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Emission profile of Pakistan's agriculture: past trends and future projections

Muhammad Ijaz[1] · **Muhammad Arif Goheer**[1]

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Abstract

Reducing greenhouse gas (GHG) emissions is a global concern after Paris Agreement (PA). Identification of GHG emission sources and accurate and precise estimation of the corresponding emissions is the first step to meet reduction targets under PA. Increasing share of agricultural emissions in the global concentration has raised concerns on this sector. Now, reducing agricultural emissions without compromising food security is a real challenge. The present study was aimed to provide the current emission profile of Pakistan's agriculture, historical emission trends and future projections under agricultural growth scenarios according to prescribed guidelines of Intergovernmental Panel on Climate Change (IPCC) for national GHGs inventory development. In this study, GHG emissions were estimated using United Nations Framework Convention on Climate Change (UNFCCC) Non-Annex-I Inventory Software (NAIIS), version 1.3.2 as per prescribed Revised 1996 IPCC Guidelines. In these emission estimations, tier-1 approach (which employs default emission factors) was used in accordance with national circumstances and data availability in the country. The emissions baseline was projected for 2030 under business as usual (BAU), food security (FS) and enhanced consumption pattern (ECP) scenarios. Agriculture sector emitted 174.6 million tons (Mt) of carbon dioxide equivalent (CO_2-equivalent) emissions, of which 89.8 Mt is methane (CH_4) and 83.7 Mt is nitrous oxide (N_2O). Carbon monoxide (CO) emissions were found to be 1.07 Mt of CO_2-equivalent. Emission from agricultural soils constituted 45.5% of the total agricultural emissions followed by 45.1% from enteric fermentation and 6.5% from livestock manure management. The rest of 1.7% of the emissions were from rice cultivation followed by 1.1% from burning of crop residue. Historical emission trends showed that the agricultural emissions grew from 71.6 to 174.6 Mt of CO_2-equivalent from 1994 to 2015, a 143.8% increase over the period of 21 years. Emissions baseline projections were found to be 271.9, 314.3 and 362.9 Mt tons of CO_2-equivalent under BAU, FS and ECP scenarios, respectively.

Keywords Greenhouse gas emissions · Agriculture · Emission trends · Emission projections

✉ Muhammad Ijaz
muhammad.ijazmalik@gmail.com

Extended author information available on the last page of the article

1 Introduction

GHG emissions from AFOLU (Agriculture, Forestry and Other Land Use) sector are adding a significant share to the total global emissions, about 24% (IPCC 2014). In AFOLU sector, crop and livestock are major emission contributors. Annual average increase of 5 billion tonnes of CO_2-equivalent from crop and livestock production has been observed from 2001 to 2010 (Tubiello et al. 2014; FAO 2014). Agricultural activities are responsible for direct as well as indirect GHG emissions. CH_4 and N_2O are the main GHGs emitted directly by the agricultural practices (Iqbal and Goheer 2008). The source categories for these emissions are: enteric fermentation, manure management, rice cultivation, agricultural soils and field burning of agricultural residues as classified in IPCC revised 1996 guidelines (IPCC Guidelines 1997).

Economy of developing countries is mostly agriculture dependent. Expansion of agriculture to meet increasing food demands of burgeoning population in these countries has contributed significantly to the global emissions. FAO in its recent estimates has attributed an increase of 14% in global agricultural emissions (which 4.7–5.3 billion tons from 2001 to 2011) to expansion of agriculture sector in developing countries (FAO 2014). Pakistan is also an agro-based economy. Agriculture, as a major productive sector of economy, is contributing about 18.9% to the gross domestic product (GDP) of the country. Besides contributing more than a fifth of the country's GDP, agriculture also engages 42.3% of the labour (Economic Survey of Pakistan 2018). Despite advances in agriculture production, a sizeable number of population is food insecure. According to the Food Security Assessment (FSA) Survey 2016, Pakistan's 18% population is undernourished (National Food Security Policy 2018). National Institute of Population Studies (NIPS and ICF 2018) reported 45% severe stunting, 15% wasting and 30% underweight. The malnutrition problems are high in countryside areas (46%) and in certain regions like Federally Administered Tribal Areas (58%), Gilgit-Baltistan (51%) and Baluchistan (52%). Similarly, about half of the population is Vitamin-A and Iron deficient (National Food Security Policy 2018). Pakistan Vision 2025 and National Food Security Policy strategize to reduce the number of food-insecure people to half and move towards zero hunger by the end of 2030 (MoPDR 2013).

Recent national GHG estimates showed that agriculture sector is a major contributor after energy. According to these estimates (of 2011–2012), agricultural emissions are 43.5% of the total emissions (Mir and Ijaz 2016). These emissions grew from 71.6 to 162.8 Mt of CO_2-equivalent from 1994 to 2012, a 127% increase over the period of 18 years (Mir and Ijaz, 2016; UNFCCC 2003). This huge increase in agricultural emissions is alarming for Pakistan. The economic development and national food security has direct dependence on growth in agriculture sector. The future potential growth of this sector will results in significant GHG emissions. To fulfil the Nationally Determined Contributions (NDCs) commitment under PA to reduce GHG emissions without compromising agricultural growth will be a real challenge for the country in near future.

Sensitivity to climate change and major contribution to national GHG emissions portend a need for decision-making on adaptation and mitigation options in agriculture sector. Under such national and international circumstances, agriculture sector will need to increasingly adapt to climate change and engage in its mitigation. In order to unlock the adaptation and mitigation potential of agriculture sector, accurate and precise estimation of agricultural emissions from the country as per prescribed IPCC Guidelines for GHG inventories development is necessary. At present, national emission data of agriculture sector according to IPCC Guidelines are limited. The last available official estimates of national

GHG emissions were communicated in Pakistan's Initial National Communication (INC) submitted in 2003, a gap of about 16 years (UNFCCC 2003). The gap is critical and needs to be bridged with latest national GHG emission estimates in order to meet NDC commitments under PA without compromising national food security.

This study will help to bridge the gap by providing the current emission picture of Pakistan's agriculture, historical emission trends and future projections under agricultural growth scenarios in accordance with IPCC prescribed Guidelines for GHG emissions estimation. This information will provide a scientific base for designing adaptation and mitigation options in order to achieve climate resilient goals and Pakistan's international commitments under Sustainable Development Goals (SDGs) and Paris Agreement.

2 Methodology

Agricultural GHG emissions for the year 2014–2015 has been estimated using UNFCCC's Non-Annex I National Greenhouse Gas Inventory Software (NAIIS), version 1.3.2 as per prescribed IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines 1997). The IPCC Guidelines provide three types of GHGs estimation methods at different levels of details, from tier 1 to tier 3, where tier 1 is the most basic method that can be readily applied using available activity data and default emission factors, tier 2 is an intermediate method in terms of sophistication and effort which, in most cases, is based on the use of available activity data and more detailed or specific emission factors, and tier 3 is the most demanding method in terms of complexity and data requirements and usually implies the use of models and other complex equations and data. If implemented properly, all tiers can ensure unbiased results (IPCC 2006).

In this methodology, tier-1 approach using default emission factors in accordance with national circumstances and the data availability has been employed. These are based on regional defaults for Asian, South Asian or Indian Subcontinent available in the IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories. The reason for choosing tier 1 method over tier 2 or tier 3 is the availability of reliable quality data at national level, which is prerequisite for accurate and unbiased emission estimation. Higher tier methods are generally considered to be more accurate; however, if the data used for a higher tier method are of low quality, then accuracy can actually be worsened if switched from tier 1 to tier 2 or tier 3 method (IPCC 2006).

The main data sources used in these estimations are Agricultural Statistics of Pakistan 2015 and Pakistan Economic Survey 2015 (MoNFSR 2015; MoF 2015).

The following five types of source categories within agriculture sector have been considered in the GHG estimation process:

- Enteric fermentation.
- Manure management.
- Rice cultivation.
- Agricultural soils.
- Field burning of agricultural residues.

The methodology for GHG emissions estimation from each source category is provided below:

2.1 Enteric fermentation

Enteric fermentation is a natural fermentation process that takes place in the digestive system of the animals particularly ruminants during food digestion. In this process, methanogenic bacteria decompose and ferment the food under anaerobic conditions, resulting in CH_4 emissions, which act as one of the GHGs having 21 times higher global warming potential (GWP) than that of CO_2. Livestock types including cattle, buffaloes, sheep, goats, camels, horses, mules and donkeys have been considered in emission estimations under this category.

Enteric CH_4 emissions from the above-mentioned livestock types have been estimated using Eq. 1:

$$\text{Emissions}_{CH_4} = \sum \text{Population}_{\text{Livestock}} \times \text{Emission Factor}_{\text{Livestock}} \tag{1}$$

where Emissions_{CH_4} = methane emissions (Gg GHG), $\text{Population}_{\text{Livestock}}$ = total population of each type of livestock, and $\text{Emission Factor}_{\text{Livestock}}$ = default emission factors that are specific to climate region of Pakistan.

2.2 Manure management

Livestock manure, besides its positive use as natural fertilizer and as a fuel source for energy in rural areas, leads to GHG emissions in the atmosphere, hence contributing towards climate change menace. These manure management practices result in the emissions of both CH_4 and N_2O.

2.2.1 Methane (CH_4) emissions

CH_4 is emitted during anaerobic decomposition of manure organic matter in storage. Liquid manure management systems (including anaerobic lagoons, ponds and storage tanks) create anaerobic conditions resulting in up to 80% emissions, while in the case of solid storage manure management systems, there is very little or no CH_4 emission (IPCC Guidelines 1997).

2.2.2 Nitrous oxide (N_2O) emissions

Nitrification and denitrification of the nitrogenous (N) manure/organic fertilizer added to the crop lands or left in pastures result in N_2O emissions. The resulting N_2O emissions fall under the category of N_2O emissions from soils, therefore calculated under agricultural soils. N_2O is also emitted in storage, handling and application process of N-manure. Volatilization and consequent deposition of ammonia (NH_3) and nitrogen oxides (NO_x) from atmosphere result in indirect emissions of N_2O. NH_3 and NO_x are the other additional gases emitted from manure resulting in indirect emissions of N_2O.

Livestock types including cattle, buffaloes, sheep, goats, camels, horses, mules, donkeys and poultry have been considered in emission estimations under this category. Manure CH_4 emissions from these livestock types have been estimated using Eq. 2:

$$\text{Emissions}_{CH_4} = \sum \text{Population}_{\text{Livestock}} \times \text{Emission Factor}_{\text{Livestock}} \tag{2}$$

where $Emissions_{CH_4}$ = methane emissions (Gg GHG), $Population_{Livestock}$ = total population of each type of livestock, and Emission $Factor_{Livestock}$ = default emission factors that are specific to climate region of Pakistan.

2.3 Rice cultivation

Rice paddies are a large source of CH_4 emissions. Wetland rice cultivation (irrigated or rainfed), provides warm flooded soil conditions, which are ideal for methanogenesis. The process involving the decomposition of organic matter by methanogenic bacteria under anaerobic conditions results in CH_4 production, which primarily diffuses out through the rice paddies to the atmosphere during the growing season (IPCC Guidelines 1997). Although a large quantity of CH_4 escapes through rice plants, a significant part of it (CH_4) is trapped in the soil under flooded conditions which either bubbles out through water or escapes into the atmosphere during aeration practices like wet tillage or harrowing. Aeration practices trigger release of trapped CH_4 in the soils. Rice cultivation with multiple aeration practices results in more CH_4 emissions (IPCC Guidelines 1997).

The decomposition of organic material in rice paddies is due to the CO_2 respiration of microscopic organisms. More CO_2 in the atmosphere triggers growth of rice plants and this extra plant growth is the main source of energy for soil microorganisms for driving up their metabolism and resulting more consequent CH_4 emissions.

In Pakistan, rice for the year 2014–2015 was cultivated on 2.89 million hectares (ha), where rice was intermittently flooded with canals or tube wells and aerated singly (MoNFSR 2015). Methane emissions from rice paddies have been estimated using Eq. 3:

$$\text{Emissions}_{CH_4} = A \times \text{EF}_{CH_4} \tag{3}$$

where $Emissions_{CH_4}$ = amount of methane emissions from rice cultivation (Gg CH_4), A_{Type} = area under cultivation, ha, EF_{CH_4} = methane emission factor integrated over integrated cropping season in g/m^2 which is based on IPCC Revised 1996 Guidelines (10 g CH_4/m^2).

2.4 Agricultural soils

N_2O is the natural product of nitrification and denitrification processes in the soils. Oxidation of ammonium to nitrate by aerobic microbial activity is nitrification, while reduction of nitrate to nitrogen gas (N_2) by anaerobic microbial activity is called denitrification. N_2O gas was produced as an intermediate during the reaction cycle of denitrification, while it was as a by-product during nitrification process, which leaks from microbes into the soil and finally into the atmosphere. Direct and indirect emissions of N_2O are highly dependent on anthropogenic net N additions to soils (in the form of synthetic or organic fertilizers, manure application, or mixing crop residues) or mineralization of N in organic/mineral soils (e.g. conversion of forest land, grassland or settlements into cropland (IPCC Guidelines 1997).

Direct N_2O emissions occur due to addition or release of N from soils, while indirect emissions (from managed soils and biomass burning) occur due to (1) volatilization of NH_3 and NO_x, and the following redepositing of these gases along with NH^{4+} and NO^{3-} to soils and waters; and (2) leaching and runoff of N in the form of NO^{3-}.

Total N_2O-N emissions are as follows:

$$N_2O = N_2O_{DIRECT} + N_2O_{ANIMALS} + N_2O_{INDIRECT}.$$

Direct annual N_2O emissions have been estimated using Eq. 4:

$$N_2O_{DIRECT} = \left[\left(F_{SN} + F_{AW} + F_{BN} + F_{CR}\right) \times EF_1\right] + F_{OS} \times EF_2. \quad (4)$$

where N_2O_{DIRECT} = direct N_2O emissions from agricultural soils in country (kg N/year), EF_1 = emission factor for direct soil emissions (kg N_2O-N/kg N input), EF_2 = emission factor for mineralization due to cultivation of organic soil (kg N_2O-N ha/year), F_{OS} = area of cultivated organic soils within country (ha of histosols in FAO data base), F_{AW} = animal manure N used as fertilizer in country, corrected for NH_3 and NO_x emissions and excluding manure produced during grazing (kg N/year), F_{BN} = N fixed by N-fixing crops in country (kg N/year), F_{CR} = N in crop residues returned to soils in country (kg N/year), and F_{SN} = synthetic nitrogen applied in country (kg N/year). $F_{SN} = N_{FERT} \times (1 - Frac_{GASF})$. $F_{AW} = (N_{ex} \times (1 - (Frac_{FUEL} + Frac_{GRAZ} + Frac_{GASM}))$. $F_{BN} = 2 \times Crop_{BF} \times Frac_{NCRBF}$. $F_{CR} = 2 \times [Crop0 \times Frac_{NCR0} + Crop_{BF} \times Frac_{NCRBF}] \times (1 - Frac_R) \times (I - Frac_{BURN})$. N_{FERT} = synthetic fertilizer use in country (kg N/year). $Frac_{GASF}$ = fraction of synthetic fertilizer nitrogen applied to soils that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N input. N_{ex} = amount of nitrogen excreted by the livestock within a country (kg N/year). $Frac_{FUEL}$ = fraction of livestock nitrogen excretion contained in excrements burned for fuel (kg N/kg N totally excreted). $Frac_{GRAZ}$ = fraction of livestock nitrogen excreted and deposited onto soil during grazing (kg N/kg N excreted) country estimate. $Frac_{GASM}$ = fraction of livestock nitrogen excretion that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N excreted) (see Tables 4–19). $Crop_{BF}$ = seed yield of pulses + soybeans in country (kg dry biomass/year). $Frac_{NCRBF}$ = fraction of nitrogen in N-fixing crop (kg N/kg of dry biomass). $Crop_0$ = production of all other (i.e. non-N fixing) crops in country (kg dry biomass/year). $Frac_{NCR0}$ = fraction of nitrogen in non-N-fixing crop (kg N/kg of dry biomass). $Frac_R$ = fraction of crop residue that is removed from the field as crop (kg N/kg crop-N). $Frac_{BURN}$ = fraction of crop residue that is burned rather than left on field.

2.5 Field burning of agricultural residues

Residual burning of agricultural crops is not considered as a net source of CO_2 emissions, because the carbon released during burning is reabsorbed in the following growing season. However, the burning process of agricultural residues is an important net source of CH_4, CO, NO_x and N_2O emissions.

The estimation of actual amount of burnt biomass in the field is the important step in estimation of GHG emissions from crop residue burning. Emissions from field burning of agricultural residues of four crops, viz. sugarcane, rice, wheat and maize, have been estimated using Eq. 5:

$$\begin{aligned} \text{Total carbon released (tonnes of carbon)} = & \sum_{\text{all crop types}} \text{annual production (tonnes of biomass per year)},\\ & \times \text{ the ratio of residue to crop product (fraction)},\\ & \times \text{ the average dry matter fraction of residue (tonnes of dry matter/tonnes of biomass)},\\ & \times \text{ the fraction actually burned in the field},\\ & \times \text{ the fraction oxidised},\\ & \times \text{ the carbon fraction (tonnes of carbon/tonnes of dry matter)} \end{aligned} \tag{5}$$

2.6 Future projections

Baseline agricultural GHG emissions have been projected under future scenarios of agricultural growth. In current circumstances, country is economically and socially in transition and facing challenge of rapidly growing population and threats to its food security. Presently, 58% of the households are food insecure, where 18% of women and 31% (about 10.7 million) of children underweight (Development Initiatives 2018; National Nutrition Survey 2011). Ensuring food security for burgeoning pollution in future, creditable/ambitious agricultural GDP growth targets has been set by the government of Pakistan (National Food Security Policy 2018; UNFCCC 2016). As GDP growth is strongly linked with GHG emission pathways, the agricultural GHG emissions have been projected on the basis of following plausible future scenarios based on the laudable agricultural GDP growth rates;

2.6.1 Business as usual (BAU) scenario

The BAU scenario has been developed on the basis of average agricultural GDP growth rate in last 30 years. An average of about 3% growth per annum in agricultural GDP has been observed in the last 30 years. Hence, the BAU scenario has been developed on the basis of 3% growth in agricultural GDP per annum.

2.6.2 Food security (FS) scenario

The GHG emissions under BAU scenario are not consistent with future agricultural and economic growth anticipated to obtain developmental objectives of Pakistan as per Vision 2025 (UNFCCC 2016). Hence, the FS scenario (for quantifying future GHG emissions) has been developed on the basis of minimum agriculture growth rate of 4% in accordance with national food security policy to improve food security and ensure minimum nutritional value for the growing population.

2.6.3 Enhance consumption pattern (ECP) scenario

In a scenario of economic growth, per capita income growth in low- and middle-income countries like Pakistan would accelerate a transition in consumption pattern towards higher caloric intake (in the form of milk, meat and fruits) in future (FAO 2017). A healthy rise in GDP (over 4% per annum) is expected due to impact of massive developmental plans and especially due to China–Pakistan Economic Corridor (CPEC). This improvement in GDP will result in changed dietary habits of the large proportion of population, hence putting

Table 1 Summary of GHG emissions from the agriculture sector (Mt of CO_2-equivalent)

Source category	CH_4	N_2O	CO
	89.8	83.7	1.1
Enteric fermentation	78.8		
Manure management	7.4	4.0	
Rice cultivation	3.0		
Agricultural soils		79.4	
Field burning of agricultural residues	0.6	0.3	1.1

agriculture growth under pressure. Accordingly, agricultural growth has to be increased over 4% to meet these needs. In this context, the ECP scenario has been developed on the basis of anticipated 5% agricultural growth in future.

3 Results and discussion

3.1 Overview of agricultural GHG emissions

GHG emission estimates for the year 2014–2015 showed that agriculture sector emitted 174.6 Mt of CO_2-equivalent emissions, including 89.8 Mt of CH_4, 83.7 Mt of N_2O and 1.1 Mt of CO emissions (Table 1). High concentration of CH_4 and N_2O emissions was attributed to large populations of different livestock types. Besides direct emissions, large amount of indirect emissions were associated with low efficiency and poor management of livestock systems, which resulted in higher emissions. The results are in line with the findings of the Gerber et al. (2013), which confirmed that CH_4 is major part of the global anthropogenic emissions, 44%, followed by 29% of N_2O and 27% of CO_2 emissionws. Livestock sector contributes 44% of CH_4 emissions, 53% of N_2O and 5% of CO_2 emissions to the global total.

Emissions from agricultural soils were 79.4 Mt of CO_2-equivalent that accounted for 45.5% of total agricultural emissions followed by 78.8 Mt from enteric fermentation constituting 45.1% emissions within agriculture. 6.5% of the total CO_2-equivalent emissions were attributed to manure management from livestock, contributing 11.4 Mt to the total GHG output. The rest of 1.7% of the emissions were from rice cultivation followed by 1.1% from burning of crop residues, both contributing 3.0 Mt and 1.9 Mt of CO_2-equivalent, respectively, to the total agricultural emissions (Fig. 1). Agricultural soils and enteric fermentation were key categories contributing more than 90% emissions to the agricultural total. The rest of three categories, i.e. manure management, rice cultivation and field burning of agricultural residues, just contributed 9.4% share to the total emissions.

The major share of 91% emissions from enteric fermentation and agricultural soils was due to the facts associated with their corresponding source activities and driving factors for emissions. The large population of livestock with higher emission factors were responsible for more than 45% emissions through enteric fermentation, while the increased use of synthetic fertilizers, large quantity of manure left in the fields or added as organic fertilizer and increased burning of crop residues had made 'agricultural soils' another major contributor (about 45.5%) to the total emissions. The findings are in line with FAO estimates reported by Tubiello et al. (2013) which showed enteric fermentation as the largest source of CH_4

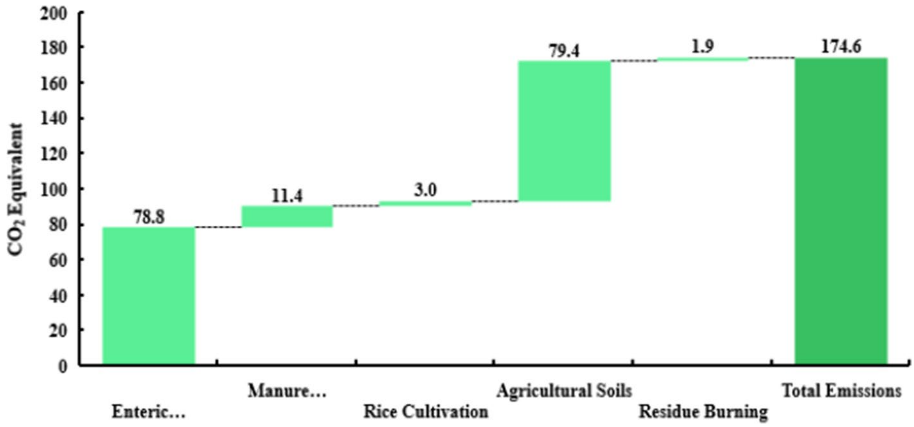

Fig. 1 Sub-sectoral emissions from agriculture sector (Mt of CO_2-equivalent)

emissions, 40% of total emissions from 2000 to 2010, followed by emissions from agricultural soils due to manure left, use of synthetic fertilizer and crop biomass burning. In 2010, agricultural soils, similar to enteric fermentation, contributed 37% to total emissions over the period of 10 years. Similar findings were reported by Patra (2014) that in India, enteric fermentation was major source of CH_4 emissions for the year 2010 contributing 91.8% of total emissions, followed by 7.04% of CH_4 and 1.15% of N_2O emissions from manure management.

3.1.1 Enteric fermentation

Livestock types, their population distribution and CH_4 emissions from each type due to enteric fermentation are shown in Fig. 2.

The results showed that total enteric CH_4 emissions were 78.8 Mt of CO_2-equivalent. Buffaloes were the single largest emitting livestock type, which contributed 1.87 Mt of CO_2-equivalent accounting for 49.8% of total enteric CH_4 emissions. Cattle were the second largest emitting type contributing 1.29 Mt of CO_2-equivalent of enteric CH_4 emissions including 0.73 Mt from non-dairy and 0.56 Mt from dairy cattle constituting 19.4% and 14.9% of the total enteric emissions, respectively. Other livestock types, namely goats, sheep, camels, horses, and mules and asses and others, emitted 0.6 Mt of CO_2-equivalent enteric CH_4 emissions constituting 15.9% of total CH_4 emissions from this category.

Major emissions by buffalo were mainly due to its large population and highest CH_4 emission factor (which is 55 kg/head/year, IPCC Guideline 1997) compared to other livestock types as shown in Fig. 2. The only livestock type having large population than buffalo was goat, but due to its lower CH_4 emission factor (5 kg/head/year), its emission contribution was far less than buffaloes. Similarly, non-dairy cattle were the second largest type in its population after buffalo. It was the large population and higher CH_4 emission factor (25 kg/head/year) that made it the second largest emitting type. The third largest emitting livestock type was dairy cattle. Although its population was small as compared to many other livestock types, its CH_4 emission factor, the second highest after buffalo, had made this type third largest emission contributor in enteric fermentation. The reasons for small emissions from other livestock types were due to either their small populations or

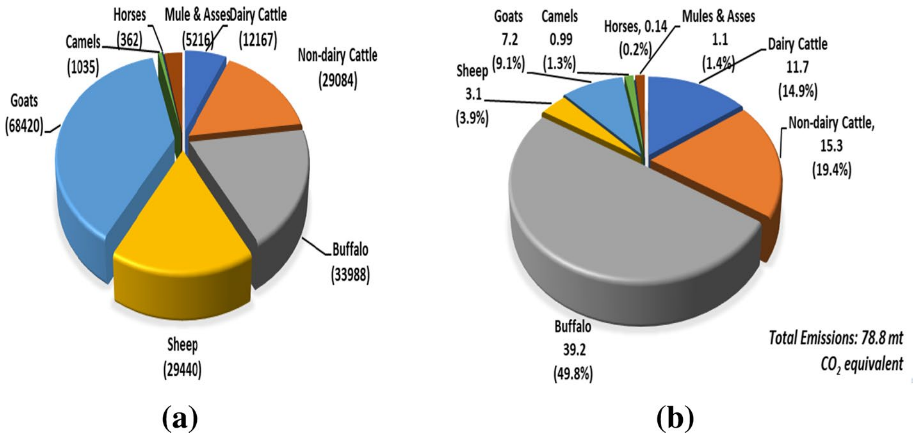

Fig. 2 **a** Livestock population (in '000 heads) and **b** emissions from enteric fermentation (Mt of CO_2-equivalent)

low CH_4 emission factor or both. Patra (2014) reported similar findings that enteric CH_4 emissions were a major share of global GHGs from livestock, 85.6% in 2010. Cattle alone contributed 73.7% of the world total enteric CH_4 emissions, followed by 11.3% of buffalo, 6.36% of sheep, 4.86% of goats, 1.17% of camel, 1.11% of horse and other livestock. Similarly, in India, cattle were the major CH_4 emitting livestock type accounting 49.1% of the total enteric emissions, followed by 42.8% by buffalo, 5.38% of goats, 2.59% of sheep and 0.73% from other livestock types.

3.1.2 Manure management

Manure management leads to emissions of CH_4 and N_2O gases. Results of CH_4 emissions from manure management of different livestock types and N_2O emissions from different Animal Waste Management Systems (AWMSs) are shown in Fig. 3a, b, respectively. The results showed the total manure emissions of 11.4 Mt of CO_2-equivalent accounting for 7.41 Mt of CH_4 and 4.03 Mt of N_2O emissions. Among all livestock types, buffalo was ranked first in emitting large amount of manure CH_4 contributing about half (48.1%) of total manure CH_4 emissions, followed by dairy cattle (20.7%), non-dairy cattle (16.5%), poultry (6.1%), goats (4.3%) and others (3.73%) including sheep, camels, horses, mules and assess (Fig. 3a). The major emissions by buffalo were mainly due to its large population and highest CH_4 emission factor (which is 55 kg/head/year, IPCC Guideline 1997) compared to other livestock types.

Similarly, dairy cattle were the third largest livestock type in its population after buffalo and non-dairy cattle. The CH_4 emission factor for manure management of dairy cattle is about three times (6 kg/head/year) of the emission factor of non-dairy cattle. It was the higher CH_4 emission factor that made it the second largest emitting type. The third largest emitting livestock type was non-dairy cattle, mainly due to its large manure contribution by its large population after buffaloes. The reasons for small emissions from other livestock types were due to either their small populations or low CH_4 emission factors or both. These findings are in line with the Patra (2014) study which declared buffaloes (50.8%) as

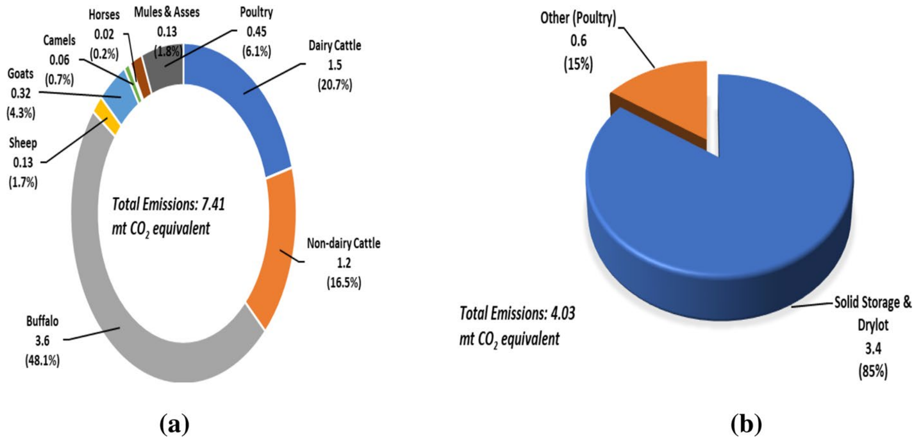

Fig. 3 Emissions from manure management: **a** CH_4 and **b** N_2O (Mt of CO_2-equivalent)

the major contributor of manure CH_4 emissions in India followed by cattle (39.6%), goat and sheep. Manure CH_4 emissions are also in line with the Khan and Baig (2003) findings which showed that enteric and manure CH_4 emissions from domestic livestock were 58.6% to Pakistan's total CH_4 emissions in 2000. Buffaloes were ranked first emitting 73.2% of total CH_4 emissions from domestic livestock.

Two AWMSs including solid storage and drylot and other (poultry) emitted 4.03 Mt of CO_2-equivalent N_2O emissions accounting 85% from solid storage and drylot and 15% from poultry manure (Fig. 3b). Major contribution of N_2O emissions from solid storage and drylot was mainly due to two reasons: i) large manure collection and management from buffaloes, dairy and non-dairy cattle and ii) higher nitrogen (N) excretion rate which is 40, 60 and 40 kg/head/year for buffaloes, dairy and non-dairy cattle, respectively, while less emission contribution from poultry waste management system was due to lower N excretion rate (0.6 kg/head/year). Similar findings were reported by Owen and Silver (2014) in their study which declared corrals and solid manure piles as major sources of N_2O emissions contributing about 1.5 + 0.8 and 1.1 + 0.7 kg N_2O per head per year, respectively. Similarly, Patra (2014) study also confirmed that the major emission contributors were buffaloes (31.4%) followed by 26.8% of cattle, 15.8% of goats, 15% of poultry, 7.8% of sheep and the rest by other livestock types.

3.1.3 Rice cultivation

Rice cultivation on an area of 2.89 million hectares for the year 2014–2015 with intermittently flooding coupled with single aeration emitted 3 Mt of CO_2-equivalent CH_4 emissions accounting 1.7% of the total national emissions from agriculture sector. In the case of Pakistan, rice is cultivated under intermittent irrigation/flooding with little or no organic amendments and single aeration. Such conditions throughout the season were the reasons of less CH_4 emissions from rice cultivation in 2014–2015. The findings are in agreement with the studies conducted by Wassmann et al. (2000) for Northern India region which found low emission rates (20 kg CH_4/hectare/season), as compared with South East Asian Countries, that were attributed to intermittent irrigation and no use of organic manure.

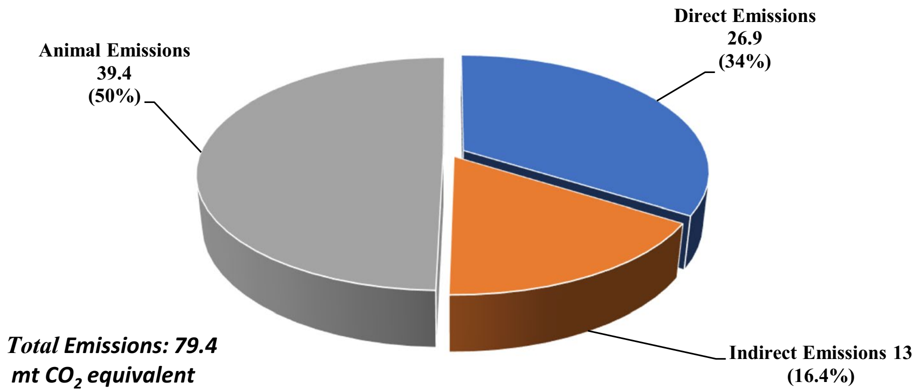

Fig. 4 N_2O emissions from agricultural soils (Mt of CO_2-equivalent)

3.1.4 Agricultural soils

Total N_2O emissions from agricultural soils were 79.4 Mt of CO_2-equivalent accounting for 39.4 (50%) Mt of animal emissions from animal waste produced by grazing animals at pasture range and paddock, followed by 26.9 (34%) Mt of direct emissions from agricultural fields and 13 (16.4%) Mt of indirect emissions from atmosphere due to deposition of NH_3 and NO_x (Fig. 4).

All types of emissions including animal emissions from pasture range and paddock, direct and indirect N_2O emissions from agricultural soils depend on amount of N present in the soils. In Pakistan, animal waste from different livestock types including cattle, buffalo, sheep and poultry is managed through four AWMSs: (1) solid storage and drylot, (2) daily spread, (3) pasture range and paddock and (4) other (for poultry). Daily grazing animals including cattle, buffaloes, sheep, goats, camels, horses, mules and asses are major source of N additions to the pasture range and paddock. It was large amount of waste produced by (large population of) grazing animals that resulted in large quantities of N_2O emissions from pasture range and paddock. The findings are in agreement with analysis of global emissions by Tubiello et al. (2013) which showed that emissions from the pastures due to left over manure by grazing animals were far larger than those from agricultural soils due to application of organic fertilizers. About 80% share was from developing countries, where grazing cattle contributed two-thirds of the total, followed by sheep and goats.

As shown in Fig. 5, direct N_2O emissions from agricultural fields included 14.5 Mt due to synthetic fertilizer (FSN), 12 Mt due to Animal Waste (FAW) and 0.4 Mt of CO_2-equivalent due to Crop Residue (FCR). Synthetic fertilizers were ranked first contributing 53.9% to the total direct emissions from agricultural fields followed by 44.7% from animal waste and 1.3% from crop residue burning. Indirect N_2O emissions accounted for 6.7 (51.6%) Mt due to volatilization of N from synthetic fertilizers followed by 6.25 (48.1%) Mt of CO_2-equivalent from leaching of N from synthetic fertilizers and animal waste.

Similarly, it was again synthetic fertilizer's N that contributed major share (to indirect N_2O emissions) of 51.6% due to its N volatilization than those of 48.1% by leaching of N collectively from synthetic fertilizers and animal waste. High concentration of N_2O emissions from agricultural fields after pasture range and paddock was due to large application

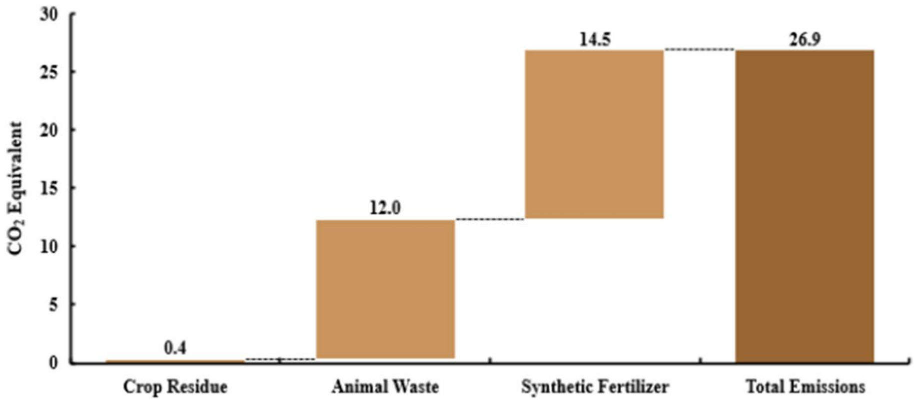

Fig. 5 N_2O emissions from agricultural fields (Mt of CO_2-equivalent)

of animal manure and synthetic fertilizers in these fields. Synthetic fertilizers due its large application than those from animal waste and crop residue burning were mainly responsible for higher emissions from agricultural fields. The findings are in line with those of the Tubiello et al. (2013) which confirmed that largest absolute growth rates for emissions were due to synthetic fertilizer, an average of 19% per year from 1961 to 2010. Similar findings were reported by Tian et al. (2015), which confirmed N_2O emissions increased with the highest increasing rate in croplands due to the increased use of N fertilizer and animal manure application.

3.1.5 Field burning of agricultural residues

In Pakistan, residues of wheat, maize, rice and sugarcane are mainly burnt in the field. The same were considered for estimation of CH_4, N_2O and CO emissions due to their residual burning at fields for the year 2014–2015. Out of 53.6 Mt of crop residue produced in 2014–2015, 8.9 Mt (16.6%) was burnt which contributed 1.9 Mt of CO_2-equivalent emissions accounting for 1 Mt (52.6%) of CO followed by 0.6 (31.6%) Mt of CH_4 and 0.3 (15.8%) Mt of N_2O emissions (Fig. 6).

Out of total 1.9 Mt of CO_2-equivalent emissions from residual burning, rice contributed about 0.85 (45%) Mt comprising 0.46 (54.1%) Mt of CO, 0.24 (28.2%) Mt of CH_4 and 0.15 (17.6%) Mt of N_2O emissions followed by 0.52 (27.4%) Mt by wheat crop comprising 0.31(59.6%) Mt of CO, 0.16 (30.8%) Mt of CH_4 and 0.05 (9.6%) Mt of N_2O emissions. Sugarcane contributed a share of 0.48 (25.3%) Mt of CO_2-equivalent emissions comprising 0.27 (56.2%) Mt of CO, 0.14 (29.2%) Mt of CH_4 and 0.07 (14.6%) Mt of N_2O emissions followed by 0.04 (2%) Mt by maize crop comprising 0.02 (50%) Mt of CO, 0.01 (25%) Mt of CH_4 and 0.01 (25%) Mt of N_2O emissions (Table 2).

Rice major contribution to emissions was due to its large amount of residues (47.7%) burnt. The results are in line with the findings of Irfan et al. (2015) where rice residues were found responsible for larger emissions constituting 51% of CH_4 and 65% of NH_3 in Sindh Province.

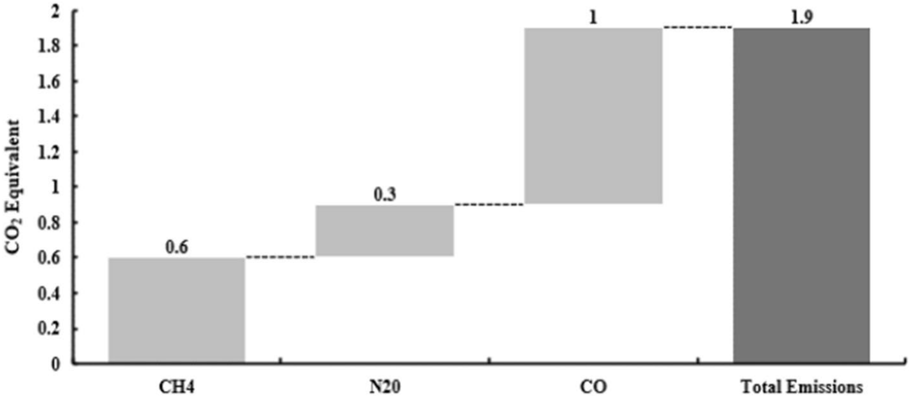

Fig. 6 N_2O emissions from field burning of crop residues (Mt of CO_2-equivalent)

Table 2 GHG emissions from field burning of crop residues (Mt of CO_2-equivalent)

Crop	CH_4 0.6	N_2O 0.3	CO 1	Total 1.9
Rice	0.24	0.15	0.46	0.85
Wheat	0.16	0.05	0.31	0.52
Sugarcane	0.14	0.07	0.27	0.48
Maize	0.01	0.01	0.02	0.04

3.2 Agricultural GHG emission: historical trends

Analysis of GHG emissions from Pakistan's agriculture in 1994,[1] 2008,[2] 2012[3] and 2015 showed an increasing trend (Fig. 7). Overall agricultural emissions grew more than two-folds from 71.6 to 174.6 Mt of CO_2-equivalent, about 144% over the period of 21 years. In all past estimates, agricultural soils and enteric fermentation were found as key categories contributing more than 90% emissions. The emissions from these two categories grew from 8.9 to 79.4 Mt (792%) and 52.3 to 78.8 Mt (50%) of CO_2-equivalent, respectively, from 1994 to 2015.

The trend showed that agricultural soil emissions increased at a higher rate than those from any other category except crop residue burning, where its share was not significant to the total emissions. This increase at a higher rate has left behind the enteric emissions which had been higher in the past. The reason behind this had been the increased use of source agricultural inputs (i.e. organic/synthetic fertilizer, crop residue burning and mixing, etc.) in order to increase per unit production, which resulted in more emissions. Over the

[1] Emissions were reported in Pakistan's Initial National Communication on Climate Change (UNFCCC 2003).

[2] Emissions were reported in Applied System Analysis Division (ASAD) GHG Inventory Report 2008 (Ahmad et al. 2016).

[3] Emissions were reported in Global Change Impact Studies Centre (GCISC) GHG Inventory Report 2012 (Mir and Ijaz 2016).

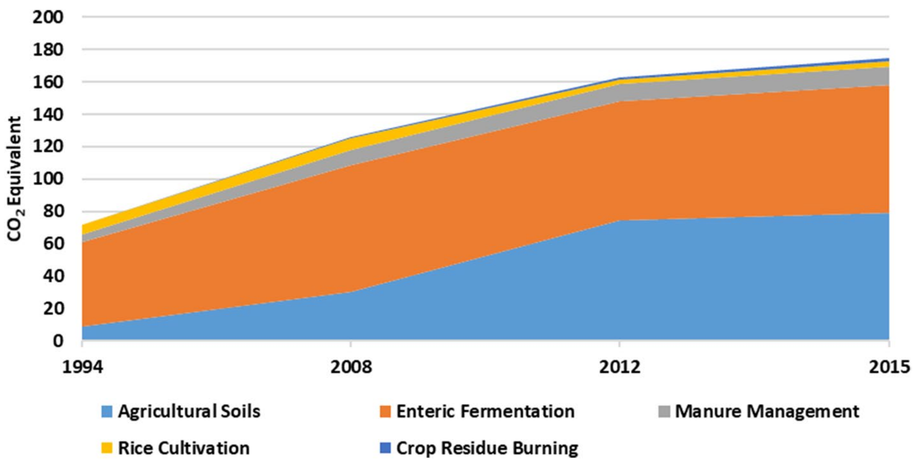

Fig. 7 Agricultural GHG emissions: historical trends (Mt of CO_2-equivalent)

period of 21 years (1994–2015), improved technology, increasing food demands and market competition had also replaced the conventional agriculture by commercial agriculture. This also added to the accelerated rate of emissions from agricultural soils. The findings are in agreement with those of the Tubiello et al. (2013) which declared synthetic fertilizers as a major source of growing emissions, where global soil emissions due to synthetic fertilizers grew more than ten times, i.e. from 0.07 to 0.68 Gt of CO_2-equivalent per annum from 1961 to 2010, with the largest absolute growth rate of 19% annually. And, during 2000–2010, average GHG emissions from synthetic fertilizers were dominated by developing countries with a contribution of 70% in 2010. Similar results were found in Iqbal and Goheer (2008) study which found more N_2O emissions (70%) due to the increased use of nitrogenous fertilizers.

A sharp increase in enteric emissions was attributed to governmental policies and increasing demand of high-value food like milk, meat and butter which had made livestock rearing a lucrative business over the period of last two decades. The share of livestock in agriculture GDP (58.92%) and national GDP (11%), in 2017–2018 has increased from 3.76 to 2.99% during the corresponding period of last one year (MoF 2018). This increase in livestock population with added high emission factors had triggered the enteric emissions. Iqbal and Goheer (2008) also confirmed that increasing enteric emissions trend during the past decade (1996–2006) was due to increasing livestock population, where enteric emissions grew from 2.6 to 3.4 Tg per year. Similar results were reported by the Tubiello et al. (2013), which showed that about 1.5 Gt of CO_2-equivalent annual enteric emissions were from the developing countries in 2010 which were 75% of the global emissions.

Manure emissions also grew with increasing trend from 4.8 to 11.4 Mt of CO_2-equivalent, an increase of 137%. This sharp increase of 137% from 1994 to 2015 was also because of increasing livestock population. The results are in agreement with findings of Iqbal and Goheer (2008) and Tubiello et al. (2013) which showed a linear increase of 10.6% in CH_4 emissions in Pakistan (from 2000 to 2001) was followed by a sharp increase of 6.6% in 2005–2006 due to increasing livestock population. Tubiello et al. (2013) also confirmed that about 80% share of emissions from manure management was from developing countries.

Rice CH_4 emissions showed a decreasing trend, where emissions decreased from 5.6 to 3.0 Mt (46%) of CO_2-equivalent, a decrease of 46%. This decrease was attributed to the practice of following intermittent irrigation rather than the complete flooding. The findings were confirmed by the Wassmann et al. (2000) study which found low emission rates (20 kg CH_4/hectare/season), in Northern India region as compared with South East Asian Countries, that were attributed to intermittent irrigation and no use of organic manure. Emissions from crop residue burning also showed an increasing trend, where they grew from 0.04 to 1.9 Mt of CO_2-equivalent, an increase of 4650% from 1994 to 2015. The reason behind this was increasing practice of burning at fields rather than using as straw for cattle due to modern harvesting technologies and commercial farming. According to an estimate, total amount of residue produced in 2014–2015 was 53.6 Mt, of which approximately 8.9 Mt (16.6%) was burnt in the fields. This included 47.7% share of rice residues burnt followed by 27.4% by wheat, 22.8% by sugarcane and the remaining 1.98% by maize residues. Irfan et al. (2015) endorsed that rice residues were responsible for larger emissions in Pakistan.

3.3 Emission baseline projections

Baseline emissions (of 2015) were projected for 2030 under BAU, FS and ECP scenarios. Overall agricultural and sub-agricultural emission trends till 2030 are shown in Fig. 8. In the case of sub-agricultural categories, emission trends of manure management, rice cultivation and crop residue burning are with respect to primary axis and those of agricultural soils and enteric fermentation are shown with respect to secondary axis.

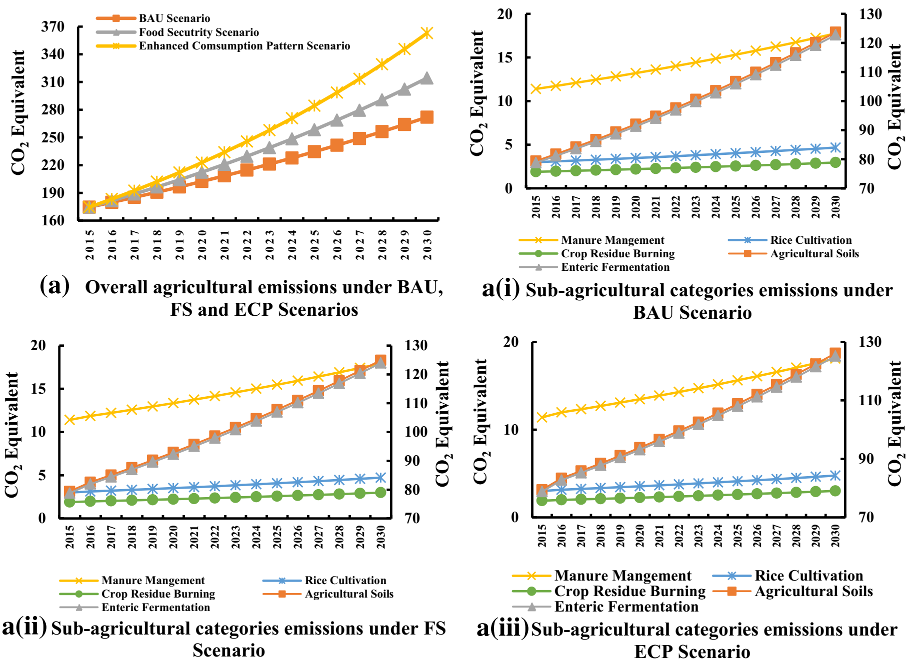

Fig. 8 Emissions projection trends till 2030 under BAU, FS and ECP scenarios

Results showed that overall agricultural emissions are expected to increase almost linearly (till 2030) up to 271.9 (56%) Mt, 314.3(80%) Mt and 362.9 (108%) Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. In the case of sub-agricultural categories, similar pattern is observed in emission trends of agricultural soils and enteric fermentation, where an almost linear increase is expected till 2030. Soil emissions from agricultural land are expected to increase up to 123.7 Mt, 124.9 Mt and 126 Mt of CO_2-equivalent followed by enteric emissions of 122.8 Mt, 123.9 Mt and 124 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. Similarly, emissions from livestock manure management are expected to increase steadily up to 17.8 Mt, 17.9 Mt and 18.1 Mt of CO_2-equivalent followed by rice CH_4 emissions of 4.6 Mt, 4.7 Mt and 4.8 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. Crop residue burning at agricultural fields following the same pattern is expected to increase up to 2.96 Mt, 2.98 Mt and 3 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively.

It has been observed that projected emissions under BAU, FS and ECP scenarios are expected to increase by 16% and 33% higher than those under BAU scenario.

The underlying reason for projected higher emission under future scenarios of FS and ECP than those under BAU is agricultural growth in future. Pakistan has set ambitious agricultural growth targets to meet future agricultural goals, in terms of supporting economy and ensuring food security under changing food patterns. Therefore, the sector will continue to remain an important emissions contributor due to inherent inter-linkage of agriculture growth with food security and poverty alleviation.

The forecasted agricultural growth rate, duly adjusted, also shows a faster growth in sub-agricultural categories as compared to historical growth trend of about 3 per cent per annum. Hence, manifold higher agricultural and sub-agricultural projected emissions can be attributed to ambitious agricultural growth targets of on average 3%, 4% and 5% under BAU, FS and ECP scenarios. The increase in emissions from the agriculture sector over the last 20 years also corresponds with economic growth and developmental pathways. The correspondence of increase in emissions with agricultural economic growth and development pathways in future is evident by the results showing more carbon emissions in response to even 1% increase in agricultural GDP. Baig and Baig (2014) endorsed these findings that per capita increase of 1% in GDP will increase per capita CO_2 emissions by 0.46%. Similar findings were reported by Xiong et al. (2016) that total emissions from agriculture are dependent on agricultural growth and increase in agricultural economy. UNFCCC (2016), in Pakistan's Intended Nationally Determined Contribution (INDC), also endorsed that following the correspondence of increase in agricultural emissions in past 20 years with economic growth and development pathways of the successive governments, the future emissions of Pakistan are predicted to increase manifold.

4 Conclusion

Agriculture is one of the major contributing sectors of economy in terms of GHG emissions. The estimates for the year 2014–2015 have shown that agricultural activities emitted 174.6 Mt of CO_2-equivalent emissions, including 89.8 Mt of CH_4, 83.7 Mt of N_2O and 1.1 Mt of carbon monoxide (CO). Agricultural soils contributed a major share of 79.4 Mt (45.5%) of CO_2-equivalent to total emissions from agriculture sector followed by 78.8 Mt (45.1%) by enteric fermentation, 11.4 Mt (6. 5%) by manure management from livestock, and the rest of 3.0 Mt (1.7%) by rice cultivation and 1.9 (1.1%) Mt by crop residue burning.

Agricultural soils and enteric fermentation were key categories which contributed more than 90% emissions to the total from agriculture. The rest of three categories, i.e. manure management, rice cultivation and field burning of agricultural residues, just contributed 9.4% share to the total emissions.

Analysis of GHG emissions from Pakistan's agriculture in 1994, 2008, 2012 and 2015 showed an increasing trend. Overall agricultural emissions grew more than twofolds from 71.6 to 174.6 Mt of CO_2-equivalent, about 144% over the period of 21 years. In all past estimates, agricultural soils and enteric fermentation were found as key categories contributing more than 90% emissions. The emissions from these two categories grew from 8.9 to 79.4 Mt (792%) and 52.3 to 78.8 Mt (50%) of CO_2-equivalent, respectively, from 1994 to 2015.

Baseline emission (of 2015) projections till 2030 under future scenarios of agricultural growth are expected to increase up to 271.9 (56%) Mt, 314.3(80%) Mt and 362.9 (108%) Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. In the case of sub-agricultural categories, soil emissions from agricultural land are expected to increase up to 123.7 Mt, 124.9 Mt and 126 Mt of CO_2-equivalent followed by enteric emissions of 122.8 Mt, 123.9 Mt and 124 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. Similarly, emissions from livestock manure management are expected to increase steadily up to 17.8 Mt, 17.9 Mt and 18.1 Mt of CO_2-equivalent followed by rice CH_4 emissions of 4.6 Mt, 4.7 Mt and 4.8 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively. Crop residue burning at agricultural fields following the same pattern is expected to increase up to 2.96 Mt, 2.98 Mt and 3 Mt of CO_2-equivalent under BAU, FS and ECP scenarios, respectively.

Besides the fact that agricultural emissions are expected to increase in future, it is also true that presently Pakistan has yet to produce more to meet the future needs and preferences of the masses which will lead to emissions at even faster rates. Till now, Pakistan has not devoted much of its efforts in curtailing the emissions from agriculture due to limited awareness and low confidence in monitoring/estimation of these emissions. Since agriculture sector offers a lot of opportunities in GHG reduction, the present estimates will aid in designing the future agriculture context, especially for emission reductions from livestock sector and soils.

Compliance with ethical standards

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

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Affiliations

Muhammad Ijaz[1] · Muhammad Arif Goheer[1]

Muhammad Arif Goheer
arifgoheer@gmail.com

[1] Global Change Impact Studies Centre (GCISC), Ministry of Climate Change (MoCC), 6th Floor, Emigration Tower, 10-Mauve Area, G-8/1, Islamabad 44000, Pakistan