Draft Working Paper

CLIMATE CHANGE MITIGATION IN INDIAN AGRICULTURE: BAIF APPROACH

B.K. Kakade

BAIF Development Research Foundation, Pune, India

1. INTRODUCTION

Global warming, caused by the increase in the concentration of greenhouse gases (GHGs) in the atmosphere, has emerged as one of the most prominent global environmental issues. These GHGs – carbon dioxide (CO2), methane (CH4) and nitrous-oxide (N2O), trap the outgoing infrared radiation from the earth's surface and thus raise the temperature. The global mean annual temperatures at the End of the 20^{th} century, as a result of GHG accumulation in the atmosphere, has increased by 0.4- 0.76^{0}C above that recorded at the end of the 19^{th} century (IPCC, 2007). The last 50 years show an increasing trend of 0.13^{0}C/decade whereas the trend of the last one and half decades has been much higher. The Inter- Governmental Panel on Climate Change (IPCC, 2007) projected a temperature increase between 1.1 and 6.4^{0}C by the end of 21^{st} Century. This global warming has shown trends of disastrous impact on human life and is going to continuously aggravate the situation. The 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) set to limit global warming to well below 2^{0}C above pre-industrial levels, with an aspiration target to limit warming to 1.5^{0} C. To realize this goal, a drastic reduction in global emissions is required. Agriculture, forestry and other land use sector contributions to climate change are the largest and the attention towards this sector has to be maximum, Refer Figure 1 for distribution of GHG Emissions by sector.

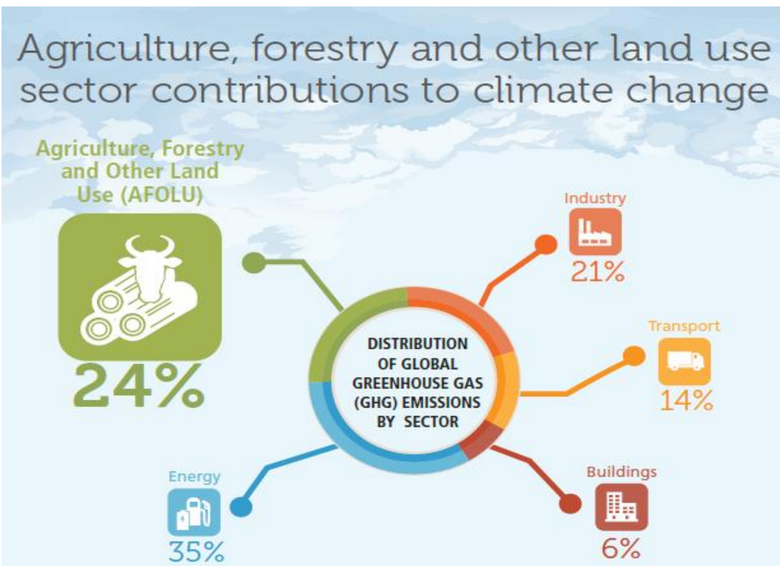

Figure 1: Distribution of GHG Emissions by Sector (IPCC, 2014)

India is the third largest GHG emitter in the world, after China and the Unites States (Mengpin, 2014) and therefore has a major role to play in reducing global emissions and determining the future climate.

The agricultural sector is responsible for 18% of gross national GHG emissions in India (INCCA, 2010) mainly through rice cultivation, livestock production, fertilizer use and burning of crop residues. India is currently experiencing the phase of rapid economic growth and demographic change. Per capita income has risen steadily since the 1980s and with this economic growth and an expected population of about 1.71 billion in 2050 (Populstat, 1999/2003) food demand is expected to double by 2050 (FAO, 2014). Therefore, emissions from agriculture in India are expected to increase further in the future. Given the significance of agriculture to total national emissions, India has identified agriculture and allied sectors as a priority area for emissions reduction in its NDC to the UNFCCC. India's Nationally Determined Contributions (NDCs) to the UNFCCC, pledges to reduce the emission intensity of its GDP by 33-35% by 2030 compared to 2005 levels (GOI, 2016).

Major Emission Contributors and Mitigation Potential in Indian Agriculture

Tek B. Sapkota, et.al. (2018) estimated that total emissions from Indian agriculture was 481 MtCO2e in 2012 of which crops and livestock contributed 42% and 58%, respectively. Refer figure 2 for the major contributors to the emission in Indian Agriculture. Through adoption of technically feasible mitigation options, the total mitigation potential in the agricultural sector in India, including restoration of degraded land, would be 85.5 MtCO2e per year. In other words, by 2030, about 18% of total emissions from agriculture could be abated by adopting technically feasible mitigation measures. The study suggests that 80% of the total technical mitigation potential (67.5 out of 85.5 Mt CO2e year-1) in Indian agriculture can be obtained by adopting cost-beneficial mitigation options (Tek B. Sapkota, et.al., 2018).

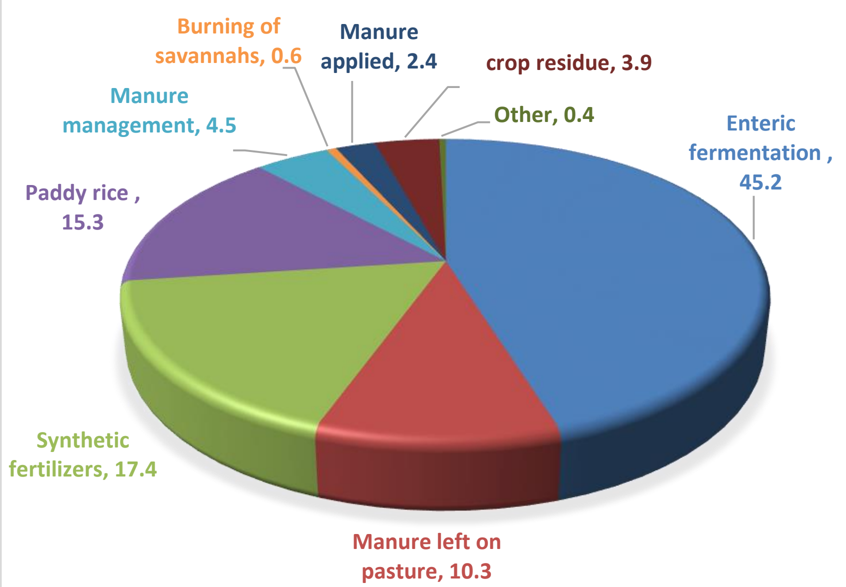

Figure 2: Largest Emmiters in Agriculture in India (2014) (Source: FAOSTAT, 2019)

Agriculture offers promising opportunities for mitigating GHG emissions focusing on reducing the major GHG emitters as well as through carbon sequestration, soil and land use management, and biomass production.

2. LIVESTOCK PRODUCTION SUPPLY CHAIN

As per the livestock census (MoAFW, 2012a; 2012b), India is home to the world's largest livestock population. As a result, enteric emissions in India are much higher (45.4 percent in 2012) than the world average (39.4 percent) (FAO 2016). The majority of Indian livestock rearing is based on open grazing and straying. In India, livestock may graze on forestlands, government land, community land, or the land of other farmers. The upward trend in the consumption of milk and meat in India and the world is incompatible with reducing GHG emissions from the livestock subsector (Herrero., et al.2016). The main considerations of Indian livestock rearing and mitigation potential is explained below:

2.1 Main Considerations

Of the enteric emitters, the major contribution is from cattle and buffaloes. Figure 4 shows the estimates by FAO of contribution to enteric fermentation by different animal species in India. (FAOSTAT, 2019).

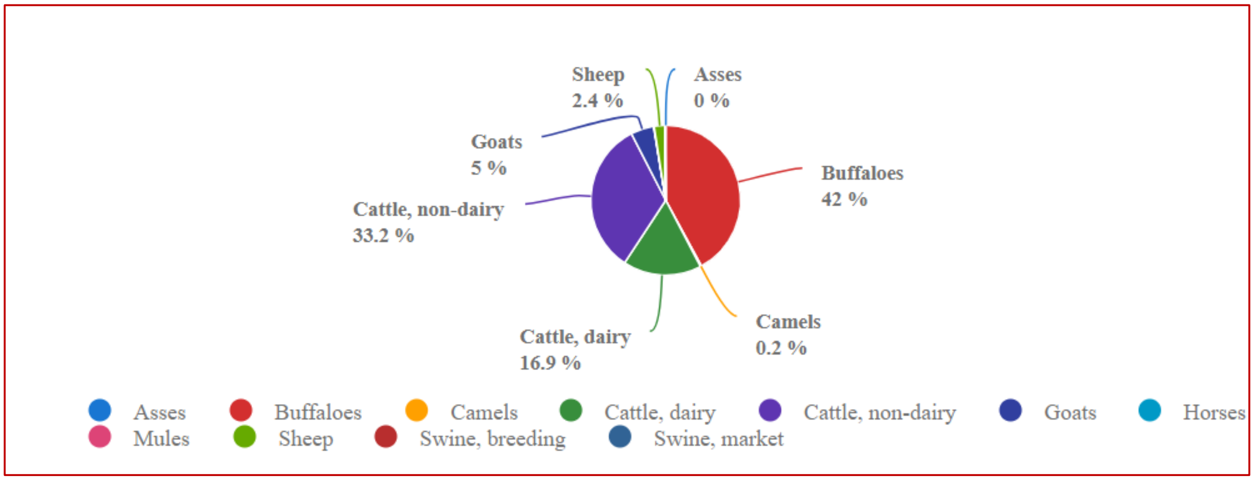

Figure 3 Emissions by Animal Type (CO2eq) in India (Average of 1990 to 2016) (FAOSTAT, 2019)

The average emission intensity in mixed farming systems in South Asia is estimated at 5.5 kg CO_2-eq/kg milk compared with the global average of 2.7 kg CO_2-eq/kg milk. The main reasons for the high level emission intensities in South Asia and India are the following:

i. Poor feed quality (low feed digestibility)

Poor feed quality leads to high enteric CH_4 emissions and low animal production performance. Indian dairy in majority of cases is a mixed farming. Dairy animals are fed through grazing, crop residues and cultivated fodder. Supplementary feeding is practiced when feasible. The milk sold in market and dung goes back to cultivated land as manure. Less digestible feed generates more CH_4 emissions per unit of energy ingested. Poor feed also affects animal productivity. Milk yields are low (less than 800 kg per cow per year, compared with a global average of 2269 kg per cow per year in dairy cattle mixed systems) and animals grow slowly, leading to older ages at first calving. As per NDRI (2014), average milk productivity is very low: indigenous cows (Indian breeds) yield on an average 2.0 kg daily, crossbred cows 6.46 kg and buffaloes 3.91kg per day.

ii. The breeding overhead

Being a mixed and non-intensive dairying, Indian dairy herds are comparatively carry more proportion of non-productive animals than productive animals (60:40). One of the cause is older age at first calving (3.1 year compared with a global average of 2.4 in mixed systems), resulting in poor herd fertility and health. The male calves are not being used for any productive purpose in many parts of country.

iii. High mortality rates

Calf mortality in India ranges from 12.5 to 30%. (Singh et.al., 2009). The mortality rate upto 5% is acceptable in the dairy farms, however, Prasad at. al., 2004 reported mortality rate from 7.21% to 17.12%. High mortality rates lead to the loss of animals and therefore to unproductive emissions. Global average of calf and adult cattle mortality are 17.8 and 6.7 respectively in dairy cattle mixed systems.

The higher emissions in India is expected to continue as per FAO estimates. The trend of emissions due to **enteric fermentation** is as given in the figure 4. It has been continuously rising so far and it is expected to rise in future too.

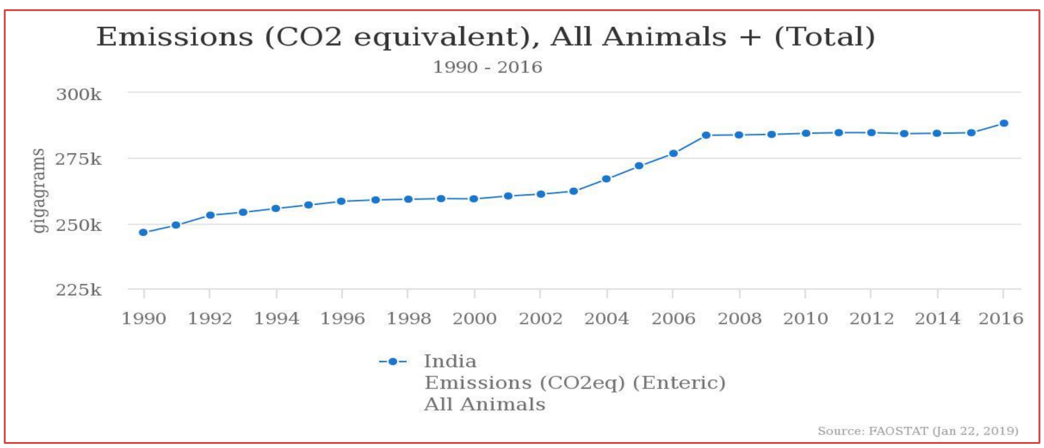

Figure 4 Emission (CO2eq) trend due to Enteric Fermentation in India (FAOSTAT, 2019)

2.2 Mitigation Interventions

Global Livestock Environmental Assessment Model (GLEAM) was developed to help improve the understanding of livestock GHG emissions along supply chains, and to identify and prioritize areas of intervention to lower sector emissions. (FAO, 2013). With a similar logic of identifying and managing the sources of emission in the livestock supply chain, the mitigation strategies suggested includes the strategies for upstream, production unit and downstream of the supply chain.

2.2.1 Upstream:

Considering the main drivers of emission intensity, the mitigation potential offered in the upstream of the dairy supply chain mainly include the feed and fodder management. India has a major shortage of feed and fodder as shown in Table 1. Table gives the deficit in feed and fodder in India as referred from the document by NDDB, 2014.

Table 1 Estimate of Feed and Fodder in India

Estimates on Feed & Fodder in India-

(Gotri Ravi Kiran et.al., **NIANP** 2012 (Million tons/year)

Fodder	Particulars	2015	2020	2025
Dry	*Requirement*	491	530	550
	Availability	387	408	433
	Deficit (%)	**-21**	**-23**	**-21**
Greens	*Requirement*	840	880	1000
	Availability	619	596	600
	Deficit (%)	**-26**	**-32**	**-40**
Concentrates	*Requirement*	87	96	105
	Availability	58	61	65
	Deficit (%)	**-34**	**-36**	**-38**

National Institute of Animal Nutrition and Physiology Adugodi, Bangalore

The primary objective of feed and fodder development is to improve the intake of livestock for enhanced productivity. In addition, many management techniques intended to increase livestock forage production have the potential to increase soil carbon stocks, thus sequestering atmospheric carbon in soils. Methods of improved management include fertilization and irrigation for cultivated fodder; intensive grazing management of pasture lands; and sowing of favorable forage grasses and legumes in both pasture lands and farmlands.

(i) Fodder Production:

Grassland management to enhance production through sowing of improved grass varieties, soil moisture or irrigation or fertilization, minimize negative impacts of grazing, or rehabilitate degraded lands can each lead to carbon sequestration (Conant et al., 2001; Follett et al., 2001b; Conant and Paustian, 2002; Ogle et al., 2004., as referred in USAID, 2015). Improved grazing management for increased fodder production leads to an increase of soil carbon stocks by an average of 0.35 t C ha-1 yr-1 (Conant et al., 2001; Conant et al. 2015, as referred in USAID, 2015). In addition, the production of larger quantities of aboveground and belowground biomass compared to shrubs or herbs makes trees more efficient in promoting soil carbon sequestration (Brady and Weil, 2007). About 11.1 M ha land is under permanent pastures in India. Carbon accrual on optimally grazed lands is often greater than on un-grazed or overgrazed lands.

Area under green fodder cultivation is 9.2 M ha. The productivity of green fodder is poor compared to the potential. This land under green fodder cultivation is available for increasing the production as well as reducing the emissions through optimization of fertilizer inputs and improved seeds.

(ii) Feed quality improvement:

Improving the digestibility of the diet, through feed processing or addition of locally available improved forages, results in better lactation performance (i. e. higher milk yields and animal growth) and reduced CH4 emissions.

Depending on local availability and cost, the maximum possible green fodder/silage should be included in the ration, with a minimum of 15-25 kg green succulent roughage given to each adult animal. (NDRI, 2014)

2.2.2 Production Unit

The two important interventions suggested at production unit level of dairy animals include genetic approaches and the management approaches.

(i) Genetic Approaches to Increasing Productivity and Reducing CH4

The Environmental Protection Agency has clearly stated that “Improving livestock productivity so that less CH4 is emitted per unit of product is the most promising and cost-effective technique for reducing emission” (EPA, 2005). More-efficient dairy cattle are expected to produce more milk relative to the amount of feed consumed and energy lost as CH4. Production efficiency can be improved by genetic selection and management practices that address not only nutrition and feeding, but also reproduction, heat stress tolerance, disease incidence, culling rates, and heifer replacement programs.

Cross- breeding Programme

Indigenous cows (Indian breeds) yield average of 2.0 kg per day while crossbred cows yield average 6.46 kg/day (NDRI, 2014). The average milk yield increase is by 3 to 4 times through cross breeding with exotic breeds. With enhanced milk production through genetic improvement by cross-breeding, the same herd size of dairy livestock the milk production at farmer’s level can be 3 to 4 times. Crossbreeding with a combination of using milch breeds of Indian cattle such as Gir, Sahiwal, Tharparker, exotic breeds such mainly HF, Gersey (the type of breed will depend upon the farmer's choices and feasibility of the specific breed in a certain locality) and the high yield buffalo breeds for buffalo breeding, the herd size can be reduced to one-third. A study conducted by Rajesh Kumar and Hema Tripathi (2011) in Bareilly district of Uttar Pradesh by collecting data from 120 cattle owning households hailing from 12 villages indicated that about 57 percent of the beneficiaries as compared to about 27 percent of the non- beneficiaries were generating income between INR 15000-25000 annually through dairying. Seventy percent of the non-beneficiaries fell under low income group i.e. INR 5000-15000 per annum. About 33 percent beneficiaries came from BAIF's adopted villages could generate even more than INR 25000 annually. Authors correlated this with adoption of crossbreeding programme which enhances the milk production, thereby increase the income of the farmers as well as reduce the CH4 emissions.

Use of Sex Sorted Semen

Sorted semen is a sexed semen either to contain X or Y sperms and the use of it would produce a desired sex i.e. male or female animal. Expected male female calf birth ratio is 1:9 against the normal ratio of 1:1. The conventional inseminations and natural service is producing 50% male calves. These male calves are both neglected and under fed by the farmers due to less utility to the farmer. The feeding and management cost causes huge economic losses to the farmer and disposal of such male calves is also a challenge to the farmer. The sorted semen technology will produce 90% female calves and will resolve the problem of cruelty against male calves to much extent. This will also eliminate the issue of stray male cattle menace in many villages and cities.

(ii) Management Approaches to Improve Productivity and Reduce CH4

Management practices that enhance the ability of individual cattle to increase milk yields and reach their genetic potential will reduce the amount of CH4/unit of milk produced in the whole herd. These management approaches may include practices to reduce non-voluntary culling and diseases, facility and equipment designs to improve the cattle's environment. Diet improvement through improved digestibility has the highest mitigation potential, owing to its large impact on several sources of emissions. Feed rich with roughage favors the production of acetate and subsequently increases CH4 production, whereas feed rich with starch favors the production of propionate and decreases the production of CH4. All of these approaches have potential to improve profitability as well as decrease CH4 emissions (Knapp et. al., 2011).

Improvements in estrus detection, estrus synchronization, prevention of early embryonic death, heat stress abatement and transition cow health would result in improvements in reproduction, reduce the number of cows culled due to poor reproduction and disease and reduce the number of replacement animals needed. These management approaches could reduce enteric CH4/ECM by 9 to 19% (J.R. Knapp, et. al., 2014)

Estimated mitigation potential

Indian bovines emit lesser amount of methane on per head basis as compared to their western counterparts due to lower size, bodyweight and productivity. Emission factor developed for Indian livestock vary significantly from IPCC recommended value due to the same reason. As per IPCC default coefficient values, (IPCC 1996), both cross breed and indigenous dairy cattle emit 46 kg CH_4/animal/year, while non-dairy cattle emit 25 kg CH_4 /animal/year. However, as per the study by A. Chhabra, et. al., 2013, the total methane emission from Indian livestock was estimated to be 11.75Tg/year with per capita emission of only 24.23 kg CH_4/animal/year for the year 2003. Enteric fermentation and manure management constitutes ~91 % and 9 %, respectively to the total methane emissions. That indicates that the enteric fermentation related emission is about 22 kgCH_4/animal/year. The average of CH_4 emission of different age group of animals from the estimations by Sultan Singh, et. al. (2012) shows that both the indigenous and cross bred dairy cattle emission is about **25 CH_4kg/head/year and that of female buffalo is 40.42 CH_4 kg/head/year. The enteric emission thus in this study (by Sultan Singh, et. al.) is also about 22.75**kgCH_4/cattle/year and that of buffalo is about 36.78 kg CH_4 /animal/year.

Methane emission and its relation with milk production

Ratio of methane emission in dairy cattle with its milk production is large, mainly due to low quality feed and genetic factor. The country average methane production per kg of milk is 72 ± 11 g kg-1 milk for cattle and in this the indigenous dairy cattle (96±16) has higher values compared to cross-bred dairy cattle (28± 4)whereas for buffalo it is about 66.21 g kg-1 milk. There existed a wide regional variation among the states and ranges from 26 g kg-1 milk in Punjab to 270 gm kg-1 milk in Orissa, in case of dairy cattle. In case of buffaloes, the state of Orissa shows highest emission of about 191.62 g CH_4 kg-1 milk and the lowest being in Haryana (35±11 g CH_4 kg-1 milk). Highest milk producing states recorded the lowest methane per kg of milk produced or in other words the lesser methane emission per kg milk indicated better nutritional status of livestock. (Jha, et. al., 2011)

With feasible improvements in feed quality, animal health and husbandry, emissions can potentially be reduced by 38 percent of the baseline GHG emissions. The adoption of semen sexing technology for 25 percent of the dairy cows in India was estimated to reduce male calf numbers by 9 percent. (Gerber, et. al., 2013). Therefore, at the production unit level, the potential of CH_4 mitigation is to the extent of about 47 %.

Enteric emission reduction strategies can be summarized as below:

- Emphasis on cross –breeding and use of sex-semen favoring female calves.
- Feeding of good-quality feed and feeding of substances to reduce methanogenesis
- Growing and using improved and high quality forages
- Emphasis on production of milk with low fat content

Health and husbandry improvement

The relative share of productive cohorts in the herd can be increased through improvements in animal health and reproduction management. For health management, the most effective routine procedures which can be used are:

- Regular vaccination programme and screening of herd against diseases.
- Promote resistance in animals that might be exposed to potentially infectious agents through good nutrition and active immunization.
- Regular deworming programme and other measures to control external and internal parasites
- Maintenance of health, production and reproduction records of all animals in the herd
- Mastitis control programme: Mastitis is one of the major causes of economic losses in crossbred dairy herds in India

MITIGATION POTENTIAL THROUGH BAIF'S LIVESTOCK DEVELOPMENTPROGRAMME

In the livestock development programme of BAIF, a livestock development center caters to about 2500 breedable dairy animals. Overall, the proportion of cows and buffaloes covered through breeding programme is 60:40 (60% cows and 40% buffaloes). Enteric Emission Mitigation of CH_4 of 47% through various genetic and management practices if applied to overall annual mitigation over a population of 2500 dairy animals (at the level of BAIF's Livestock Development Centre), the annual CH_4 mitigation will be 70.90 Mg year-1 (Mega gram per year). (0.6*2500*22.75 + 0.4*2500*36.78). In terms of C equivalent, the level of mitigation is 1.77Gg (Giga Gram year-1 centre-1) of CO_2equivalent.

Through a network of 4500 centres annual mitigation is estimated to be about 7.98 $TgCO_2e$ year-1 (or about 7.98 $MTonCO_2e$) through BAIF's programme, which is 9.3% of overall mitigation potential of 85.5 l in agriculture sector in India.

2.2.3 Downstream

Post production or downstream management aspects include the transport of milk and manure management. In this note, only manure management is considered for mitigation.

(i) Manure Handling

Animal manure and it's use as fertilizer contribute to gaseous emissions. Manure contains complex organic compounds (e.g. carbohydrates and proteins), which are broken down by bacteria resulting in the production of carbon dioxide (CO_2) under aerobic and methane (CH_4) under anaerobic conditions. With open grazing, manure is spread thinly and aerobic decomposition predominates. In intensive livestock practices, animals are stall-fed, and manure is stocked in piles or pits where anaerobic conditions predominate and CH_4 is

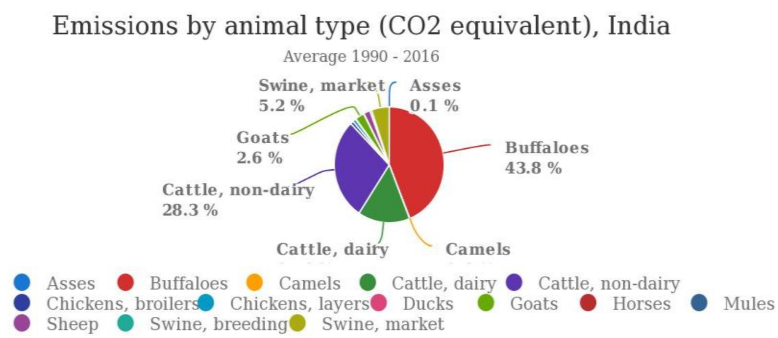

Figure 5 Emission through Manure Handling by Animal Type in India (CO2 equivalent) (FAOSTAT, 2019)

produced. Figure 5 shows emission through Manure Handling by animal type in India (CO2 equivalent) (FAOSTAT, 2019). As shown in figure, the major sources of emission are cattle and buffaloes. Bacteria, archaea, and other groups are also involved in microbial activities taking place during manure storage. Thus, manure is a source of greenhouse gas (GHG) emissions due to a multitude of microbial activities. Besides these GHGs, other emissions from livestock manure management systems are ammonia (NH3), nitric oxide (NO), and non-methane volatile organic compounds (NMVOC). (Veerasamy Sejian, 2015). As per FAO, estimates, the emission levels through the manure, post its disposal, had been continuously rising and are expected to continue so in future.

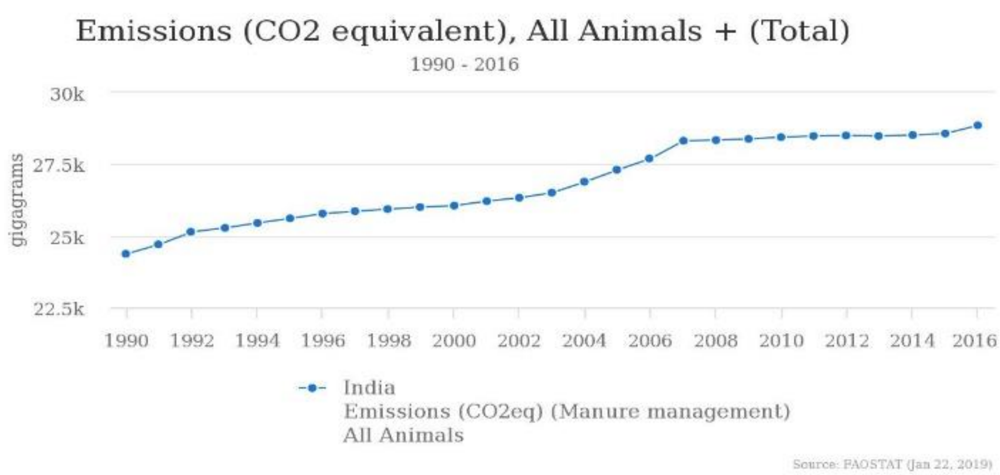

Figure 6 Trend of Emission through Manure Handling in India (FAOSTAT, 2019)

Figure 6 shows the trend of past emissions of all animals in India.

Measures to reduce greenhouse gas emissions from stockpiles

Measures include manure stockpile aeration and composting that reduces methane emissions. A practical and efficient way is to convert dung into vermicompost and use as a crop nutrient source. If designed properly, better management of manure can reduce the need for synthetic fertilizers, reduce use of fossil fuels, create profitable products for producers, and increase the productivity of croplands (Dickie, A., et. al., 2014)

Measures to capture and use methane

Methane can be best captured using biogas and used for energy production for heat or power. The strategies adopted by BAIF include capturing the methane using biogas at household level, filtration of slurry for converting it to biological Phosphate Rich Organic Manure (PROM) at community level (50 household biogas plants are the catchment area of one BIO-PROM production unit) thereby reducing the use of synthetic fertilizers.

Integrated Biogas and Bio-PROM:

This model is conceived by BAIF to tackle both CH_4 and CO_2 emissions of manure, capturing methane through biogas and converting biogas slurry into Phosphate Rich Organic Manure. The Integrated Renewable Energy and Sustainable Agriculture (IRESA) approach presents a complete package comprising of a portfolio of activities around the central theme of household level biogas units. The global warming mitigation potential of a family size biogas plant is about 10 t CO_2 eq. yr-1. (Pathak et al., 2010).

ESTIMATION OF MITIGATION THROUGH FAMILY SIZE BIOGAS PLANT:

The size of the biogas plant needs to be decided based on availability of raw material. The production of dung by young to adult bovine varies from 5 kg to 15 kg per day. Thus the average cattle yield is about 10 kg dung per day. The average gas production from dung may be taken as 40 lit/kg of fresh dung. The total dung required for production of 2 m^3 biogas is 2/0.04= 50 kg. Hence, a minimum of 3 cattle is required to generate the required quantity of cow dung. One cubic meter of gas is equal to 0.43 kg of LPG. (Vikaspedia). 1 cum of methane weighs 0.717 kg. Considering that about 60% of the gas contents CH_4 and remaining is CO_2 and traces, the mitigation potential if trapped, CH_4 is used to replace LPG or used for producing energy is about 0.335 kg CH_4/day/cattle. (2cum = 2*0.717 = 1.434 kg/day per plant of 3 cattle. Means 1.434/3 = 0.478 * 0.7 = 0.335 kg CH_4/day/cattle). This is about 13.08 TonsCO2e per year per plant.

The plant incorporates the following components.

- The pre-fabricated biogas technology which is compact, standardized, failure-proof and clean captures CH_4 generated through anaerobic digestion. A plant of 2 cum capacity is installed at family level.
- Introduction of an integrated package consisting of a well- tested , low cost, in-house developed slurry filter effecting water recycling and better slurry handling
- Use of filtered slurry to produce vermicompost and finally the Phosphate Rich Organic Manure (PROM)

- PROM is produced by co-composting of high grade (32%P2O5) rock phosphate in very fine size with the digested slurry cake from biogas plant.

Other than contribution to mitigation, Bio-PROM has the benefits of potential saving to the government on forex out flow towards import of phosphate, saving on subsidy on Phosphatic fertilizers, saving on forex outflow on LPG import, saving on subsidy on LPG and increase in soil fertility and organic content in soil.

(ii) Milk Transportation and Processing

The two major sources of emission in the last portion of supply chain are the CO2 emission during the transport of animals and milk and the processing unit. Both are due to use of conventional energy. Since this part of the supply chain is not being dealt with in BAIF programme, the strategies are not considered in this paper. Nevertheless, the solar and other renewable sources of energy can be the options for mitigation.

3. RICE CULTIVATION

India is one of the world's largest producers of rice accounting for 20% of all world rice production. The FAO estimates of the past trends of CO2 equivalent emissions from rice-paddy in India is provided in figure 7. Although there have been fluctuating trends of emissions, in the majority of years, the emission were above 90k gigagrams. The future estimates as per FAOSTAT for the year 2030 and 2015 are at the level of 75k gigagrams. This indicates the need of providing adequate attention towards mitigation in the rice cultivation.

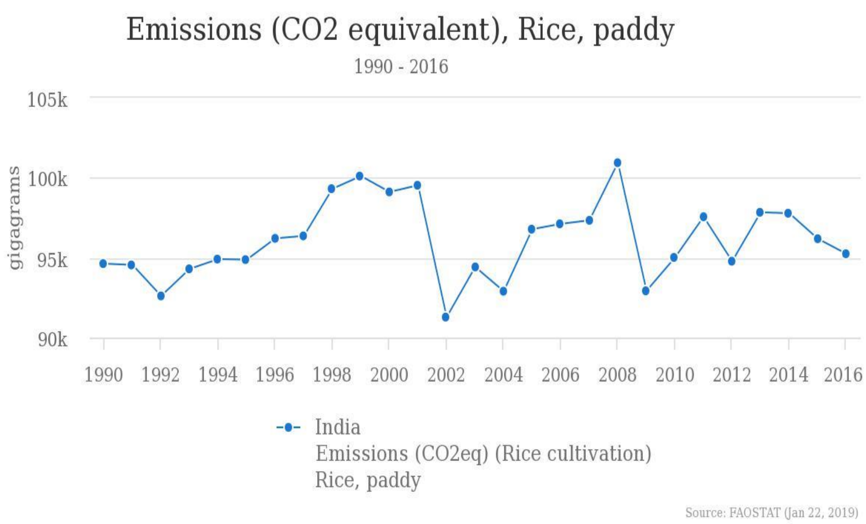

Figure 7 Emissions (CO2eq) through Rice Cultivation in India

The researchers found an inverse correlation between methane and nitrous oxide emissions from rice farming. Water and organic matter management techniques that reduce methane emissions can increase nitrous oxide emissions. However, total carbon equivalent emissions from the irrigated rice growing areas of the country can be reduced.

The Denitrification and Decomposition (DNDC) model was applied for estimation of GHG emissions from 10 rice fields in India using a newly compiled soil/climate/land use database. Continuous flooding of rice fields (42.25 million ha) resulted in annual net emissions of 1.07-1-10, 0.038-0.048 and 21.16-60.96 Tg of CH_4 –C, N_2O –N and CO_2 –C, respectively, with a cumulated global warming potential (GWP) of 130.93-272.83 Tg CO_2 equivalent. Intermittent flooding of rice fileds reduced annual net emissions to 0.12-0.13 Tg CH_4 –C and 16.66-48.80 Tg CO_2 15 –C while N_2O emission increased to 0.056-0.060 Tg N_2O-N. The GWP, however, reduced to 91.73-211.80 Tg CO_2 equivalent. (H. Pathak, C. Li and R. Wassmann, 20015). The emission estimates, emission factors and area covered under different rice ecosystems used in the study are given in Table 2. The highest emission was from the irrigated continuously flooded rice. (Pathak, et. al., 2014).

Methane emission pattern from a rice field illustrates that the peaks of the flux are dictated by the moisture content of soil. Continuously saturated rice fields gave higher methane emission compared to intermittent wetting and drying soil conditions (Jain et al., 2000; Pathak et al., 2003 as referred in Pathak et al., 2010). Average methane emission in saturated soil was 0.3 to 0.6 kg ha^{-1} d^{-1} while in intermittent wetting and drying it was 0.1 to 0.4 kg ha^{-1} d^{-1}. Saturation of soil creates anaerobic conditions conducive for the formation of methane as methanogens are strict anaerobes. When such saturated soils were allowed to dry making them aerobic, formation of methane almost stops. (Pathak et al., 2010). However, the N_2O emission increases due to aerobic conditions. In another study, if the changes in methane and nitrous oxide emissions from SRI rice paddies are converted to global warming potential (GWP) as CO_2-equivalent, it has been found that ***net GHG reductions with intermittent irrigation have ranged between 20% and 40% and even***

Table 2 Methane emission from different rice ecosystems in India in 2010(Pathak, et al, 2014)

Ecosystem	Water regime	Rice area (Mha)	Emission coefficient (kg ha^{-1})	Methane (Mt)
Irrigated	Continuous flooding	6.78	162 ± 28	1.10
	Single aeration	8.98	66 ± 10	0.59
	Multiple aerations	9.39	20 ± 3.8	0.19
Rainfed	Flood-prone	3.05	190 ± 0	0.58
	Drought-prone	8.22	66 ± 4	0.54
Deep water		1.29	190 ± 0	0.25
Upland		5.16	0	0.00
Total		**42.86**		**3.25**

up to 73%. (Gathorne- Hardy A. et al. 2015., Choi J. et al. 2014, Chu G. et al. 2013, and Jain N. et al. 2014, cited in sri.ciifad.edu) .

4. SYNTHETIC FERTILIZERS

On an average, of every 100 units of nitrogen applied in agriculture, only 17 are consumed by agriculture that is crop, dairy and meat production (UNEP and WHRC 2007). Emissions of N2O increase when the soil becomes anaerobic and saturated with water. In this situation, bacteria are forced to use nitrate and produce N2O; further, this situation is suitable for CH4 emission. India consumes 14Mt of synthetic N per year, of which about 80 percent is produced, and is the second largest producer and consumer in the world, after China. (Reyes Tirado, 2009).

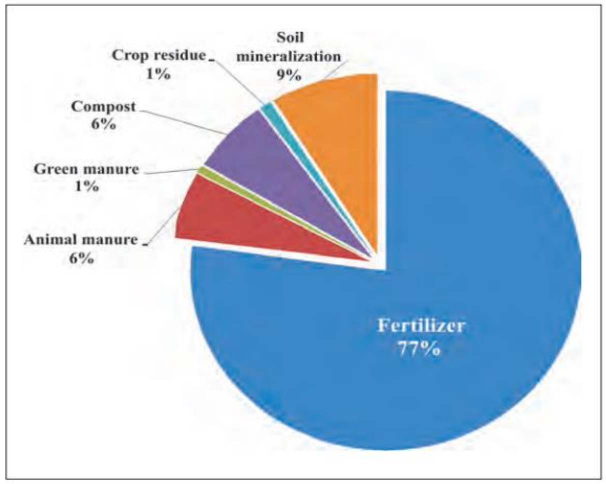

Figure 8 Contribution of different sources to Nitrous Oxide emission from Indian agricultural soils in 2010 (Pathak, et.al., 2010)

The concern over N2O emissions arises from its long atmospheric life (166+16 years) and its higher global warming potential (296 times that of CO2) (IPCC, 2007). IPCC global emission factor is 1.25kg N2O per 100kg N (IPCC, 2006). Figure 8 shows the contribution of different sources to Nitrous Oxide emission from Indian agricultural soils in 2010 (Pathak, et.al., 2010). The FAOSTAT estimates of the emissions (CO2eq) through synthetic fertilizers in India is provided in figure 9. The future trend of emission is also provided in figure 10.

It is important to highlight that nitrogen added to the soil by leguminous nitrogen fixation is also susceptible to emission from the soil in the form of N2O. However, growing leguminous crops indirectly reduces the industrial emissions involved in producing and transporting nitrogenous fertilizer. More emphasis is needed on adopting practices that increase the efficiency of use of nitrogenous fertilizers by crops. Commonly known practices are application

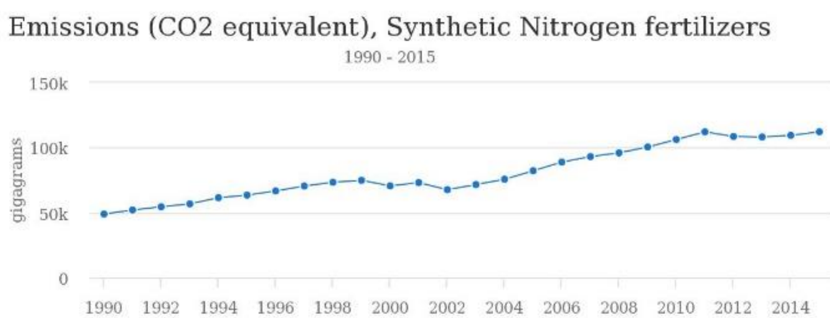

Figure 9 Trend of Emission (CO2eq) through Synthetic Nitrogen fertilizers in India (FAOSTAT, 2019)

Source: FAOSTAT (Jan 22, 2019)

of fertilizer based on soil health (after testing the soil) and based on the requirements of the crop/variety, use of slow- or controlled release nitrogenous fertilizer, and root placement of nitrogen fertilizer to control emissions. The time of application of nitrogenous fertilizer should coincide with the time nitrogen is required by the crop.

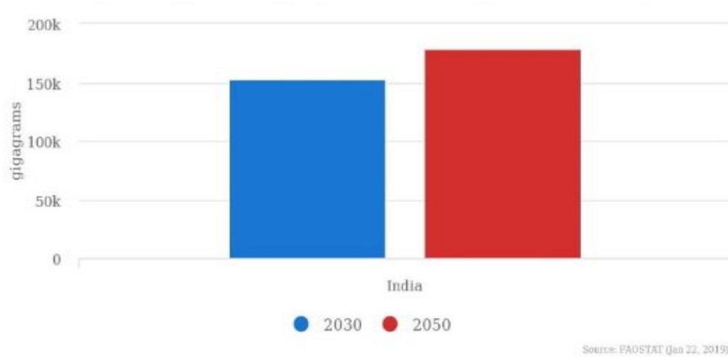

Figure 10 Future Estimate of Emission (CO2eq) through Synthetic Fertilizers in India (FAOSTAT, 2019)

Figure 11 shows the mitigation potential (Mt CO2-e per year) for emissions from N fertilizer production and application in India, relative to emissions in 2006/2007, from a shift to ecological fertilization and an increase in N use efficiency from 30 to 60 percent (Reyes Tirado, 2009).

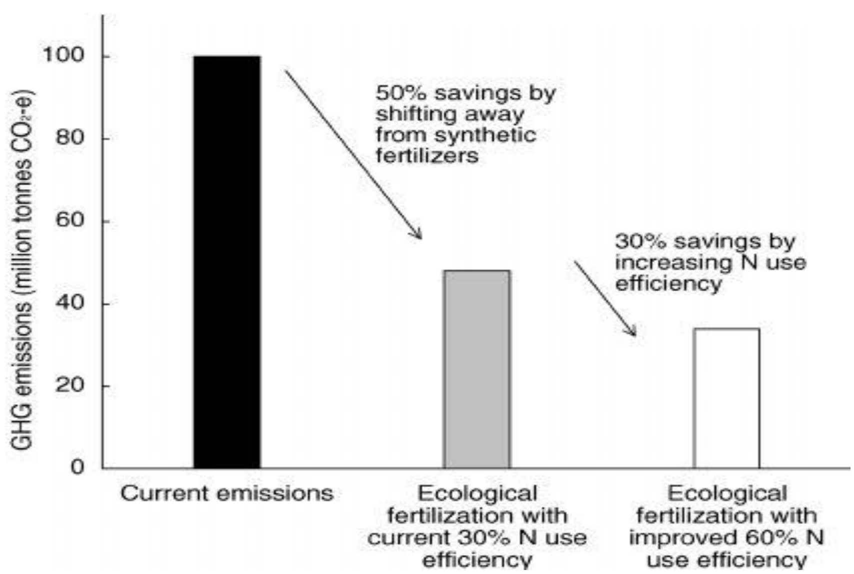

Figure 11 Mitigation Potential (Mt CO2-e per year) for emissions from N fertilizers (Reyes Tirado, 2009)

5. CROP RESIDUES

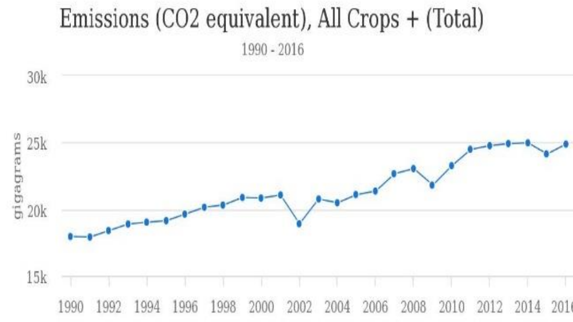

Figure 12 Emission (CO2eq) through crop residues on field in India

About 500 to 550 Mt of crop residue is produced per year in India. After being used in competitive alternatives such as cattle feed, animal bedding, cooking fuel, organic manure etc. nearly 234 million tonnes/year (i.e. 30%) of gross residue generated in India is available as surplus. The highest crop residue estimate was recorded for Uttar Pradesh (60Mt). Other high crop residue producing regions were Punjab (51Mt) and Maharashtra (46Mt). (Saroj Devi, 2017). 'Crop residues are of tremendous value to the farmers. However, a large portion of the residues is burnt on-farm primarily to clear the field for sowing of the succeeding crop' (S. Pathak, et. al., 2012). Crop residues on fields and the burning of crop residues contributes substantially in climate change. Refer figure 12 and figure 13. About half (52% to 53%) of the contributor to emission is through residues of rice left on field and burning. Another major crop contributing to over one-fourth of the emission from crop residues is wheat. The human health costs from rice residue burning in rural areas of Punjab are estimated at Rs. 7.61 crores annually (NAAS, 2017).

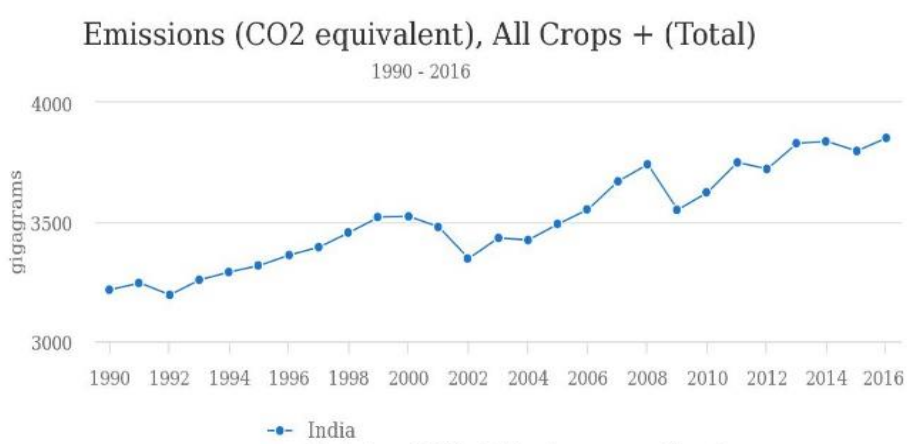

Figure 13 Emission (CO2eq) through burning of crop residues in India

The use of crop residues for biogas production is the most effective option to control GHG emissions from crop residues. Minimizing the burning of crop residues is an effective method to control emissions. Collection of straw, stubble, crop roots, vegetative parts of plants or haulms, and root exudates (a wide range of substances are released from the roots into surrounding soils, containing compounds such as simple sugars as well as complex proteins) and their use in biogas production or proper composting is also an effective way to reduce emissions from crop residues. (Nirmal Kumar Patra, 2017).

Converting Agro Waste to BioCNG

It is known that field preparations after one crop is taken starts with the first step as burning the agricultural harvest waste, as straw, stem etc. Agriculture crop residue is an important biomass resource for use in multiple applications. Apart from fodder and compost, its properties make it extremely suitable for biochemical action to produce methane, since it has easily breakable lignin and cellulose structures. But with urgency in agriculture cycle and non-availability of labour, farmers are often forced to burn their on farm waste, which leads to intense smoke. The activity puts immense pressure on nearby environment with the carbon emissions from burning of crops The activity although produces high pollution, but still has not found a replacement even in some developed countries of the world, merely because of the convenience of it, as compared to employing system for collection and disposal of postharvest agriculture waste.

As every coin has two sides, the same is true in this scenario. There are encouraging signs on the horizon as there is a solution, which is first -of-its kind in the country. A better future has been envisaged with sufficient fuel, no burning of Agro waste, reduction in imports of petroleum products saving a huge chunk of foreign exchange every year and above all, ‘no pollution.

Concept – BioCNG

The concept envisages the establishing of a unit to produce BioCNG from agriculture waste and packaged produce to be sold to direct consumers. Bio CNG is the purified form of biogas where all the unwanted gases are removed to produce>95% pure methane gas. Bio CNG is exactly similar to the commercially available natural gas (CV:~52000 kj/kg) in its composition and energy potential. As it is generated from biomass, it is considered a renewable source of energy and thus, attracts all the commercial benefits applicable to other renewable

THE PROPOSED PILOT

As BAIF always believes in developing futuristic technologies by collaborating with able partners intends to associate with Primove Engineering, which has set up a pilot plant in Pirangut (in Pune)as a Proof of Concept (inaugurated on August 14, 2016) as technology providers that provide turnkey installation of production and dispensing station, along with compliance licences from appropriate authorities . BAIFs long association with farmers and extensive presence in rural areas, would enable it to make the necessary backward linkages for such a ‘one-of-its-kind’ initiative.

Mr. Nitin Gadkari Minister for Road Transport, Highways and Shipping said, “If we initiate 5,000 such Bio CNG plants across the country then fuel import cost of INR 7 lakh crore could be reduced to almost INR 3 lakh crore. If such plants are initiated in every village, then it can provide employment to at least 500 people from that community. In addition to this, BioCNG can prove to be a good import substitute as it is cost effective and pollution free.”

Project Costing

This is an ambitious project, both by its scope, reach and potential impacts. The area requirement for a 5 Tones Per Day (TPD AgroGas (BioCNG) production facility is approx. 7500 Sq. Meter (approx. 2 Acre) and the feed requirement is approx. 40 TPD. Close to 25 crore is required to construct an entire standalone facility for producing 5 tons of Bio CNG per day with support for operations for a year meanwhile, identifying & training the farmers to establish backward linkages.

sources of energy. Bio CNG can directly replace every utility of LPG and CNG in India. It has the potential to be the future of renewable fuel because of the abundance of biomass in India.

BAIF envisages introducing such innovation, which can be rightly tagged as future skills, like BioCNG plants to rural India to ensure higher fuel substitution, more livelihood opportunities to the farmers and above all, reduction of carbon footprint, thereby lending a hand to the nation's goals of fighting the effects of pollution at a global level. A small size plant of 5 tonnes per Day capacity of BioCNG consumes the biomass of 40 tonnes per day (14600 tonnes per year).

It is estimated that one tonne rice residue on burning releases 13 kg particulate matter, 60 kg CO, 1460 kg CO2 , 3.5 kg NOx, 0.2 kg SO2 (NAAS, 2017). With this level of emission, the estimated mitigation of 5 ton BioCNG plant is about 21.31 gigagrams year-1.

6. CARBON SEQUESTRATION

Of the total land area of 329 million hectares (Mha), 297mha is the land area comprising 162 Mha of arable land, 69 Mha of forest and woodland, 11 Mha of permanent pasture, 8 Mha of permanent crops and 58 Mha is other land uses. The soil organic carbon (SOC) pool is estimated at 21 Pg (petagram=Pg=1*1015g=billion ton) to 30-cm depth and 63 Pg to 150-cm depth. The soil inorganic carbon (SIC) pool is estimated at 196Pg to 1-m depth. The SOC concentration in most cultivated soils is less than 5 g/kg compared with 15 to 20 g/kg in uncultivated soils. Low SOC concentration is attributed to ploughing, removal of crop residue and other biosolids, and mining of soil fertility. Accelerated soil erosion by water leads to emission of 6 Tg C/y (Lal, 2004).

CS Practices:

Mitigation of CO2 emission from agriculture can be achieved by increasing carbon sequestration in soil through application of organic manure, change in soil management and restoration of soil carbon on degraded land. Soil management practices such as reduced tillage, manuring, mulching, residue incorporation, improving soil biodiversity play important roles in sequestering carbon in soil. Lal (2004) estimated CSP in Indian soils at 7 to 10 Tg C yr-1 for restoration of degraded soils and ecosystems, 5 to 7 Tg C yr-1 for erosion control, 6 to 7 Tg C yr-1 for adoption of recommended management practices on agricultural soils and 22 to 26 Tg C yr-1 for secondary carbonates. Total potential of sequestration thus was 39-49 (44+-5) Tg C yr-1 (Lal, 2004). ***Earlier Swarup et al. (2000) calculated SOC sequestration rate of 5 to 44 Mg C ha-1 yr-1 in various locations of India.***

'The application NPK plus FYM emerged as a cost effective technology for Indian farmers. In view of the potential of C sequestration by major zeolitic and non- zeolitic soils, the present SOC stock of about 30 Pg in India can be further increased' (Pal DK, 2015).

Agroforestry

The study conducted on 25 agroforestry systems in BAIF programme area in Rajasthan state of India, estimated that the total above ground woody biomass in a 10 year old agroforestry farm having Indian Goosberry (amla) or mango with forestry trees contained 23 Mg C /Ha of carbon which is equivalent to 84.67 Mg CO2 /Ha. (Nimbalkar, et. al., 2017).

The potential of agroforestry systems for C sequestration depends on the biologically mediated uptake and conversion of CO2 into inert, long-lived, C –containing materials, a process which is called biosequestration (U.S. DOE 2008). Agroforestry promises to create synergies between efforts to mitigate climate change and efforts to help vulnerable populations adapt to the negative consequences of climate change. 'The conjecture of AFS (Agroforestry system) contribution to SCS (soil carbon sequestration) in the major agro ecological regions of the tropics, suggested values range from 5 to 10 kg C ha^{-1}in about 25 years in extensive tree-intercropping systems of arid and semiarid lands to 100-250kg C ha^{-1}in about 10 years in species-intensive multistrata shaded perennial systems and homegardens of humid tropics' (P.K. Ramachandran Nair, et. al., 2009).

The average carbon storage potential in Indian agroforestry has been estimated to be 25tC.ha-1 over 96 million ha (Sathaye and Ravindranath, 1998, cited in Basu, 2014). Substantial regional variability is associated with biomass production. Estimates of the rate of carbon sequestration under different agroforestry systems in India by Maikhuri et al. (2000) cited in Basu, 2014, are (a) Degraded forest land: 1.1t ha-1 yr-1 (b) Central Himalayas: 3.9 t ha-1 yr-1 (c) Indo-Gangetic plains: 8.5- 15.2 t.ha-1 yr-1 (d) Strip plantation aged 5.3 yr in Haryana: 15.5 t ha-1 during the first rotation € Agricultural soils of Indo-Gangetic plains: 12.4-22.6 t ha-1 yr-1.

7. CLIMATE SMART AGRICULTURE

More practical and easy to adopt practices have been recently advocated, known as Climate- smart agriculture (CSA). Climate – smart agriculture (CSA) may be defined as an approach for transforming and reorienting agricultural development under the new realities of climate change (Lipper et al. 2014). The most commonly used definition is provided by the Food and Agricultural Organization of the United Nations (FAO), which defines CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals".

Climate-smart agriculture (CSA) is an integrated approach to managing landscapes- cropland, livestock, forests and fisheries- that address the interlinked challenges of food security and climate change. CSA aims to simultaneously achieve three outcomes:

i. **Increased productivity:** Produce more food to improve food and nutrition security and boost the incomes of 75 percent of the world's poor who live in rural areas and mainly rely on agriculture for their livelihoods.

ii. **Enhanced resilience:** Reduce vulnerability to drought, pests, disease and other shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic weather patterns.

iii. **Reduced emissions:** Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and identify ways to suck carbon out of the atmosphere.

8. CONCLUSION

A combination of the adoption of simple emission control practices in agriculture and introduction of innovative strategies in the mixed farming system in India has great potential for mitigation of climate change. The concerted efforts through all the stakeholders will help introduce the CO2 mitigation methods. BAIF's strategy is to undertake a combination of livestock and land-based livelihood for rural people integrating CSA along with low emission practices.

REFERENCES

- Abha Chhabra, K.R. Manunath, Sushma Panigrahy, J.S. Parihar, 2013. Greenhouse gas emissions from Indian livestock. Cilatic Change (2013) 117:329-344. DOI 10.1007/s 10584-012-0556-8. Available from: https://www.researchgate.net/publication/257547949_Greenhouse_gas_emissions_from_Indian_livestock (accessed Jan 31, 2019).
- Basu: Agroforestry, climate change mitigation and livelihood security in India. New Zealand Journal of Forestry Science 2014. 44 (Suppl 1): S11.
- Boadi, D., C. Benchaar, J. Chiquette, and D. Masse. 2004." Mitigation Strategies to Reduce Enteric Methane Emissions from Dairy Cows: Update Review." Canadian Journal of Animal Science 84: 319-335. https://doi.org/10.4141/A03-109. https://community.data.gov.in/average-milk-yield-from-indigenousnon-descript-cows-in-india-during-2014-15/
- Choi J.et al. 2014. Effect of SRI water management on water quality and greenhouse gas emission in Korea. Irrigation and Drainage, 63:263-270.
- Chu G. et al. 2015. Alternate wetting and moderate drying increases rice yield and reduces methane emission in paddy field with wheat straw residue incorporation. Food and Energy Security, 4:238-254.

- EPA. 2005. EPA (Environmental Protection Agency). 2005. Opportunities to Reduce Anthropogenic Methane Emissions in the United States. Publication 430-R-93-012. EPA, Washington, DC.
- FAO (Food and Agriculture Organization of the United Nations) **World Livestock 2011: Livestock in food security.** FAO, Rome, Italy. (2011)
- FAO (Food and Agriculture Organization of the United Nations). 2016. FAOSTAT Agricultural Data. Accessed September 1, 2016. http://faostat.fao.org/.
- FAO, 2014. Building a common vision for sustainable food and agriculture: principles and approaches. American Journal of Evaluation. Food and Agriculture Organization of The United Nations, Rome, Italy.
- Gathorne- Hardy A. et al. 2013. A Life-Cycle Assessment (LCA) of greenhouse gas emission form SRI and flooded rice production in SE India. Taiwan Water Conservancy, 61: 110-125.
- Gerber, P.J., Steinfeld, H. Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., and Tempio, G. 2013. *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities.* Food and Agriculture Organization of the United Nations (FAO), Rome.
- GOI, 2016. India's Nationally Determined Contribution (NDC) to UNFCCC. http://www.moef.nic.in/climate-change-docs-andpublications
- Herrero, M., B. Henderson, P. Havlik, P.K. Thornton, R.T. Conant, P. Smith, S. Wirsenius, et al. 2016. "Greenhouse Gas Mitigation Potentials in the Livestock Sector." *Nature Climate Change* 6: 452-461.
- India, MoAFW (Ministry of Agriculture and Farmers' Welfare). 2012a. *19th Livestock Census- 2012: All India Report.* http://dahd.nic.in/documents/statistics/livestock-census. New Delhi.
- IPCC.2007 The Physical Science Basis. In: Solomon, S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds.) Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- J.R. Knapp, G. L. Laur, P.A. Vadas, W. P. Weiss, J.M. Tricarico, 2014. Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. Journal of Dairy Science Volume 97, Issue 6, June 2014, Pages 3231-3261.
- Jain N. et al. 2014. Mitigation of greenhouse gas emission with system of rice intensification in the Indo- Gangetic plains. Paddy and Water Environment, 12:355-363.
- Jha AK, Singh K, Sharma C, Singh SK, Gupta PK (2011). Assessment of Methane and Nitrous Oxide Emissions from Livestock in India. Journal Earth Science and Climatic Change 1: 107. Doi:10.4172/2157-7617.1000107

- Knapp, J. R, G.L. Laur, P.A. Vadas, W.P. Weiss, and J.M. Tricarico.2014." Enteric Methane in Dairy Cattle Production: Quantifying the Opportunities and Impact of Reducing Emissions." *Journal of Dairy Science* 97 :3231-3261
- Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science (80-.)304, 1623-1627. Source- FAO, 2016 (www.fao.org/climate-change)
- Mengpin Ge, Johannes Friedrich and Thomas Damassa - November 25, 2014. World's Top Ten Emitters. World Resources Institute. https://wri.org/blog/2014/11/6-graphs-explain-world%E2%80%99s-top-10-emitters.
- MoAFW 2012a; 2012b. 19th Livestock Census District Wise Report 2012. New Delhi. (http://dahd.nic.in/documents/statistics/livestockcensus)
- NAAS 2017. Innovative Viable Solution to Rice Residue Burning in Rice-Wheat Cropping System through Concurrent Use of Super Straw Management System-fitted Combines and Turbo Happy Seeder. Policy Brief No. 2, National Academy of Agricultural Sciences, New Delhi. 16 p.
- NDDB, ---, A K GARG DGM (AN). Overview of Fodder Scenario in India and Strategies for Up Scaling Fodder Seed Production and Marketing Programs in Dairy Cooperatives. http://www.dairyknowledge.in/sites/default/files/dkp-overview-of-fodder_akgarg.pdf
- NDRI, 2014. M.L. Kamboj/Shiv Prasad/P.S. Oberoi/ A,. Manimaran/S.S. Lathwal/ Khushboo Guptal National code of practices for management of dairy animals in India. CAR- National Dairy Research Institute, Karnal.
- Nirmal Kumar Patra, Suresh Chandra Babu. 2017. Mapping Indian Agricultural Emissions. Lessons for Food System Transformation and Policy Support for Climate-Smart Agriculture. FPRI Discussion Paper 01660. July 2017.
- Pal DK, Wani SP and Sahrawat KL 2015. Carbon Sequestration in Indian Soils: Present Status and the potential. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. 85 (2), 337-358.
- Pathak H, Bhatia A and Jain N. 2014. Greenhouse gas Emission from Indian Agriculture: Trends, Mitigation and Policy Needs. Indian Agricultural Research Institute, New Delhi- 110012, p39.
- Pathak H, Bhatia A and Jain N. and Aggarwal PK (2010) Greenhouse Gas Emission and Mitigation in Indian Agriculture- A Review, In *ING Bulletins on Regional Assessment of Reactive Nitrogen*, Bulletin No. 19, (Ed. Bijay Singh), SCON-ING, New Delhi, pp i-iv and 1-34.
- Pathak H, C. Li, and Wassmann, R., 2005. Greenhouse gas emissions from Indian rice fields: calibration and up scaling using the DNDC model. Biogeosciences Discussions, 2, 77-102, 2005. www.biogeosciences.net/bdg/2/77 SRef-ID: 1810-6285/bdg/2005-2-77. European Geosciences Union.

- Populstat, 1999/2003. http://www.populstat.info/Asia/indiac.htm
- Rajesh Kumar and Hema Tripathi, 2011. *Profitability of Cross Breeding among the Dairy Farmers.* Indian Research Journal of Extension Education 11 (1), January, 2011. Available from: https://www.researchgate.net/publication/11493845_Profitability_of_Cross_Breeding_among_the_Dairy_Farmers (accessed Jan 30, 2019)
- Reyes Tirado, 2009. Greenhouse gas emissions and mitigation potential from fertilizer manufacture and application in India. Subsidizing Food Crisis - Synthetic fertilizers lead to poor soil and less food. Greenpeace India, #60 Wellington Street, Richmond Town, Bangalore 560 025. Pp 13-19. (http://environmentportal.in/files/Subsidising%20Food%20Crisis.pdf – downloaded on 23.03.2019)
- S.D. Nimbalkar, D.S. Patil, J.P. Sharma, J. N. Daniel, 2017. Quantitative estimation of carbon stock and carbon sequestration in smallholder agroforestry farms of mango and Indian gooseberry in Rajasthan, India. Environment Conservation Journal 18 (1 and 2) 103-107, 2017 ISSN 0972-3099 (Print) 2278-5124 (Online).
- S.R. Shafer, C.L. Walthall, A.J. Franzluebbers, M. Scholten, J. Meijs, H. Clark, A. Reisinger, K. Yagi, A. Roel, B. Slattery, I.D. Campbell, B.G. McConkey, D.A. Angers, J.F. Soussana, G. Richard **Emergence of the global research alliance on agricultural greenhouse gases.** Carbon Management, 2 (2011).pp. 209-214
- Saroj Devi, Charu Gupta, Shankar Lal Jat, M.S. Parmar, January 2017. *Crop residue recycling for economic and environmental sustainability: The case of India.* Open Agriculture. 2017;2:486-494. DOI: 10.1515/opag-2017-0053 Available from: https://www.researchgate.net/publication/320198729_Crop_residue_for_economic_and_environmental_sustainability_The_case_of_India (accessed Feb 02 2019).
- Shipli K, Naik SN, Dahiya RP. GIS-based Assessment of Methane Emission from Livestock in India. Dairy and Vet Sci J. 2018; 7(5):555721. DOI: 10.19080/JDVS.2018.07.55572
- sri.ciifad.cornell.edu ---. http://sri.ciifad.cornell.edu/index_files/ClimateChangeMitigation.pdf
- Sultan Singh, B.P. Kushwaha, S.K. nag, S. Bhattacharya, P.K. Gupta, A.K. Mishra and A. Singh, 2012. Assessment of enteric methane emission of Indian livestock in different agro-ecological regions. CURRENT SCIENCE, VOL.102,NO.7, 10 APRIL 2012
- Surendra Pathak, Niveta jain, arti Bhatia, 2012. Crop Residues management with Conservation Agriculture: Potential, Constraints and Policy Needs. Indian Agricultural Research Institute Indian Council of Agricultural Research (IARI). New Delhi-110012. (https://www.researchgate.net/publication/256378461_Crop_Residues_Management_with_Conservation_Agriculture_Potentail_Constraints_and_Policy_Needs) (accessed Feb 02, 2019)

- U.S. Department of Energy (2008) Carbon cycling and biosequestration: integrating biology and climate through systems science, report from the March 2008 Workshop, DOE/SC-108, U.S. Department of Energy Office of Science. http://genomicsgtl.energy.gov/carboncycle
- USAID, 2015. United States Agency for International Development by Colorado State University (CSU), through the 'Grasslands, Rangelands, Livestock and Climate Resilient Mitigation'.
- Veerasamy Sejian, Lipismita Samal, M. Bagath, R.U. Suganthi, Raghavendra Bhatta, Rattan Lal, 2015. **Gaseous Emissions from Manure Management Chapter.** January 2015. In book: Encyclopedia of Soil Science, Edition: Second Edition, Chapter: Gaseous Emissions from Manure Management, Publisher: Taylor and Francis, DOI: 10.1081/E-ESS2-120052908.
- Vikaspedia, 2019. vikaspedia.in/energy/energy-production/bio-energy/biogas. Downloaded in January 2019.
- Singh, D.D., Kumar, M., Choudhary, P.K. and Singh, H.N. 2009. Neonatal calf mortality - An overview. Intas Polivet, 10(11): 165-169.
- Prasad, S., Ramachandran, N. and Raju, S. (2004) Mortality pattern in dairy animals under organized herd management condition at Karnal, India. Tropical Animal Health and Production, 36:645-654.