and water stress,
- vegetation change and changes in forage quantity and quality,
- altered pests and disease risk, and
- increased risk of soil degradation.

It was mentioned earlier that emission statistics from the livestock sector got somewhat lost in the IPCC big picture about GHG emission. Similarly, virtually nothing is mentioned in the IPCC Assessment Report 5 – either in the synthesis or in the chapter on AFOLU- about adaptation options for the livestock sector. However, within strategic and general adaptation approaches to climate change recommended in AR5, examples of some specific options relevant for the livestock sector can be given (Table 17).

Genetics, feeds and health are three fundamental biological pillars of livestock production systems. As indicated in Table 18, there are opportunities for interventions in all three domains for adaptation to climate change. Dairy sector in the developed countries are better prepared to exploit these opportunities because of their longstanding accumulated experiences in the generation of technology and management practices suited to their own environments. Strategic application of some of the mitigations options in these domains may enhance adaptive capacity. The developing countries in Asia and SSA are less prepared in this regard. In the absence of significant efforts for mitigation of GHG emission in these regions, adaptation efforts will be long way ahead.

The Second Global Assessment of Animal Genetic Resources recognized that " livestock diversity facilitates the adaptation of production systems to future challenges and is a source of resilience in the face of greater climatic variability" (FAO, 2015b). In fact genetic diversities of both animals and forages are essential for food and livelihood security of millions of poor livestock keepers in the developing world. Thousands of genetically diverse breeds of domestic animals adapted to a wide range of environmental conditions, feed resources, disease conditions and human needs have resulted from human and natural selection over 12000 years. Many of these breeds have also become extinct because of human activity and many more are in the process of extinction. Similarly diverse varieties of crops and forages have evolved creating synergies with livestock as observed in crop-livestock mixed production systems.

Exploitation of domestic genetic diversity of animals and forages is not only the best bet strategy to cope with climate change in the developing countries; failure of numerous dairy development projects based on exotic breeds and forages in the tropics reinforces arguments based on longstanding historical experiences from the developed countries that domestic genetic diversity should be the basis for development of dairy breeds through selection and grading. At a later stage, crossing with exotic genes may be pursued once limits to gains from selection and grading of domestic breeds are reached.

Table 17: Approaches for managing the risks of climate change through adaptation and examples of specific options for the livestock sector

Adaptation approach or category	**Generic adaptation options for agriculture and NRM**	**Example of specific adaptation options for livestock sector**
Disaster risk managem ent	Early warning system	Livestock keepers warned about possible flood or drought to help take precautionary steps to face the situation and avoid losses.
Ecosystem managem ent	• Maintenance of genetic diversity • Seed bank, gene bank and other *ex situ* conservation	• Conservation and use of indigenous animal genetic diversity • Conservation and use of indigenous forage genetic diversity
	Community based natural resource management	Collective action for management of common property feed resources like grazing land, rangeland and forest margins
Physical/ technologi cal /services	New crop and animal varieties	New animal breeds and forage varieties developed to adapt to environmental stresses
	Conservation agriculture	• Arrest degradation of grazing land, forest margins, rangeland • Conservation of animal and forage genetic diversity
	Vaccination and disease control programme	• Epidemiology for disease mapping • Vaccine and control programmes to address new diseases

Institutional	Financial incentives	• Subsidies or other incentives for adoption of emission reducing and yield increasing technology • Easy loans for adoption of innovations
	Laws and regulations	• Laws and regulations to protect breed and forage varieties at risk • Regulations to protect common property resources & to support collective management • Regulations to control transboundary diseases
Social	Indigenous, local, traditional knowledge, technologies and methods	Exploit indigenous, local, traditional knowledge about adaptive traits and performance of animal breeds and forage varieties to local environments and stresses for designing breed and variety development programmes

Source: Columns 1 and 2 from IPCC (2014), p.27 and 96. Column 3, this study

The state of dairy animal breeding programmes in most of the developing countries in the Asia-Pacific region with the exception of Thailand and China, is very poor and unsystematic. The challenges of establishing and sustaining effective dairy animal breeding programmes in these countries should be addressed both for short term goal of increasing yield and mitigating GHG emission and the longterm goal of sustainably coping with climate change. In this endeavour, it will be useful to exploit indigenous, traditional knowledge about adaptive traits and performance of animal breeds and forage varieties to local environments and stresses (Jabbar et al., 1999).

At the general level, social, institutional, and ecosystem-based measures taken in any country for adaptation to climate change will directly or indirectly have some effects on livestock sector outcomes. Such measures are likely to be embedded in national planning processes. Adaptation options specific to the livestock sector should be undertaken with a view to reduce vulnerability and exposure to risks keeping in mind potential for co-benefits and opportunities within wider strategic goals and development plans. The adaptation strategies should be designed to achieve two complementary goals: (a) to enhance resource use efficiency throughout the livestock or dairy supply chains; in some cases, these efforts may generate mitigation co-benefits, e.g. increased feed use efficiency may also accompany reduced emission intensity; (b) to secure the livelihood of smallholder livestock producers and increase their food security.

Some adaptation options may be implemented based on existing knowledge. However, in the absence of precise future prediction of climate scenarios, it will be necessary to undertake systems modelling and longterm studies to monitor likely future climate scenarios especially focused on parameters that may have implications for the smallholder livestock systems. In terms of policy, efforts should be made to enhance macro level national decision making capacity to take sound risk-based and informed policy decisions, and increase the array of options available to cope with climate change (Howden et al., 2013).

Most of the developing countries may not have internal scientific capacity and resources to undertake such work. So opportunities for productive collaboration and link with international efforts like those of IPCC and FAO should be proactively exploited. IPCC recommended that "effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation" (IPCC, 2014).

5 SUMMARY AND CONCLUSIONS

Evidence on dairy sector GHG emissions was reviewed from two perspectives. First, taking 'a view from above' perspective, global trends in GHG emissions, sources of emission by type of gas and by sector were reviewed to trace the share of dairy in global emissions. Then taking 'a view from below' perspective, estimates done for livestock sector emissions including dairy, dairy sub-sector emissions alone, and emission from sample dairy herds using survey or experimental data were reviewed.

It appears from the 'view from above' perspective that the contribution of livestock to global GHG emissions got somewhat lost in the IPCC big picture about global emissions. Because of the use of IPCC guidelines, only direct non-CO_2 emissions have been considered yet due to aggregation of several manure related emission categories with other categories from agriculture sector into one category called 'agricultural soils', a full account of the direct emissions from livestock activities was not available. Information about specific contribution from dairy sub-sector has not been presented in IPCC reports.

From the 'view from below' perspective, it appears that there were few estimates of global livestock sector emissions and fewer still for global dairy sector. An increasing number of national level estimates based on varying sizes of sample dairy herds and geographic coverage are becoming available, especially from developed countries.

IPPC guidelines for estimation of GHG emission from the livestock sector recommend only non-CO_2 gases assuming CO_2 emission from the sector as neutral due to the balance of emission and sequestration. But most of the sectoral studies, irrespective of scale or geographic coverage, used LCA approach covering the entire supply chain, hence estimated CO_2 as well though the length of the chain covered varied across studies – some covered cradle to farm gate while others covered up to processing point, yet others up to retail point. Consequently sources of emissions considered were not the same. There are also differences in terms of other methodological issues e.g. emission factors (IPPCC default emission factors vs national or other sources), allocation methods (share of milk and meat, and other functions of livestock in multi-function mixed farming systems in developing countries), tools or methods used for estimation of emissions, especially methane emission, systems of production and manure management covered.

Subject to these conceptual and methodological limitations, some general findings are as follows:

- Livestock sector contributes around 14% of global GHG emissions.

- Dairy sub-sector accounts for about 4% of global emissions of which 2.7% is contributed by milk alone. Dairy contributes about 66% of livestock sector emissions and 36% of emissions by all ruminants.
- Developing countries share about 70% of ruminant emissions, mixed systems share nearly 60% and grazing systems about 40%.
- CH_4, N_2O and CO_2 share 40, 30 and 30% of livestock sector emissions.
- Methane alone account for about 75% of dairy sector emissions, N_2O and CO_2 account for 15 and 10% respectively.
- In sectoral studies, emission intensity for milk is several times higher in developing countries compared to developed countries (e.g. 5.2 or 4.6 in South Asia vs <2 in developed countries), and intensity is also higher in grazing systems compared to mixed systems of production but within both systems, intensity is higher in arid and topical ecozones compared to temperate zones
- However, in national level studies based on sample herds, emission intensity is only marginally higher in developing countries compared to developed countries (e.g. 1.7-2.3 vs 0.7 -1.5). With application of ration balancing diet, the gap in emission intensity between developed and developing countries reduce significantly to bring them closer. In some developed countries, national estimates show lower than IPCC estimate, e.g. Australia's national estimate for methane emission based on national inventory was 24% less than IPCC estimate.
- Generally, there is an inverse relationship between milk yield and emission intensity over a wide range of yield typical of developing country situations. In developed country situations with very high milk yield, the relationship is weak indicating marginal potential for reduction of emission intensity from increased milk yield. Where emission intensity is high, share of CH_4 and N_2O, especially CH_4, in total emission is large because of poor digestibility and feed conversion efficiency of low quality feeds and high enteric fermentation.

However, the above estimates and shares are subject to varying degrees of uncertainty due to differences in methodology and lack of appropriate data and emission factors. Estimates of livestock sector share in global emission vary from 8-51%. Coefficient of variation for estimates of other emission rates are as follows: methane from enteric fermentation 18%, methane from manure management 27%, N_2O from manure management 46% and for CO_2 from feed production, processing and land use change is even larger. Some national level estimates, mostly from developed countries, show even larger degrees of uncertainty. Usually direct measurement is a better option for more accurate estimation of both CH_4 and N_2O (Hammond et al., 2015).

In fact, inclusion CO_2 emission makes the estimate of total GHG emission highly uncertain especially in the developing countries because of the complexity and problems in using the LCA approach. This approach has been developed for standard industrial production systems and chains, and because of the highly uniform and standardized large scale dairy production systems in the developed countries, it may be fruitfully used there. But application of LCA is problematic for developing country situations dominated by smallholder mixed farming systems due to diverse species and breeds of animals with multiple products and functions, scales of production and processing and final product types, production and feeding systems, digestibility, feed conversion efficiency and productivity of animals, health and nutritional status of animals, and manure disposal and management systems.

Emission intensities for milk found in India, Iran and Kenya are only marginally higher than those found in the developed countries. Application of IPCC default emission factors from its 2006 guidelines (IPCC, 2006) on the large ruminant population in South Asia and other developing regions led to significantly over estimate total emission from these regions. Consequently, shares of these regions in global GHG emission have also been significantly over estimated. It is desirable to revise IPCC default emission factors for these regions on the basis of recent evidence from national and regional studies before the next IPCC assessment report is prepared so that national and regional shares in global emissions are realistically estimated.

From the findings, it is debatable whether LCA is better or more useful than IPCC guidelines for developing country situations, whether efforts spent on the estimation of CO_2 from feed production and land use change due to livestock or dairy in the developing countries is useful or worthwhile. Given scarcity of resources, a further point is whether it is necessary to spend resources simply to generate accurate data or precise data on emissions as argued by the Global Research Alliance on Agricultural Greenhouse Gases (GRA, 2014) or whether it will be more useful to generate more accurate estimation on emissions simultaneously with mitigation efforts.

In the developed countries various mitigation options targeted at both animal and herd/farm levels are being tried. Though both yield increase and emission reduction are goals, the emphasis is more on emission intensity reduction since yield levels are already high. Among various options considered includes increased feed efficiency, management practice for animals, manure and pasture, improving rumen function, changing herd structure to reduce size with fewer high productive animals, and genetic selection with probability of various degrees of emission reduction within short to medium term. Research on microbial genomics and ecology, measurement technique, and mathematical modelling are also pursued with a view to generate new strategies and technologies to significantly further reduce methane per unit of fluid milk.

In the developing countries in the Asia-Pacific region, technology and management interventions in the dairy sector are primarily aimed at improving productivity of low yielding local breeds. Planned and conscious efforts to address mitigation of GHG emission are rare. Studies have shown that compared to poor quality diet based on local feed resources, ration balancing diet with locally available resources results significant increase in milk yield and decrease emission intensity. Since studies have shown that there is inverse relationship between yield and emission intensity over a large yield range, hence developing countries have large latitude to simultaneously increase milk yield and reduce emission intensity by adopting appropriate mitigation options suited to local environments, breeds, feed resources and health conditions. For potential adoption, cost effectiveness of the mitigation options need to be given adequate attention.

A system modelling has shown that globally there is significant technical potential for reduction of emissions of various GHGs from the livestock sector through application of various mitigation options. But economic potential of emission reduction appeared to be less than 10% of the technical potential because of costs, adoption constraints and various trade-offs. Whether technical and economic potential for reduction for the dairy sector and in the Asia-Pacific region were any better than the global livestock sector was not clear from the modelling exercise. However, such modelling at the regional level might shed more light on the prospects for emission reduction.

The dairy sector in the developed countries are better prepared for adaptation to climate change because of their long-term experiences in generating technology and production systems based on domestic breeds, feed resources and health conditions. Some of the efforts currently being pursued for mitigation of GHG gas emission may eventually enhance capacity to adapt to long-term climatic change. In the absence of significant efforts to deal with mitigation, developing countries are less prepared to adapt to climate change. However, their best strategy will be to exploit domestic genetic diversity of animals and forages and design animal breeding and dairy development programmes on that basis. In this endeavour, it will be advisable to learn from historical experiences of dairy development in the developed countries as well as local and traditional knowledge about adaptive and performance traits of domestic breeds of animals and varieties of forages and crops.

Macro level national decision making capacity should be increased to take sound risk-based and informed policy decisions, and increase the array of options available to cope with climate change. For this, proactive and productive collaboration should be pursued with regional and international bodies dealing with climate change.

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