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Greening of Indian Livestock and Poultry Sector: Policy Options for Developing Sustainable Approaches

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Preface

The 'triangle of sustainable development' consists of water, energy, and food sources. Meeting the nutritional needs of 1.6 billion Indians by 2050 necessitates an increase in livestock and poultry production. However, the conventional production methods currently in use are largely seen as significant contributors to climate change, biodiversity loss, and freshwater depletion. It becomes imperative to analyze the current status of mixed crop-livestock-aquaculture and small-holder local production and consumption patterns in India. Greening these sectors presents a viable alternative to the existing practices, offering a possible way to deal with the substantial environmental footprint—one of the most significant challenges of the 21st century.

Out of 26% greenhouse gas emissions (GHG) from food production globally, livestock, poultry, and fisheries sector contribute 14.5%. This suggests that 56% of all emissions from the food system are related to livestock, poultry, and fisheries. Notably, the dairy, meat, and poultry processing industries stand out as the most energy-intensive sectors, while fish culture represents one of the most water-intensive activities. Addressing these challenges is critical to fostering a sustainable and resilient future for food production in India. Mitigating climate change impacts associated with livestock and poultry sector involves implementation of sustainable practices and green technologies that minimizes environmental degradation and ecological footprint. Greening of livestock sector will ensure use of low-carbon technology. This will protect environment, add to circular economy with increased productivity and profits while meeting SDG's and providing global competitive edge.

There are number of approaches to reduce emissions, including mediations on the supply side and reducing the demand for animal products especially red meats from industrialised nations. While there is a growing demand for animal proteins worldwide, solutions like bettering animal wellbeing, novel breeding practices, cutting down on food loss and waste, and directly addressing GHG emissions have the potential to benefit people and the planet. By integrating these measures and adoption of comprehensive approach to sustainability, the livestock and poultry sector can reduce its environmental impact while responsibly meeting the growing global demand for animal protein.

In order to develop policy measures to drive change, National Academy of Agricultural Sciences organized a brainstorming session on "*Greening of Indian Livestock and Poultry Sector: Policy Options for Developing Sustainable Approaches*"on September 01, 2023 to seek inputs from various stakeholders representing livestock and poultry industry, researchers and policy makers for decarbonising livestock and poultry sector towards circular bioeconomy. I thank the Convener Dr. Naveena B. Maheswarappa for taking this initiative, Dr. Dheer Singh and Dr. R. Bhatta for reviewing the paper and to all the eminent participants for their valuable inputs. I also take this opportunity to thank Dr. V.K. Baranwal and Dr. R.K. Jain for their editorial support. I hope this document will be useful to the policymakers and other stakeholders.

(Himanshu Pathak)
President, NAAS

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Greening of Indian Livestock and Poultry Sector: Policy Options for Developing Sustainable Approaches

1. LIVESTOCK SECTOR: INDIA VS. WORLD

With an impressive Compound Annual Growth, the livestock sector is an engine of global economic growth and source of inclusive societal development. More than 18 percent of the world's population is engaged in animal husbandry and/or the processing and marketing of animal-based foods (OIE, 2020). Today, livestock is the fastest-growing agricultural sub-sector, making up to five of the six highest-value commodities in the world and contributes more than 40 percent to agricultural Gross Domestic Product (GDP) in developed nations (Livestock Global Alliance, 2016).

In India, during the year 2021-22, the livestock sector contributed 5.73% to National GVA and 30.19% to agriculture and allied sector GVA with an annual growth rate of 6.0% (BAHS, 2023). The livestock sector output in India at current basic prices in the year 2021-22 is Rs. 15,63,399 crores. Out of the total livestock sector contribution, milk group contributes Rs. 9,95,215 crores (63.35%),meat and eggs group contributed Rs. 4,40,669 crores (28.18%), dung and dung fuel is worth Rs. 1,17,816 crores (7.53%) and others worth Rs. 14,009 crores (0.89%)(National Accounts Statistics, Central Statistical Office, Ministry of Statistics and Programme Implementation, Govt. India). In the year 2022-23, the annual growth rate of milk sector was 3.83% against 5.13% and 6.77% of meat and egg respectively. India has the highest per capita availability of milk with 459 g/day, whereas the per capita availability of meat (7.1 kg/annum) and egg (101 eggs/annum) was among the lowest in the world. Global average meat consumption is 30 kg/person/annum (BAHS, 2023).

Demand for meat and meat products will continue to increase till 2050 in low- and middle-income countries (Desiere *et al*., 2018; Gouel and Guimbard, 2019). The significant portion of meat, milk, poultry and eggs production and consumption is anticipated to take place in developing nations. Thus, we need to produce more livestock products to meet the nutritional security of growing global population especially in developing country like India. Hence, the livestock sector has to deliver more, utilizing less resources with maximum profits to all.

As of 2019, the 69% of total livestock (measured in livestock units) in India was owned by landless agricultural labourers, marginal and small farmers implying more equitable distribution of livestock holdings (NSS 77th Round, 2021). Therefore, transformation of small-holder, subsistence-level Indian livestock sector to viable and economic model, while preserving community and national resource systems need technological, institutional and policy support. This document provides comprehensive approaches for greening of livestock and poultry production to ensure inclusive, resilient, sustainable and adoptive low-emission livestock-agri-food systems. The challenges and opportunities facing the livestock and poultry sector and developing “green growth” strategies and path towards sustainability have been discussed.

2. GREEN MOMENT

Climate change is causing significant rise in atmospheric temperature, collective heat and drought stress, variation in seasons, substantial rain events and water scarcity, unusual pest infestation and disease outbreaks and sea level rise and ocean acidification. All these factors affect the agricultural activities together with livestock and associated value chains, livelihoods and ecosystems. While livestock sector provides source of livelihood, promote inclusive growth, ensures sustainability, women empowerment and child nutrition, other issues like human-wildlife-livestock conflicts, zoonotic diseases, antimicrobial resistance, one-health and child labour issues need to be addressed. In the meantime, there is also an extensive apprehension regarding the environmental impressions of milk, meat and poultry.

Over the past 50 years, the global supply of foods derived from animals has more than tripled, as a result of rising per capita food consumption and population growth. At the same time, the amount of crops required to produce animal feed has increased threefold (FAO, 2018). Growth in human population and the increased per capita demand will require an added demand for 21 percent of animal proteins by 2050 all inclusive. In Asia, the demand for animal proteins (milk, meat and egg proteins) is expected to increase from 36.20 Mt in 2020 to 42.57 Mt by 2050. In 2015, animal-agriculture which includes cattle, water buffaloes, sheep, goat, pigs and chicken resulted in approximately 6.2 billion tonnes of CO_2 equivalent emissions (Gigatonnes carbon dioxide equivalent or $GtCO_2eq$) per year which is 40 percent of total emissions from agrifood systems (FAO, 2023). Without any mediations and efficiency gains, meeting augmented demand is expected to take global livestock emissions to approximately 9.1 $GtCO_2eq$ by 2050. Additional 20% increase in demand globally for animal proteins by 2050 will witness most substantial increase in absolute demand in Asia. Without appropriate interventions and proper strategies to reduce greenhouse gases (GHG) emissions will result in global warming. The implementation of sustainable activities is vital in accomplishing lesser emissions and mitigating the environmental impact of livestock systems. There are some pathways to lesser emissions, including mediations on the supply side and discounts in the demand for animal products.

The Food and Agriculture Organization (FAO) hosted Global Agenda for Sustainable Livestock (GASL), a partnership of livestock sector stakeholders and FAO-Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative which pursues to advance the livestock and environmental sustainability using coherent methods, metrics and data. Animal Production and Health Division of FAO utilized the Global Livestock Environmental Assessment Model (GLEAM) and developed the report on “Pathways towards lower emissions” based on life cycle assessment (LCA) findings computing global emissions and mitigation possibilities for animal-agriculture. These studies have estimated the livestock's carbon footprint through "lifecycle assessment" and quantified ecological impact of animal-agriculture. However, livestock industry is not uniform all over the world and local climatic factors, production methods, production systems, processing, distribution and retailing of milk, meat and eggs, behavioral issues and consumer preferences will differ between the countries. Indians do not farm and process just like Americans, Europeans or south east Asians do. This means, environmental sustainability challenges vary among developed, developing and under-developed countries and therefore, region-specific strategies must be developed to ensure greening of livestock sector.

The greening of the livestock sector refers to efforts aimed at making livestock production more environmentally sustainable. Greening of livestock and poultry sector requires a multi-faceted approach involving technological innovation, policy support, consumer education and collaborative efforts across all the stakeholders throughout the supply chain to achieve environmental sustainability while meeting the burgeoning demand for animal products. The author takes this case to claim for less biased presumptions about harmful impacts of animal-agriculture actions and processing on the planetary wellbeing, for less top-down forecasting based on remote and Western technocratic points-of view, and for more all-inclusive and conditional approaches to the food system.

3. ENVIRONMENTAL IMPACT OF LIVESTOCK SECTOR

Worldwide, agriculture accounts for a staggering 90% of human freshwater consumption, raising concerns about potential threats to future agricultural production due to energy and water shortages (Hoekstra and Mekonnen, 2012). Meeting the United Nations-mandated Sustainable Development Goals (SDGs) by 2030 necessitates urgent attention to ensure water and energy sustainability. This compels a thorough examination of the rational use and re-use of these precious resources. Notably, the dairy, meat, and poultry processing industries stand out as the most energy-intensive sectors, while fish culture represents one of the most water-intensive activities, demanding significantly higher energy and water inputs. Addressing these challenges is critical to fostering a sustainable and resilient future for food production in India.

At the core of the current challenge in addressing the energy and water crisis lies a fundamental lack of comprehension of the water-energy nexus, along with its associated technical and financial implications for the industry. The misjudgement of water usage often leads to a misinterpretation of the water footprint of livestock and fisheries, subsequently impacting the achievement of Sustainable Development Goals (SDGs). Errors in calculating GHG emissions have arisen from a scarcity of primary data, reliance on extrapolation from secondary data, and an excessive dependence on data from developed countries. Therefore, a comprehensive approach is imperative, necessitating a nuanced understanding of the intricate water-energy nexus and its financial ramifications.

The ‘nexus of sustainable development’ comprises food, energy, and water. Meeting the nutritional needs of 1.6 billion Indians by 2050 necessitates an increase in livestock, poultry, and aquatic product production. However, the conventional production methods currently in use are widely seen as significant contributors to climate change, biodiversity loss, and freshwater depletion. It becomes imperative to analyze the current status of mixed crop-livestock-aquaculture and small-holder local production and consumption patterns in India. Greening these sectors presents a viable alternative to the existing practices, offering a potential solution to address the substantial environmental footprint—one of the most significant challenges of the 21st century.

3.1 Water

Water is one of the most basic resources needed in agricultural production, and agriculture is the single largest water user accounting for 70% of global freshwater withdrawals (FAO, 2019a). Globally, livestock farming represents 70% of agriculture land use including 40% of arable crop land, when accounting for pasture grazing and feed production. Livestock sector activities consume more than quarter of humanities fresh water and accounts for 20% global nitrogen and phosphorous application mainly for feed production. 97% of total water footprint in livestock sector is emanating from feed production (Mekonnen and Hoekstra, 2012). On the contrary, India uses only 4.7% of total cultivable land for growing livestock feed (Koli and Bhardwaj, 2018). Annually, 4,387 km^3 of water is required to produce the feed consumed by the global livestock sector, of which 94% is green water (rain water). Livestock water productivity (LWP; defined as protein produced per m^3 of CWU) varies by numerous orders of magnitude between livestock categories, areas, and production systems, showing huge potential for enhancement (Heinke *et al*., 2020).

Globally, livestock sector produces a total of 53.7 MT of human edible protein with an average of 12.2 g protein per cubic meters (gP/m^3) LWP of consumptive fresh water use (CWU; water that is removed from available supplies without being returned to a water resource system) (Heinke et al, 2020). Out of the total human edible livestock protein, more than 50% (29.2 MT) is generated from ruminants (cattle, buffalo, sheep and goat), but utilizes around two thirds of total annual livestock CWU (2,893 km^3). On the contrary, monogastric animals (pig and poultry) produced 24.5 MT of human edible protein while utilizing only 1,494 km^3 CWU. With these findings, Heinke et al, (2020) suggested that pig and poultry produce over 60% more protein per unit of total CWU than ruminants (16.4 gP/m^3 compared to 10.1 gP/m^3). These researchers further indicated that, variation in type, composition of feed and feed conversion ratio between ruminants and mono-gastric animals might be resulting in different CWU. The CWU is reported to be highest for bovine meat animals>dairy bovines>industrial pigs>layer hens>dual purpose poultry>smallholder pigs. The share of blue water (irrigation water) in total CWU for monogastric animals varies from 6.8% for commercial broilers to 12.1% for smallholder pigs. Within ruminants, dairy bovines had relatively greater share of blue water as a result of higher proportion of cultivated feed crops and forages in the feed mix (21.5% compared to 14.6% average for remaining ruminants) (Heinke *et al.*, 2020). However, these CWU reported across the world, mainly comprises of data collected from large-scale, intensive, factory system of production. Fresh water withdrawal for different commodities is presented in Table 1 which indicates lower water usage for animal products like milk, eggs, pork and chicken relative to rice. These figures vary significantly under free range, extensive grazing system followed in India for cattle and buffaloes. Nomadic, pastoral production system followed for sheep and goat and backyard poultry production which constitutes 30% of total poultry production in India consumes significantly lower water. Considering 18-30 litres of water/day/livestock, the National Commission on Integrated Water Resources Development has suggested direct water consumption requirement for livestock sector in India is roughly about 5 billion cubic meters per year. Assuming 240 million MT of dry matter consumption by livestock in India @500 litres of water requirement per kilogram of dry matter, the indirect water consumed by Indian livestock would be of the order of 120000 million ton per annum Phansalkar (2006). In another study, based on the livestock population growth between 1997-2007 in India, Khan and Parashari (2015) estimated the water demand of 24483.64 cubic meters per day. A pilot study conducted at ICAR-National Meat Research Institute, Hyderabad has indicated 5.8 litres of water per bird during primary processing, whereas an average water consumption of 30.87 litres/kg value added product has been reported (Naveena *et al*., 2023).

Table 1. Fresh water withdrawal and total energy consumed per kilogram of food product

Food product	Fresh water withdrawal (L/kg product)*	Total energy^ used (MJ/kg product)#
French fries	---	15.16
Milk powder	---	16.22
Whey powder	---	10.01
Cheese	5605	5.04
Ice cream	---	4.52
Chicken	660	3.85
Pork	1796	2.09
Lamb	1803	---
Beef	3515	---
Milk	628	2.73
Egg	578	---
Rice	2248	---

*Poore and Nemecek (2018); #Ladha-Sabur *et al*. (2019); ^Energy consumed during primary and secondary processing

Water Footprint (WF) measurements from various sources worldwide generally state that every kilogram of beef consumes more than 15,000 litres of water. In any case, 90% of the water used by livestock (Boulay *et al*., 2022) is to be classified as "green water," or precipitation that does not contribute to runoff (Leroy *et al*., 2022). Pasture production utilizes more than one third of the green water in livestock production mainly on marginal lands where crop production is severely limited by environmental constraints (Ran *et al*., 2017). This indicates that green water is mostly utilized worldwide to grow pastures, particularly in marginal terrain that are unsuitable for growing crops intended for human consumption. To some extent, in poultry farming, usage of extractive water (blue water) for feed production is definitely a concern, but in cattle, buffalo, sheep and goat the blue water usage for feed production in India is very minimal considering the fact that grain feeding of ruminants is not followed except in few cases involving high milk yielding dairy animals. For example, the life cycle analyses of Australian lamb production indicated a CWU between 5 and 500 litres per kg of meat and for US beef it was an average of 2,000 litres of extractive water/kg carcass weight. Some of these studies remind us to comprehensively consider the livestock footprint values when drawing general conclusions.

3.2 Energy

In general, livestock production and primary processing activities consumes greater share of water, whereas processing, value addition and distribution (secondary processing) are high energy consuming sectors. Globally food sector consumes approx. 200 Exajoules (EJ) per year and approximately 45% corresponds to processing and distribution activities (Ladha-Sabur *et al*., 2019). For example, instant coffee, milk powder, French fries, crisps and bread are highly energy intensive products which consumes more than 10 MJ/kg product. Within the food industry, dairy processing is considered as one of the most energy intensive sectors as many dairy products are processed through concentration and separation of raw milk solids to varying degrees. For operation of pumps/ cold chain logistics etc., normally electricity is used, whereas for washing and sanitisation operation, evaporation and pasteurisation, thermal energy is utilised (Ladha-Sabur *et al*., 2019).

The meat processing industry is acknowledged as a high-energy-consuming sector, with poultry slaughtering consuming more energy than other meats due to high energy consuming operations like scalding and de-feathering, and singeing. An increase in the use of automated equipment, thermal control and hot water cleaning has elevated the energy consumption in slaughterhouses. Meat and meat products are very often made into cut-up parts, deboned, processed and frozen to provide convenience and variety to consumers which results in significantly higher energy consumption. Different cut-up, deboned and frozen poultry, pig and ruminant meat was reported to consume 5.64, 3.88 and 2.87 MJ/kg finished product, respectively (Table 1). Similarly, cut-up, deboned and chilled poultry, pig and ruminant meat was reported to consume 3.85, 2.85 and 2.15 MJ/kg finished product, respectively (Ladha-Sabur *et al*., 2019). Increase in energy and water usage in the meat and dairy processing sectors is attributed to rise in hygienic standards and cleaning requirements.

In India, only 11% of total poultry meat (4.99 MT) produced undergoes processing and marketed under chilled conditions, whereas major portion of meat is marketed under fresh (un-chilled) condition (APTEC, 2022). A pilot study has reported an average electricity consumption of 7.01 units per kg of value-added chicken product processing under small scale operations (Naveena *et al*., 2023). Almost all sheep, goat and pig meat produced in India are sold fresh in local, retail meat shops without any chilling excepting for some pork products. Further, processing and value-added meat products and frozen meat is very limited in India except for frozen buffalo meat exports. Poultry and meat processing and retailing in India is highly decentralised with local production through wet-markets which is highly energy efficient (Naveena *et al*., 2018). Hence, energy consumption during processing, transportation, storage and distribution of meat and poultry is significantly lower in India resulting in lower food miles which is highly sustainable. However, modernisation of wet-markets on scientific lines to ensure the safety and quality of meat and meat products must be ensured. At the same time, livestock in India have the potential to generate 2600 million tons dung per year, capable of yielding 263,702 million m^3 of biogas if exploited. Estimates by Kaur *et al*. (2017) suggest that if the livestock biomass is utilized judiciously, it has the potential of generating 477 TWh (Terawatt hour) of electrical energy per annum.

3.3 GHGs

An overview of livestock sector activities indicating inputs, output and the accompanying environmental impact is represented in Figure 1. The methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) are important GHG's emitted from livestock systems and the goal is to reduce the emission or ameliorate these three GHG's. Among these three gases, even though methane is short-lived, it is extremely compelling GHG, and hence in the race to manage global warming, mitigating methane emissions can yield quick returns.

- **Direct emissions** from the livestock sector globally, encompassing CH_4 from enteric fermentation, and N_2O and CH_4 from manure management, amount to 3.7 $GtCO_2eq$ which is identical to roughly 60 percent of the total livestock emissions.
- **Indirect emissions** through upstream and downstream activities. Upstream activities include feed production which involves use of synthetic fertilizers, pesticides, energy, land use changes (tractors), transportation etc. Downstream activities include transport, primary and secondary processing, cold storage, packaging, distribution, retailing and consumption.

Total global GHG emission was estimated to be 50-52 $GtCO_2$ eq. (food + non-food) during the year 2015 (FAO, 2022). Out of this, food production which includes land use, crop production, livestock and fisheries and supply chain, constitutes 26% and the remaining 74% is through non-food items. Animal protein production was

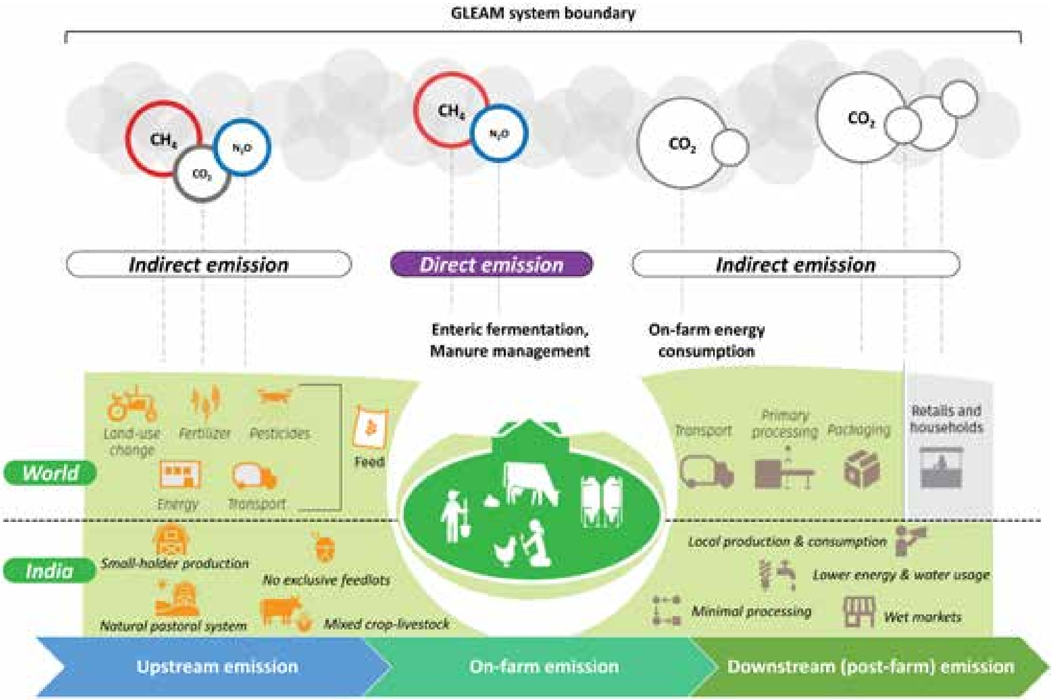

Figure 1. An overview of livestock sector activities from cradle to consumer and the associated GHG emission scenario (Modified from FAO, 2023)

estimated to emit 6.2 GtCO_2 eq. which is 12% of total emissions. The FAO-Livestock Environmental Assessment and Performance Partnership (LEAP) has reported the contribution of livestock to total greenhouse gas (GHG) emissions as 14.5%, which is mostly ascribed to feed production (45% of contribution) and enteric fermentation by ruminants (39%). Overall, 54% of livestock emissions expressed as CO_2 eq., are in the form of CH_4, while CO_2 and N_2O represent 31 and 15%, respectively. Especially, the production system influences the comparative extents of these gases and their level vary altogether between ruminant and monogastric structures. Hence, real activities to manage emissions ought to be custom fitted to distinct production systems and local situations.

The CH_4 emission is mainly originating from cattle, buffalo and small ruminants mostly through enteric emission and manure handling, whereas CO_2 and N_2O are resulted chiefly through poultry and pig production because of growing feed (maize and soya) production, use of synthetic fertilizers and pesticides, land use changes and excreta management, transportation, cold stores and primary processing activities. With an annual production of roughly 5 GtCO_2 equivalent which roughly accounts for more than 60% of total livestock emissions, cattle are the primary source of GHG emissions. Small ruminants, chickens, buffaloes, and pigs all contribute significantly less to the sector's emissions, accounting for about 7 to 10% of total emissions each

(FAO, 2023). But, livestock production is an essential component of global efforts to reduce hunger and poverty and therefore it is appropriate to consider GHG in the context of emission intensities (rate of emission relative to unit of production). Emission intensities will assist in augmenting efficiency of livestock systems in low- and middle-income countries (LMICs) where greater degree of inefficiency is prevalent in livestock. Even though, high income countries have a greater share of emissions, the LMICs with high livestock densities where ruminant farming is prevalent also tend to have higher emissions. At the same time greater variation in productivity and related emissions (ruminants versus monogastric) are reported within and between livestock systems. Large chuck of poultry and pigs with higher feed conversion ratio (FCR) are increasingly produced under intensification resulting in greater efficiency, but with a significantly higher N_2O and CO_2 relative to CH_4. Hence, highly industrialised factory system of production is a global concern due to shift from short-lived CH_4 to much more persistent N_2O and CO_2.

In general, ruminant products have the highest intensities: buffalo meat (404 kg CO_2 equivalent per kilogram of protein), beef (295 kg CO_2 equivalent per kg of protein), and small ruminant meat (201 kg CO_2 equivalent per kg of protein). However, cattle milk, pork, chicken meat and chicken eggs were reported to have lower emissions at 87 kg, 55 kg, 35 kg and 31 kg CO_2 equivalent per kg of protein, respectively (FAO, 2019b). These emissions notwithstanding, a substantial portion of food emissions, constituting 26%, stems from losses in supply chains or wastage by consumers. Nearly two-thirds, i.e. 15% of food emissions results from supply chain losses caused by inadequate storage and handling practices, insufficient refrigeration, and spoilage during transport and processing. Hence, effective waste management strategies and greening approaches must be adopted to contribute towards India becoming a net-zero emitter by 2070.

3.3.1 Reduction of enteric methane emission

In addition to contribution to global warming, enteric methane is also responsible for substantial loss of 2-12% of dietary energy as each litre of enteric methane emission carries 39.5 kJ of dietary energy away from the animal (Guan *et al*., 2008; Johnson and Johnson, 1995). According to estimates from the Food and Agriculture Organization, better management methods alone may cut net emissions from livestock systems by roughly 30%, with methane being the main source of emissions. By enhancing several action areas concurrently, an integrative approach can produce better results faster and with an even higher global benefit. Goopy (2019) have suggested few measures to ameliorate GHG emissions which includes introduction of reductive acetogens, defaunation, anti-methanogen vaccines, early life programming and genetic selection at both the rumen and animal level. His study concluded that, with the exception of selective breeding, which comes at a high cost and with questionable efficacy, there is currently little *in-vivo* evidence to support the practical success of any of the aforesaid measures. Lastly, it is proposed that dietary and management techniques to lower emissions will benefit developing nations the most, quickly, and affordably.

Various international and national agencies project livestock resources from south Asia, especially India as high enteric methane emitting animals considering poor quality feed, lower productivity, disease outbreaks etc. To address these issues, ICAR-National Institute of Animal Nutrition and Physiology (NIANP) has developed a state-wise enteric methane emission inventory from the ruminant animals in India based on the primary data on the methane production potential of more than 1500 feed ingredients/diet combinations and prevailing feeding practices. While developing the inventory, the NIANP has considered the seasonal and regional variability in feed resources, feeding practices, physiological stages of animals etc. (Bhatta, 2023).Their study has revealed that the Indian livestock annually emits about 9.25 Tg (teragrams) enteric methane. Five states, namely Andhra Pradesh (undivided), Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh, together contribute to almost half of the total enteric methane emission. Their database also indicates that amongst different species, cattle emit 56%, buffaloes 29%, sheep 5% and goats 10%.The 10 states in India are resulting in 55-65% of milk, egg and meat production. These states have highest livestock and poultry population. The UP, Rajasthan, MP, Gujarat and AP contributes more than 53% of milk production; AP, TN, Telangana, WB and Karnataka contributes 65% of egg production, whereas UP, WB, Maharashtra, AP and Telangana produces 58% of meat. Therefore, livestock and poultry induced GHG emissions both total emissions (absolute) and emission intensity (emissions produced per unit of product) is higher from these states.

Yan *et al*. (2024) suggests 3 key stages in livestock production, i.e., animal housing, manure storage and treatment, and manure application as effective management strategies to reduce GHG emissions. On the other hand, two key strategies like methane capture/utilization and feed modification and digestive support have been suggested (Duff and Lenox, 2019). Few suggested measures include daily removal of manure during animal housing, acidification (example, use of lactic acid) during manure storage and treatment, shallow injection of manure for field application. Utilization of anaerobic digestors to capture the methane (biogas) and use as energy source for heat or electricity, addition of other organic wastes such as food waste and crop residues to manure. Viable feed additives and supplements including natural substances, inclusion of tropical tree leaves such as jack fruit, neem and banyan and use of seaweed in feed, anti-methanogenic feed supplement like 'Harit Dhara' developed at ICAR-NIANP (Bhatta, 2023; Yan *et al*., 2024). A study by Bhatta et al. (2015) revealed in-vitro reduction in methane production using tannin containing tropical leaves of *Ficus bengalensis*, *Autocarpus integrifolis* and *Azadirachta indica*. Ration balancing in lactating buffaloes with the locally available feed resources at the farmers' doorsteps as suggested by National Dairy Development Board (NDDB) and National Dairy Research Institute (NDRI) are also effective in mitigating methane emission (Garg *et al*., 2012). Another potential option is effective culling of unproductive animals as per the market demand which will reduce the GHG emission significantly. For example, the environmental benefits of culling @10% of unproductive female buffaloes in India i.e. 11.92 million buffaloes/year was reported to reduce 0.059 GtCO2eq. in each year (Sen *et al*., 2022).

4. ANIMAL SOURCED FOODS IN SUSTAINABLE DIETS

Consumption of foods of animal origin provide considerable advantages due to their nutrients with a superior bioavailability, high biological value, higher protein digestibility corrected amino acid score and superior digestible indispensable amino acid score (Naveena *et al*., 2020). In addition to health worries associated with consumption of red meats and processed meat products, there are rising apprehensions regarding the environmental effects of animal source foods. Various livestock sector activities like intensive cropping for growing pasture, overgrazing, soil erosion, deforestation, water pollution, etc. that are detrimental to the environment requires significant mitigation measures. These harmful impacts, however, are not connected to animal husbandry activities.

Food animal production, especially ruminants help in up-cycling of pastures/feed and agriculture by-products like forage, dry leaves, stubbles etc. mainly grown in marginal/ dry land that are not suitable for growing human food. If managed well and raised with good husbandry practices, the livestock sector augment soil health and planetary benefits in addition to providing nourishing milk, meat and eggs. Amalgamation of livestock and crop production may encourage natural/organic practices through upgraded supplement reusing, while limiting the application of synthetic nitrogen and chemicals. A small-scale, livestock-crop integrated sustainable and circular model practiced in South Africa has been depicted in Figure 2. Similar models need to be demonstrated for wider adoption among stakeholders. Likewise, the effects of livestock activities on land use, water usage, and GHG emissions are extremely circumstantial, and their assessment is frequently wrong as a result of deflationist use of measurements (Leroy *et al*., 2022).

Studies revealed that global warming must be kept below two degrees Celsius to avoid significant global disruptions. Getting there will require near total de-carbonization of all economic activity by 2060. Agriculture, forestry, and other land use represent 24% of global greenhouse gas emissions in which livestock and nitrogen fertilizers are key drivers of agriculture emissions. Therefore, FAO 2030 and 2050 projections predict that, decarbonising enteric fermentation, manure management and synthetic nitrogen fertilizer emissions through reduced meat consumption and reduced N fertilizer use will decrease GHG emissions by 50% (2030) and 100% (2050) (Duff and Lenox, 2019). While reducing meat consumption may seem a straight forward option for developed countries who consume far more meat than necessary to bring down the greenhouse gas emissions from livestock, increasing consumption sustainably mainly among malnourished population in developing or undernourished countries is a challenging task. Everything in balance advocates consideration of meat and meat products as a part of sustainable diet. However, elimination or substantial ceiling on meat and poultry might result in extra-delicate food system causing nutritional deficiencies among population.

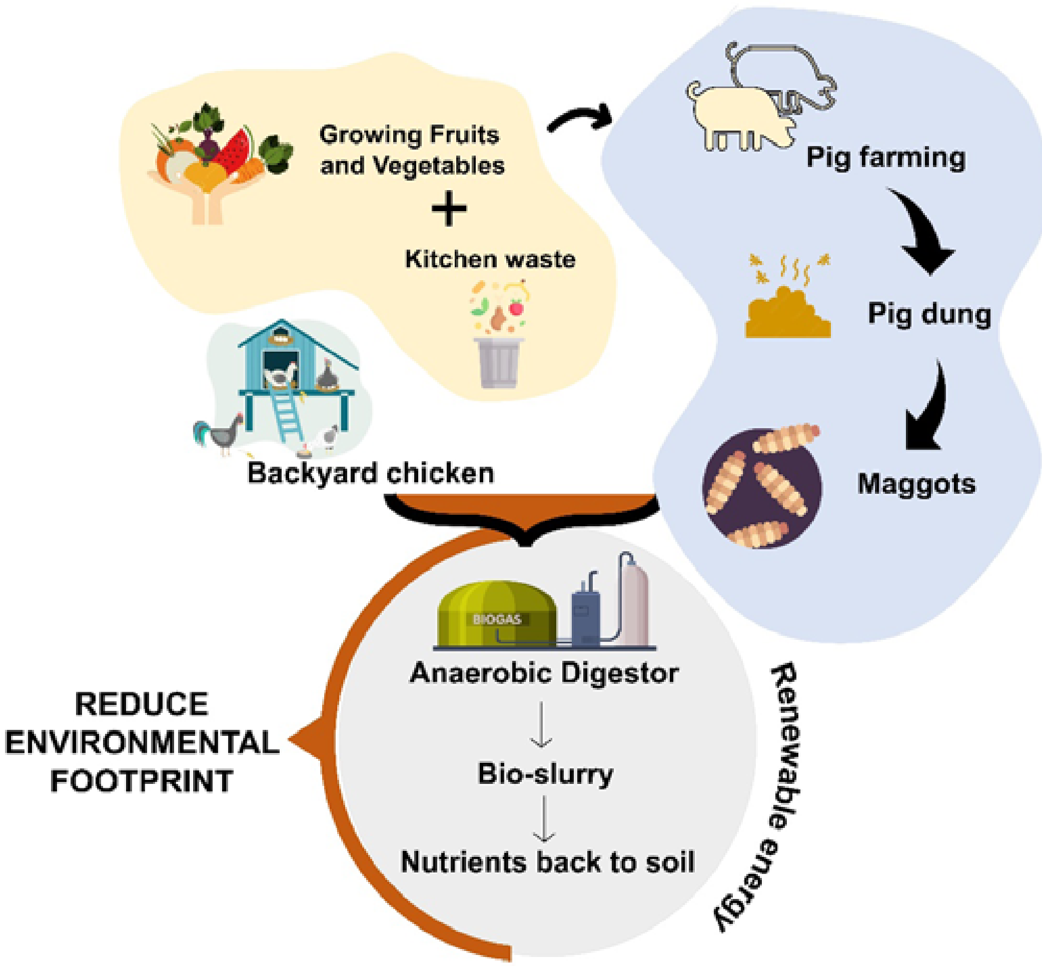

Figure 2. Livestock-crop integrated model demonstrating sustainability and circular approach

4.1 Feed versus food

Arguments about animal feed competing with crops that would be used as human food exaggerate that 6-20 kg grain is needed to produce 1.0 kg meat, while in reality, this is around 3.0 kg of grain (Mottet *et al*., 2017). Dried leaves, hay, crop residues, and other by-products that are not suitable for human consumption constitutes 86% of livestock feed and only 5% of the global feed intake by ruminants consists of grains and soybean meal that may compete with the human diet (Mottet *et al*., 2018). Under Indian conditions, grains and soyabean usage in ruminant feeding is negligible and there are no exclusive feedlots to ensure fattening of beef cattle in India. Rumen-centred metabolism in ruminants basically reprocess the human-inedible materials to highly nutritious foods, thereby functioning as clear suppliers of edible protein to human consumption. However, a study by ILRI scientists shows that inadequate levels of nutrition in ruminants can result in higher levels of methane emissions per unit of animal product (Goopy *et al*., 2020). When more than 30 percent of Africa's agricultural emissions are generated by the digestive processes of livestock, providing sufficient high quality feed can make all the difference to the sustainability of the meat sector by increasing livestock productivity and reducing emission intensity (Kasyoka, 2018).

5. TRANSFORMATION TOWARDS LOW-CARBON MILK, MEAT AND EGG PRODUCTION

Almost 197 countries around the world have declared to become net zero CO_2 emitters by 2050 during 2015 Paris Climate Agreement. India has targeted to become net zero by 2070 (COP-26). In spite of low per-capita emissions (1.8 tons CO_2), India is the 3rd largest emitter globally, emitting a net 2.9 $GtCO_2$ eq every year as of 2019. However, India has the potential to create 287 gigatons of carbon space for the world (Gupta *et al*., 2022). Livestock and poultry sector can significantly contribute towards establishing climate finance and emission trading schemes in India.

If a producer reduces the greenhouse gases emission to at least 10 percent lower than the industry's standards baseline, USDA-approved low-carbon certification can be obtained which is mainly for beef production (lowcarbonranch.com). If a milk/meat that has zero carbon footprint or if the carbon emission associated with milk/meat have been offset, a provision of carbon-neutral certification is being adopted in Australia (mla.com.au). Accordingly, milk, meat and poultry industries around the world have set the target to achieve zero carbon footprint/net zero by 2050. In this direction, few poultry producers have declared to reduce their emissions up to 30 percent by 2030. Even in India, private companies namely large urban dairy farms, milk processors, poultry integrators, and export meat plants must target to create positive impacts on society and environment in support of SDG's and contribute towards India achieving net zero targets.

6. GREENING STRATEGIES AND ACTIONABLE POINTS

Based on the above analysis, strategies perceived to mitigate the environmental impact of livestock sector along the demand-supply chain including production, processing, distribution and retailing are listed below.

1. **Improved feeding practices:** Deforestation free sourcing of feed (eg. Sustainable soymeal in animal feed), optimizing feed formulations for maximum feed efficiency with smart supplements (eg. Water fern, *Azolla caroliniana*) and tailored practices to local culture to minimize environmental impacts while ensuring animal health and productivity. Adoption of hydro and aero ponic mode of feed and fodder production for both environmental and animal feed sustainability is perceived.

2. **Reducing methane emission:** While scientific advancement in containing and managing methane emission based on real-time monitoring and generation of data is advocated, large scale field trial of already developed methane emission reduction technologies like *Harit Dhara* by ICAR-NIANP and ration balancing program of NDDB are suggested to bring down the emission at-least by around 20 percent. In addition, methane absorbing vertical gardens or walls may be explored as one of the options to contain its impact on environment.
3. **Adoption of energy efficient and water conservation practices:** Practices like water recycling and reusing (effluent treatment plants), energy-efficient housing systems (eg. net zero energy building for poultry), discouraging production of energy intensive products (eg. cheese, milk powder and fries etc.), encouraging energy efficiency labeling and overall operation efficiency can contribute to greening the sector. Similarly, sensor based precision use of water from production to consumption value chain is perceived.
4. **Harvesting renewable energy:** Animal strength specific bio-green gas plants and even vety-voltaic (solar and animal farms in the same land) are suggested for nature based self sufficiency in power requirement and even sale of solar power so generated for extra revenue. Transformation of animal dung and dairy waste into energy; poultry litter and poultry farm waste into bio-diesel illustrated and being practiced in some places in India may be reproduced in other parts.
5. **Manure management:** Technologies such as anaerobic digesters and high temperature composting can convert manure into biogas for energy generation, reducing methane emissions while producing renewable energy.
6. **Grassland management:** Rotational grazing, reforestation of degraded pastures, restoration of riparian zones, stopping conversion of pasture land to crop land in buffer zones and encouraging family farms can help preserve biodiversity, prevent soil erosion, and sequester carbon.
7. **Genetic improvement:** With the OMIC technologies including Marker assisted selection and genome edited technologies and further progress/ innovations on these technologies, it is expected that efficient resource using future ready designer animal that will demand less competitive input resources while giving optimum output in terms of products will be evolved through time matching animal breeding technologies that will reduce the environmental footprint per unit of product. Such possibilities have already been demonstrated through melanocortin-4 receptor (*MC4R*) and callipyge (CLPG) gene selection in sheep pedigree farms for higher slaughter yield; identifying the polymorphism of estrogen receptor (ESR) gene with effect on litter traits in pigs etc. Future breeding will also have to encompass addressing the animal health issue identifying resistant lines and introgressing the identified gene for overall disease resistance. Breeding for miniature animal for slaughter at an early age to save resource need and provide quality meat is yet another option.

8. **System-based integrated approaches:** Integrating livestock production with other agricultural activities like crop farming or agroforestry and aquaculture (eg.silvi-pasture; urban forests) can create synergies and improve overall resource efficiency while reducing environmental impacts.

9. **Waste reduction, circular- economy and automation:** W2W (Waste to Wealth) has emerged as a viable model for circular economy both for additional income and environmental safeguard. In animal houses, irrespective of the type of animal, lot of wastes is generated right from residual dung (after collection) to urine to wasted feed. Similar is the scale of waste generation in slaughter establishment right from valorisation of slaughter house by-products to milk, meat and egg processing waste. Every large and medium size farms ought to create facilities to convert these wastes into high value wealth generating means in a systematic way so as to create a zero waste zone around the animal farms. Some of the wealth products could be biogas, production of bio-stimulant/ bio pesticides including varmi-wash, production of bio-bricks from ruminal contents and their use to generate steam energy as has been done at Allanasons buffalo meat processing plant, Zaheerabad, Telangana; Collection of poultry retail meat shop waste from across Coimbatore Muncipality, TN and converting into rendered meal and pet food etc. Adoption of automatic feeding/ watering/ washing systems shall minimize loss and optimize return.

10. **Disruption technologies:** Adoption of hybrid processing and disruption technologies, Co-Generation (heat + power), Green/clean hydrogen, LED lights and Sensor switch-off and encouraging minimal processing to ensure sustainability. Use of novel Artificial Intelligence tools and techniques, methods and methodologies developed appropriately for animal farm operations shall be an added technological advantage towards achieving green farming.

11. **Education, awareness and outreach:** Each animal science institute, veterinary universities and colleges may develop suitable green animal farming models for promoting awareness and adoption of the model by the stakeholders along the demand - supply chain through ON and OFF line means of training.

12. **Certification and standards:** Regulators, DAHD, Govt. India, FSSAI, Govt. India or APEDA, State Animal Husbandry Departments and others to provide organic/natural and grass-fed certifications, low-carbon milk, meat and egg labeling guidelines will help to promote sustainable practices.

    Similar to Sustainable Rice Platform (SRP), a multi-stakeholder alliance to provide low-carbon certification based on self-declaration and audits, a new platform may be created in India to safeguard and capitalize livestock producers, processors and exporters.

13. **Ecosystem services:** Efforts must be consolidated to document and validate energy-efficient, water-saving, sustainable and circular practices contributing towards ecosystem services. This documentation will prove instrumental in formulating a regulatory framework and policy options.

7. EXECUTION PATHWAYS

Lower efficiency in majority of Indian breeds, poor quality feed with lower digestibility resulting in under productivity, regular disease outbreaks resulting in poor performance, absence of infrastructure for live animal marketing and transportation, lack of culling policies for unproductive animals, non-availability of hygienic slaughterhouses, waste utilization and effluent treatment plants, food losses and waste along the value chain, poultry litter waste etc. will all contribute towards increased environmental impact of livestock sector unless counter measures are not taken. Cross-sectoral, multi-disciplinary approach from different state and central departments, regulatory bodies, policy makers, exporters, integrators, processors, e-commerce retailers, farmers etc. must be evolved to ensure overall sustainability of livestock sector. In this direction, it is proposed to execute various activities along the supply/value chain from the concerned stakeholders to realise the greening of the livestock and poultry sector (Table 2).

Table 2. Suggested pathways - greening livestock and poultry sector in India

DAHD, Govt. India	**State Animal Husbandry Dept's**
• Disease monitoring, surveillance & vaccination • Quality feed & boosting productivity • Disease free zones • Certifications	• Live animal market infrastructure • Good animal husbandry practices • Disease control & diagnostics • Regulation of slaughter policies and culling
MoFPI, Govt. India	**APEDA**
• Hygienic slaughterhouses • Cold-chain facility • Exclusive SEZ for meat and poultry	• Value addition • Certifications • Hand-holding of producers • Global competitive edge
FSSAI	**Producers, Exporters & Poultry Integrators**
• Food safety • Labelling • Regulation and enforcement	• Sustainable practices • Decarbonisation • Processing and value addition • Valorisation of waste
MoEFCC, Govt. India	**E-commerce platforms**
• Ecosystem services • Green credit incentives & climate finance • Effluent treatment & waste management	• Disruptive technologies • Food loss & zero-waste • Consumer awareness

(DAHD, Department of Animal Husbandry & Dairying, Min. Fisheries, Animal Husbandry & Dairying, Govt. India; MoFPI, Min. Food Processing Industries, Govt. India; APEDA, Agricultural and Processed Food Products Export Development Authority; FSSAI, Food Safety & Standards Authority of India, Min. Health & Family Welfare, Govt. India; MoEFCC, Min. Environment, Forest & Climate Change, Govt. India.)

If the concerned departments take appropriate collaborative initiatives involving also the farmers, panchayats and other civil societies, achieving green livestock and poultry farming in India will be a reality and for the interest of both the environment and animal source food consumers.

WAY FORWARD

1. Constitution of sub-sectoral (Green strategies, from sl 1 to 13 above) teams to develop and work upon the areas, individually and collectively, with financial resource support both from the center and state at 75:25 ratio.
2. Policy decision and facilitation of support for conversion of solar in the livestock farms into electrical energy for zero dependence on fossil fuel – Agrivoltaic/ vetyvoltaic.
3. Funding operational research on *Harit dhara* and Ration Balancing for immediate mitigation of methane emission under ICAR Network mode with ICAR-NIANP in the lead.
4. Develop Waste to Wealth models (Circular economy) initially at major institutional farms like in NDRI, IVRI, CIRB, CSWRI, DPR, Hyderabad etc. employing appropriate disruptive technologies. Also develop green animal farming package of practices as ready reckoner for animal owners.
5. Explore premium prices for animal products produced under green technology which could be used as incentives to the followers of green technology.
6. Develop mechanism to involve panchayats, women SHGs and other stakeholders in successful implementation of green technology initiatives for achieving Net zero-carbon emission target of the country by 2070.

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