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Micro Livestock: A Key Component of Gender Inclusive Sustainable Animal Farming and Net Zero Methane Emission in Developing Countries

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Abstract
This study examines the potential of micro livestock farming as a gender-inclusive and sustainable strategy to achieve net-zero methane emissions in developing countries. By replacing ruminant farming with low-methane-emitting micro livestock, the environmental impact of animal production can be mitigated. The study underscores the significance of context-specific climate mitigation strategies, taking into account socio-demographic and biophysical factors. Promoting micro livestock farming can enhance climate-resilient smallholder agriculture, particularly in developing countries where small-scale mixed farming systems are prevalent. This approach presents a cost-effective strategy for reducing global methane production, thereby contributing to climate change mitigation and sustainable development in under developed countries.

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1. Introduction

Methane, a greenhouse gas, contributes to global warming and ozone depletion at a 1% annual rate, primarily from microbial fermentation in rumen feedstuffs (Kerven, 2024; Scoones, 2023; Graham *et al*. 2022) [61, 92, 49]. Over the past decades, food systems have significantly improved global food security and poverty reduction, but they also contribute significantly to greenhouse gas emissions, including methane (IPPC, 2016). The global demand for sustainable land use to optimize animal production while reducing greenhouse gas emissions has become increasingly significant (Kyriazakis *et al*. 2024; FAO. 2021; Mackenzie and Kyriazakis, 2021) [65, 70]. Cattle and ruminants produce significant amounts of methane, a potent greenhouse gas, contributing to 6% of total CH4 emissions from anthropogenic-related sources (Difford *et al*., 2018) [30]. Methane production in livestock depends on factors such as size, number of animals grown, and digestive system Monteny *et al*. 2001 [75] Larger animals produce more methane, and the amount emitted increases with the number of animals. Cattle have a polygastric digestive system designed for microbial fermentation, producing methane as a by-product. Poultry and pigs have a monogastric digestive system with less microbial fermentation, producing less enteric methane (Miller, 2010) [73].

Mitigating methane emissions from ruminant livestock is crucial due to their substantial contribution to global greenhouse gas emissions (Graham *et al*. 2022) [49]. The International Energy Agency (IEA) has emphasized the considerable impact of methane on climate change, with atmospheric levels now 2.5 times higher than pre-industrial levels (IEA, 2021; Nature, 2021) [78]. Methane emissions totaled 570 million tons annually, with 40% originating from natural sources and 60% from human activities including agriculture (Jackson *et al*. 2020). Cattle and sheep are the primary contributors to greenhouse gas emissions, accounting for 48% of emissions, whereas small ruminants, such as goats and buffaloes, emit less enteric methane (Søren *et al*., 2015). The livestock industry, particularly beef and dairy production, generates substantial emissions, with approximately 6.3 billion metric tons of CO2-equivalent emitted annually, equivalent to 14-18% of human-caused greenhouse gas emissions (Cusack *et al*., 2021; Gerber *et al*., 2013; Herrero *et al*., 2016; Friedlingstein *et al*., 2019) [28, 47, 44]. Within the agricultural sector, 73% of the methane emission originates from farm animals (USEPA, 2020, with beef (35%) and dairy (30%) cattle, and 15% from small ruminants and buffalos (Tseten *et al*. 2022; Opio *et al*. 2013) [1, 82].

Micro livestock includes naturally small species such as small ruminants, poultry, and rabbits, which are roughly half the size of their more common counterparts. Micro livestock, also known as mini-livestock offers a potential avenue for reducing methane emissions from animal husbandry, thus lessening the global environmental impact (van Huis and Oonincx, 2017) [104]. Poultry and rabbits, as micro livestock, emit little to no methane. The difference in CH4 emission is thought to be primarily due to variations in the microbiota of the rumen and the hindgut of non-ruminant herbivores (Difford *et al*., 2018) [30]. While it is believed that small herbivores produce minimal methane, it remains unclear whether this is due to physiological differences or simply a matter of scale (Franz *et al*. 2011) [41]. Studies have shown that guinea pigs produce more methane relative to their body mass (BM) compared to rabbits, indicating an increase in methane output with BM. Regarding rabbit production's contribution to global warming, estimates of greenhouse gas emissions range from 3.13 to 3.25 kg of CO2 eq. per growing rabbit over a 35-d period (Savietto, 2024) [91]. Both cattle and small ruminants emit CH4, with the former producing significantly more (Franz *et al*., 2010, 2011; Cabezas Garcia, 2017) [41-42, 15]. Various rodents and rodent-like animals are utilized as micro livestock, including Guinea pigs, capybaras, giant rats, cane rats, agouti, and rabbits (Branckaert, 1995) [14]. Lesser-known edible insects, such as water beetles, palm grubs, grasshoppers, and agave worms, provide essential nutrients in many parts of the world (Abbasi *et al*. 2015) [1]. Insect farming can be considered mini-livestock due to its limited land requirements and reduced greenhouse gas emissions. Certain birds, like pigeons, quails, and guinea fowl, are also important food sources with low emissions. Encouraging micro livestock in small-scale farming is part of the strategy to reduce methane emissions in developing countries, particularly in sub-Saharan Africa where agricultural land is becoming scarce due to population growth (Cicogna, 2000) [24].

Climate change responses and agricultural practices in developing countries are influenced by gender (Theis and Martinez, 2018; Habtezion, 2016; Perez *et al*. 2015) [50, 98, 84]. Climate change and animal agriculture are interconnected, with climate change affecting animal farming and contributing to global warming (Theis and Martinez, 2018; Habtezion, 2016; Perez *et al*. 2015) [50, 98, 84]. Micro livestock farming, a subset of animal agriculture predominantly managed by women, has been a means to improve food security in rural communities and could potentially be extended to climate mitigation efforts (Assan 2021; Barwa, 2009) [7]. This approach can serve as a link between women's empowerment and resilience, leading to enhanced food security and environmental stewardship (Leder, 2015) [67]. The climate crisis is disproportionately affecting women and girls, exacerbating existing gender inequalities and posing unique threats to their livelihoods (Huyer *et al*. 2020) [53]. Engaging women in micro livestock farming can improve their community status and address the growing household food demand due to the increasing human population while addressing climate change issues. A holistic approach considering climate, gender roles, and animal agriculture is crucial for optimizing animal production and ensuring food security. Addressing gender equality concerns can promote inclusive, equitable, and community-driven prosperity in the context of climate change (Ingweye and Kalio, 2020) [55].

Gender equality concerns influence the development and maintenance of environmentally responsible small-scale animal agriculture systems, which could be an important avenue for addressing methane production in developing countries. Building on the contributions of women and taking steps to alleviate constraints can strengthen and accelerate sustainable agriculture efforts by national governments and the international community. Women make essential contributions to the agricultural and rural economies in all developing countries, but their roles vary considerably between and within regions and are changing rapidly in many parts of the world. Climate mitigation efforts in agriculture that includes methane reduction to be effective should ride upon the numerical advantage of women who comprise 43% of the agricultural labour force in developing countries, ranging from 20% in Latin America to 50% in Eastern Asia and sub-Saharan Africa. If they had the same access to productive resources as men, they could increase yields on their farms by 20–30% (Mishra *et al*. 2022). This can be extended to sustainable livestock farming to address environmental challenges in these regions.

2. Ruminant overshadows the non-ruminants'(i.e. micro livestock) contribution of GHG emissions that causes global warming

Climate change is significantly influenced by greenhouse gases (GHGs), which originate from various sources such as fossil fuel burning, agricultural activities, and industrial operations (Figure 1). Figure 1. shows the greatest contributor to worldwide GHG emissions by gas is CO2 (from fossil fuels and industrial processes), which accounts for 65% of emissions. CH_4 comes in second at 16%, followed by CO_2 (from forestry and other land use) at 11% and NO2 at 6%. Livestock-related greenhouse gas (GHG) emissions, estimated at up to 3.75 Gt CO2-eq annually, are considered a major factor in climate change (FAOSTAT, 2021). Globally, these emissions constitute 14.5% of all human-caused emissions (Gerber *et al*. 2013) [47], with beef and dairy cattle responsible for 41% and 21%, respectively. Although livestock production contributes to climate change, it is also highly vulnerable to its effects. In 2015, food systems worldwide generated 18 Gt CO2 equivalent, representing 34% of total GHG emissions (Crippa *et al*. 2021). Livestock production accounts for over half of agricultural GHG emissions (Steinfeld *et al*. 2006; IPPC, 2007; Herrero *et al*. 2013a), resulting in 7.1 billion t CO2-eq. yearly. The agricultural sector produces approximately 10–12 percent of global anthropogenic GHG emissions (Smith *et al*., 2014), while the entire food production system may contribute up to 29 percent (including indirect emissions from land use changes) (Vermeulen, 2012).

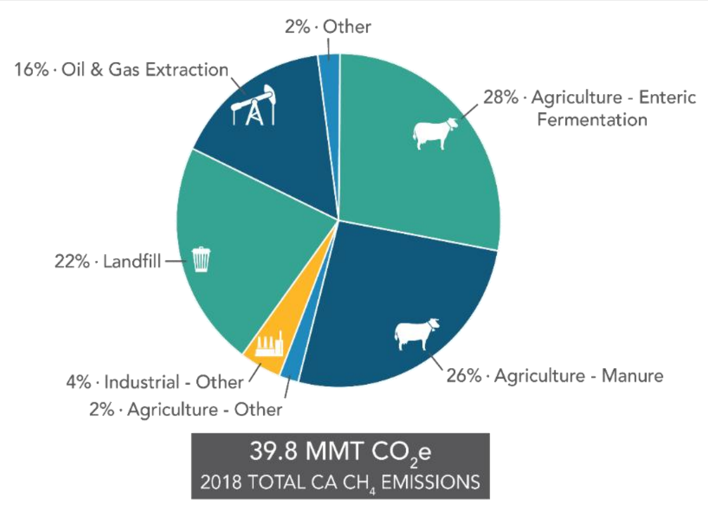

Fig 1: Sector specific GHG emission Contribution (California Air Resource board, 2018).

Carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) are the primary GHGs contributing to global warming (Figure 2). Farm animals are responsible for 5% of CO_2 emissions, 44% of CH_4 emissions, and 53% of N_2O emissions worldwide (Gerber *et al*. 2013) [47], The high levels of every one of these gases are most likely due to the livestock system's diminished productivity and effectiveness due to a large loss of calories and nutrition (Gerber *et al*., 2013) [47]. With climate change becoming an increasingly pressing issue, there is a great deal of pressure on global agriculture, which is expected to be the main source of 13.5% of the world's anthropogenic GHG emissions (IPCC, 2007). According to Sejian *et al*. (2016), the demand for animal products is expected to nearly quadruple by 2050 as a result of urbanization, population growth, and rising wages in some areas. At the same time, there is a greater likelihood of unfavorable changes that are mostly brought on by GHG emissions from livestock-related activities that cause the atmosphere to warm. The development of pasture and livestock is a serious issue given the growing human population and the rising demand for animal products (World Bank, 2010). The effects of this phenomenon include more frequent extreme weather events, elevated sea levels, disruptions to ecosystems, and threats to human health. Human activities increase GHG levels, leading to global temperature rise and alterations in weather patterns and ocean levels (Filonchyk, *et al*. 2024) [40]. Efforts to address climate change involve reducing GHG emissions and developing sustainable alternatives for the future. The Kyoto Protocol, adopted in 1997, aimed to reduce greenhouse gas emissions by committing developed countries to do so (Lau *et al*., 2012) [66]. However, due to its limited scope and non-participation by developing nations, it proved ineffective.

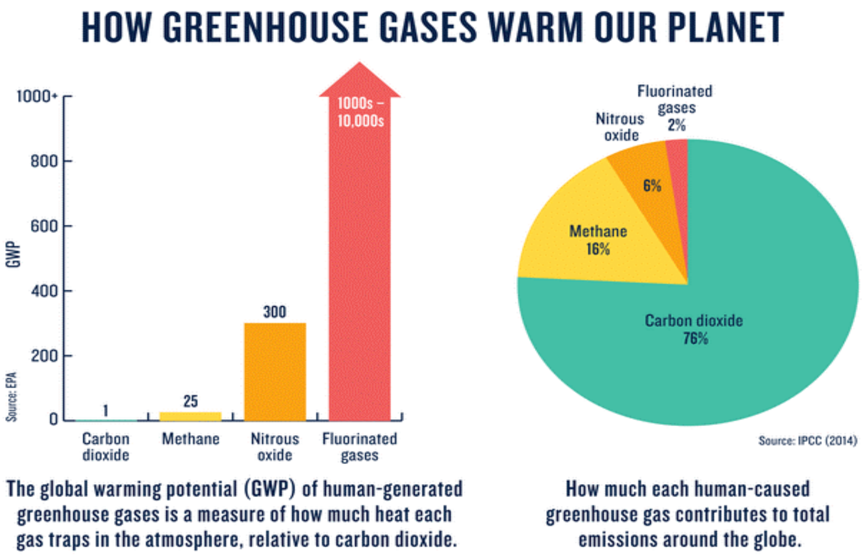

Fig 2: Greenhouse Gas Emission and their proportions (IPCC, 2014)

Ruminant production is gaining public attention due to its significant role in methane production. Methanogenic archaea, a group of microbes in anaerobic environments, primarily use H_2 and CO_2 as substrates (Morgavi *et al*. 2012) [76]. Other microbes also influence methane production through hydrogen metabolism or microbiota numbers. Methane is produced as a byproduct of the fermentation and is expelled from the rumen (Leuning *et al*. 1999).

"Monogastric" animals produce small amounts of methane as the result of incidental fermentation that occurs during the digestion process. Non-ruminant herbivores such as rabbits produce methane at a rate that is intermediate between monogastric and ruminant animals. Although these animals do not possess a rumen, significant fermentation takes place in the large intestine, allowing substantial digestion and utilization of plant material (Murray *et al*. 1978).

Both ruminants and non-ruminant herbivores emit CH4, but the former emits much more CH4 than the latter (Franz *et al*., 2010, 2011; Cabezas Garcia, 2017) [41, 42, 15]. It has been speculated that such difference in CH4 emission is probably attributable primarily to the differences in the microbiota of the rumen and the hindgut of non-ruminant herbivores (Yang *et al*., 2016) [108]. Extensive research has been conducted to reduce CH4 emissions in beef, lamb, and dairy production for sustainability. Future studies on intensive rabbit farming should prioritize CH4 reduction and other aspects that enhance production efficiency, as these are interconnected. Ruminant livestock production systems generate about 80 million tons of CH4 annually, accounting for roughly 28% of global anthropogenic CH4 emissions (Beauchemin, *et al*. 2008) [11]. CH4 is primarily eructated or exhaled through the mouth and nostrils as a result of rumen anaerobic fermentation, where ruminal microbes break down feed into absorbable nutrients for the host animal. Methane is generated as a fermentation byproduct and expelled from the rumen (Figure 3). Methanogens predominantly produce CH4 during the anaerobic degradation of plant biomass in the rumen (Leuning *et al*. 1999)

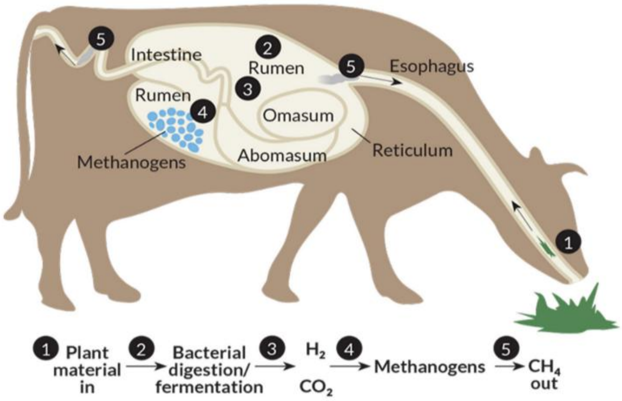

Fig 2: Methanogenesis in ruminants (Hook *et al*. 2010) [52].

Steinfeld *et al*.'s (2006) report revealed that meat production contributes between 4.6 and 7.1 billion tonnes of greenhouse gases annually, accounting for 15% and 24% of total greenhouse gas production. This is largely due to deforestation and longer animal life requirements in meat production processes. Ruminants farming operations are susceptible to the effects of climate change while simultaneously generating substantial amounts of CH4 and N2O, both of which contribute to the risk of global warming. It is of paramount importance to comprehend CH4 control over ruminant gases and manure (Sejian *et al*. 2015) [97]. To address enteric gases and manure handling effectively, it is necessary to understand the mechanisms of CH4 production in farm animals and the variables that influence such gases. Furthermore, it is crucial to understand the available estimation methodologies and forecasting models for GHG monitoring (Bellarby *et al*. 2013).

Knowledge of food production systems (livestock and cropping) that influence land use impact can help develop effective mitigation strategies for reducing CH4 in farm animals (Malik 2015) [97]. Figure 3 shows global greenhouse gas emissions by livestock species. Dairy cattle are only second to beef cattle as the largest livestock contributors to methane emissions. Beef and dairy produce the largest emissions, primarily due to methane from cattle digestion. Poultry, sheep, and goats emit less greenhouse gases (Figure 3), highlighting the need to promote these species to reduce methane production and combat climate change. Rabbits and other lesser-known animal species are absent due to other negligible emission. It is plausible to assume that promoting micro livestock, such as chickens, small ruminants, and other poultry, can significantly reduce greenhouse gas emissions because they produce minimal greenhouse emissions.

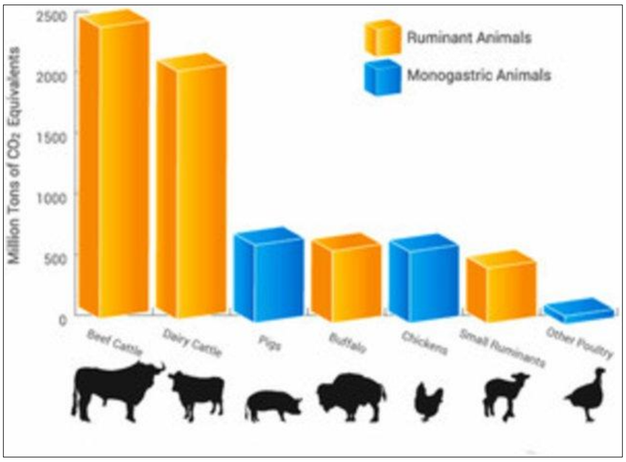

Fig 3: Global greenhouse gas emissions by livestock species (Gerber *et al*. 2013) [47].

Ruminant animals are the primary source of emissions due to their production of the highest quantity of methane per unit of feed consumed (Tapio *et al*. 2017). The distinguishing feature of ruminant animals is their "fore-stomach" or rumen, a large, muscular organ. The rumen is characterized as an extensive fermentation chamber where approximately 200 species and strains of microorganisms are present. These microbes ferment the plant material consumed by the animal through a process known as enteric fermentation. The products of this fermentation provide the animal with the necessary nutrients for survival, enabling ruminant animals to subsist on coarse plant material.

Herbivorous monogastric animals such as rabbits produce little methane, but due to the large number of such animals, their total production can be huge. It was noted that all mammals usually produce some amounts of CH4, and that the CH4 emission intensity of some non-ruminants remains comparable low to that of ruminants (Clauss *et al*. 2020). However, it is not fully understood which factors and their parameters determine the level of CH4 production in different animal species. Critics point at animal agriculture and ruminant production in particular, for being a major contributor to GHG emissions and other forms of global environmental change. This suggests that the non-ruminants contribute greenhouse gas emissions unexplored and requires more investigation. The majority of livestock's C footprint is made up of CH_4 from grazing ruminants, as many of them are raised in less-than-ideal grazing conditions, which typically result in low herbage intake and poor animal performance (Barneze *et al*., 2022).

The Rationale and State of Global Micro Livestock Production: Trends and Insights on GHG emissions.

Over sixty animal species provide food, shelter, and energy, but only domestic cattle, sheep, goat, pig, and poultry are key in modern livestock production (Ingweye and Kalio, 2020) [55]. These conventional livestock, consisting of sixteen mammalian species and fourteen avian species (guinea fowl, turkey, duck, pigeon) contribute 30% of livestock products for agricultural production and human food needs satisfaction (Assan 2022) [8]. Their popularity attracts most money for research and development. The world ruminant population increased by 66.1% from 1960 to 2017, whereas the population of non-ruminants has even more rapidly increased by 435% over the same period (FAOSTAT, 2017). Both ruminant and non-ruminant populations are projected to further increase in the coming years, which will further raise GHG emissions from animal agriculture.

Sub-Saharan Africa is home to 20–25 percent of the world's ruminants, and there is a tremendous amount of livestock there, especially ruminants (Erdaw, 2023). Studies show that 150 million rural poor people in Sub-Saharan Africa, or nearly 70% of the population, depend on cattle for at least some of their income, with pastoralists making up the majority of this group (AU-IBAR, 2016). Africa is home to one-third of the world's cattle, and its agricultural industry accounts for nearly 40% of the continent's total GDP (Panel, 2020) [83]. Africa raises 1.5 billion chickens, with local chicken groups accounting for 80% of them contend that native chickens make a major contribution to the food security and economic viability of rural households (Faustin, *et al*. 2010) [39]. SAPA, (2012) and Skapetas and Bampidis (2016) [96] noted that one of the reasons why chicken farming would be considered as a quick solution to try to reduce rural poverty is because it is a sort of farming that most rural people are familiar with.

Despite contributing to global warming, ruminant production has been vital for improving societal well-being (Pulina *et al*. 2016) [86]. Local production of ruminant-derived products like milk and meat lags behind demand. This gap could be addressed by micro livestock, potentially reducing the methane footprint. Promoting micro livestock as a partial replacement for animal product supply to the growing and urbanizing population could strategically address the animal product demand bottleneck (Assan, 2013) [4], while simultaneously reducing methane emissions. Between 20-25% of the world's ruminants are found in Sub-Saharan Africa (SSA), yet their productivity fluctuates due to uneven progress in addressing factors like disease, inadequate feed, and breed quality (Millar & Photakoun, (2008) [72]. The inefficient ruminant production system in SSA raises concerns about its potential environmental impact. As the population in SSA grows, the demand for ruminant products is expected to surge. Research projects a population of 3·07 billion in SSA by 2100, which, although lower than the UNPD estimate of 3·78 billion, remains problematic (Ezeh *et al*. 2020) [33]. SSA is undergoing positive demographic growth, with over half of global population increase until 2050 anticipated in this region. This demographic shift and urbanization will necessitate intensified ruminant production, potentially increasing the carbon footprint.

Ruminants have lower feed efficiency and higher methane emissions compared to monogastric livestock and a 12% switch from monogastric to ruminant livestock production can reduce emissions (Cheng *et al*. 2022) [22]. Ruminant contributes the most to GHG emissions, with small ruminants accounting for 12.25% of total emissions from enteric and manure CH4 (Zervas and Tsiplakou, 2012) [107]. CH4 emissions are primarily sourced from methane from enteric fermentation and manure management, with ruminants (dairy and beef cattle) being the largest emitters (Dunkley and Dunkley, 2013) [31]. Dairy cattle emit the highest levels of GHG per animal followed by beef cattle and pigs. The global methane release to the atmosphere from cattle totals 54 Tg annually (Crutzen *et al*. 1986) [26]. Of this about 40% is produced in the developing world.

Within the agricultural sector, 73% of the methane emission originates from farm animals (USEPA, 2013), with beef (35%) and dairy (30%) cattle, and just 15% from small ruminants and buffalos (Opio *et al*. 2013) [82]. The question arises: why not promote micro livestock as a partial substitute for ruminants to meet animal protein demand, thereby indirectly reducing methane emissions? By bolstering local production to satisfy animal protein needs, replacing some ruminant contributions with micro livestock protein sources could help decrease the methane footprint. SSA's urbanization and population growth are driving a nutritional transition, with rising demand for livestock-based and processed foods (van Berkum *et al*., 2017) [103]. Global meat demand is projected to double in the next 27 years (Ritchie *et al*., 2017) [88], which has implications for environmental carbon emissions. If SSA follows global trends of shifting from plant-based to animal-based foods, with the population expected to consume two-thirds more animal proteins by 2050 (Salvage, 2011) [89], environmental consequences due to increased methane emissions will follow. If greenhouse gas emissions intensities of ruminant animal commodities are not reduced, the production required to meet demand will lead to proportionate increases in GHG emissions.

Rabbit farming significantly reduces greenhouse gas emissions, with lower levels of methane and carbon dioxide compared to conventional livestock farming, thus contributing to climate change mitigation efforts (Bobbitt, 2003) [13]. Rabbit farming is emerging as an ethical and sustainable protein source, offering numerous benefits for consumers and the environment (Siddiqui *et al*. 2024) [94], making it a model worth addressing as the world faces sustainability challenges associated with methane production in ruminants. Greenhouse gas emission and waste production are relatively low, making rabbit farming a sustainable farming model (Olaleru *et al*. 2024) [81]. Rabbit farming encompasses on one health approach that can balance the act between environmental impact, farmers' livelihood and animal welfare.

Rabbits are known for their low gas emission in addition to being a very nutritious and healthful meat source, rabbits are growing in popularity (Petracci *et al*., 2009) and they are likely meat the animal protein demand in developing countries if they are promoted (Wonganaa *et al*. 2024). In 2017, the world output of rabbit meat was estimated to reach around 1,482,000 tons (FAOSTAT, 2019). The FAO estimates that 770 million rabbits are raised globally annually, with an average increase of 2.6% over the past decade. (FAO-STAT, 2016). Asia dominates rabbit production with 83%, followed by Europe at 14%. Africa and the Americas follow at 2% and 1% respectively. The global value of rabbit meat is projected at 1,482,441 TEC, equivalent to 971,951 million put to slaughterhouse (Trocino *et al*. 2019) [100]. Production volume increased by 85% from 1998 to 2017. Many studies have already been conducted to examine rabbit management, dietary regimen, and hereditary factors; nevertheless, the effects of intensive rabbit farming on carbon foot print are not fully understood. Few studies have examined the impact of greenhouse gas emissions from rabbit farms, despite their negligible methane emissions due to their digestive systems (Cesari *et al*. 2018) [19]. Goats produce 3.8-5.5 kg of CH4 per kg of meat, similar to sheep and cows, but emit more CO2 than cows, indicating their superior performance in ruminant production (Curtis, 2022) [27]. Goats contribute 4% to the global emissions from animal farming, which accounts for 7-18% of anthropogenic greenhouse gas emissions (Chang *et al*. 2019). Goats and sheep are essential for enhancing livelihoods and food security in Africa, with around a billion goats and 420 million heads estimated worldwide (Lebbie, 2004). Asia and Africa are home to the majority of these animals, with 35% found in Africa. Goats are the only source of a healthy diet for most rural Africans, and their production in 2017 was 1.3 million tons, compared to 1.1 million tons in 2008(FAOSTAT, 2017). The support of small ruminants implies that efficient methods of animal production, focused on small-scale farmers, may greatly enhance food security and animal production output, which in turn can reduce methane emissions in climate action. Goats emit less methane per unit body weight than cattle and sheep (Figure 4), but their GHG emissions vary significantly based on diet, management system, and environmental conditions (Kerven, 2024) [61].

The 1.2 billion sheep population contributes 6.4% of total enteric CH4 from livestock, making them the third most-emitting ruminant species after cattle and buffaloes (FAOSTAT, 2020; Patra, 2014). Methane emissions from sheep increased with live weight, feeding level, and digestibility of dry matter, but decreased for rations with wider ratios of crude fiber intake and N-free extracts (Belanchea *et al*. 2023). The percentage loss of methane was 7.22, 7.23, and 7.22%, respectively. Crude fibre content and energy density showed no clear effect on methane emissions, while feeding levels and digestibility of dry matter were significant factors.

Extensive systems, where small ruminants forage naturally, may produce low GHG emissions due to minimal reliance on high-energy feed. Intensive systems, which use more cultivated energy feed, produce lower emissions but incur carbon costs. More research is needed to accurately measure small ruminants' GHG impacts, considering factors like feed quality and management practices. Figure 4 shows livestock species GHG emission within animal production, the largest emissions are from beef followed by dairy, and largely dominated by the methane produced in during cattle digestion.

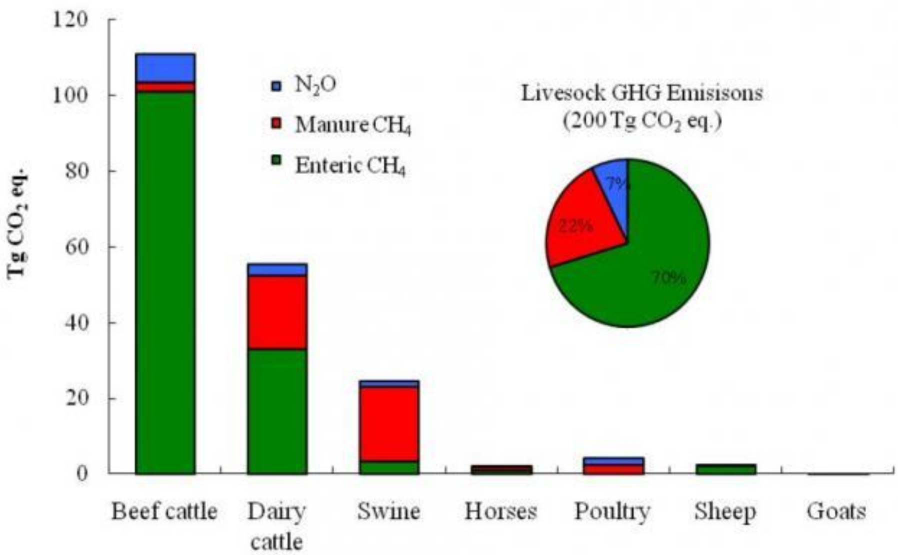

Fig 4: Greenhouse gas emissions from livestock in 2008 (USDA, 2011)

Future meat consumption is predicted to rise, with the poultry sector seeing the largest growth. This has significant consequences for reducing greenhouse gas emissions, making it a topic worth addressing as the world deals with sustainability issues related to ruminant methane generation. Mottet and Tempio (2017) [77] state that chickens are a globally important and plentiful animal that thrives in a variety of climates and locales. Although they create very little methane, their emissions have been linked to the management of waste. Their population growth is largely due to the demand for meat and eggs, making them a cornerstone of the global food industry. As the human population increases, so does the reliance on chickens for protein and other nutritional needs.

The FAO's latest estimates suggest that the global chicken population reached approximately 33 billion in the three years prior to 2020, increasing from 32.6 billion in 2018 to 33.1 billion in 2020. (FAO 2025). Chickens, the world's most abundant domestic livestock, have experienced a tripled global population since 1990, reaching over 34.4 billion in 2023. Roughly 46% of chickens worldwide are in Asia. Egypt and Nigeria had the largest chicken livestock in Africa in 2022, with Egypt having 300 million heads and Nigeria having 249 million heads, and Africa had 2.4 billion live chickens, the major species for livestock farming (Galal, 2024) [45]. Enteric fermentation is the most important source of methane in beef and dairy production, while most of the methane from poultry originates from manure (Dunkley and Dunkley, 2013) [31].

Over the next 30 years, there is expected to be a significant increase in the global demand for meals derived from animals, particularly in transition countries (Friel *et al*., 2009). According to Giuseppe *et al*. (2022), the demand for livestock products, which are primarily found in developing and economically transitioning nations, is expected to rise by 60–70% by the year 2050. Additionally, the increasing global population is driving up demand for high-protein rabbit meat products. As a result, technologies for producing rabbits that need a lot of energy have been developed (Giuseppe, *et al*. 2020). Ruminants are the main producing animals of meat and milk, but they also produce more CH4 than monogastric animals per unit of BW0.75 or product (Franz *et al*., 2010) [42]. Indeed, up to 20% of the global anthropogenic CH4 is emitted by ruminants (Bhatta *et al*., 2007). Kumar and Roy (2021) [65] noted the most pressing climate change in modern times is the rise in global temperatures brought on by rising atmospheric levels of GHGs the likes of CO_2, CH_4, NO_3, nitrous oxide (N_2O), and chlorofluorocarbons (CFCs). There is much worry about how the climate will change in the future and how that shift will directly or indirectly affect agriculture sub-sectors such as livestock production due to the concentration of these GHGs.

To prevent global warming, efforts are being made to cut emissions in each of these sectors. This paper explores the potential of micro livestock (mini livestock), particularly small ruminants, poultry and rabbits, as a sustainable source of minimizing methane production. It suggests that micro livestock may have contributed less to global warming although it's a long term strategy through transformation of animal food systems. Micro livestock are also prized delicacies in advanced countries, making them not just a subsistence food for impoverished people. They have high food-to-animal weight conversion efficiency, quick growth rate, enormous variety, and worldwide distribution, making them a more sustainable source of animal protein than conventional large ruminants hence minimizing methane production.

4. Promoting micro-livestock in sustainable farming and methane reduction as a key component of net zero GHGs climate action.

Clauss *et al*. (2020) emphasize the importance of promoting low-emission animal production systems, such as rabbits, to reduce methane emissions. They argue that these systems complement zero-emission technologies and can be a complementary approach to conventional decarbonization strategies. The work suggests that reducing ruminant populations for micro livestock utilization can significantly decrease methane emissions. Micro livestock farming is a potential avenue for a gender-inclusive and climate-smart initiative that can address methane production in developing countries. The little known animal species are low enteric methane emitters making them valuable for climate change mitigation and adaptation. Additionally, micro livestock farming support women empowerment due to minimal investment and small herd sizes, hence their promotion can empower women to be climate change mitigation agents.

Micro livestock, a subset of low-emission animal species, are essential for human nutrition and may play a significant role in food security, environmental conservation, and economic diversity in the future (Hardouin *et al*. 2003) [51]. They are classified into broad ecological range animals like small ruminants, poultry, rabbits, guinea pigs, and guinea fowls, and animals suited to specific ecological niches like grass-cutters, snails, and camels. Farm animals, such as pigs, cows, goats, and sheep, are often emphasized in development projects. Micro livestock also serve as protein sources, with over a thousand reptiles, rodents, insects, and birds. Some micro livestock are domesticated, while others live on farms or forests. Micro breeds, such as cattle, sheep, goats, and pigs, are common in developing countries and deserve greater recognition for their contribution to human nutrition and environmental conservation.

Promoting low methane animal emitters can help reduce agricultural emissions to meet the 2°C target. Micro Livestock Farming can be a mitigation strategy towards gender equality and a move towards zero hunger and net zero methane. Micro livestock due to their low greenhouse gas emissions can be an avenue to meet the climate targets in developing countries that has a gender component. A combined gender analysis and animal product demand-side changes in food and animal agriculture can effectively drive this agenda. Micro livestock farming's efficiency and impact on family livelihood, food security, and environment compared with large livestock is undisputable hence its role in methane reduction. Micro-livestock are considered are dominant animal species for poor majority in developing countries (Behera *et al*. 2029). Apart from this traditional aspect, micro-livestock are gaining increasing interest as alternative food sources for the increasing world population and land constraint in rural and urban areas.

The growing demand for animal protein and the eco-degrading nature of animal agriculture, and the proposition of an eco-friendly alternative, mini-livestock is critical to reduce methane emission (Ingweye and Kalio, 2020) [55]. Traditional livestock, like cattle, have a significant ecological footprint, consuming more food, producing more waste, and requiring more land (Hardouin *et al*. 2003) [51]. Micro-livestock offers a greener alternative, reducing greenhouse gas emissions due to their smaller size. As global concern over greenhouse gases increases, the environmental advantage of micro-livestock becomes even more apparent. They can enhance total yields, provide diverse products in conservation areas and agroforests, and are environmentally friendly and compatible with trees. Micro livestock provides an opportunity to tackle climate change through a global assessment of emissions and mitigation opportunities.

Development and promotion does not favor the concept of reduced meat and dairy consumption for meeting stringent climate change targets, but it favors equal meat and dairy production with low methane foot print. Where micro livestock is providing the same or more protein to meet the increased demand due to population expansion with low emission (FAO, 1999). Micro livestock is part of the potential for land sparing to offset greenhouse gas emissions from animal agriculture. Optimization of a cheap and residential small-scale production of micro livestock with local by-products as an alternative protein-rich human food source in part of for land sparing to offset greenhouse gas emissions from animal agriculture (Lamb *et al*. 2016). There is nexus of land use and carbon footprints from life cycle assessments of animal food products and their substitutes (Nijdam *et al*. 2012). There is less environmental impact of the production of micro livestock as a protein source for humans—a life cycle assessment (Oonincx and De Boer, 2012) [104].

Micro livestock production and the global environment means will balance consume more with producing sustainably with less methane foot print. Near zero manure goals may be attainable in industrial mass rearing of microlivestck because manure has been a major source of methane production in ruminant production. The environmental destruction and emission contribution caused by the improper use of large animals like cattle is well-known (Hardouin *et al*. 2003) [51]. Micro livestock can also be highly productive in environments not suitable for other animals, such as steep hillsides, degraded areas, and urban environments (FAO, 1999). In some parts of the tropics, large introduced farm animals may not be suitable, while local species of micro livestock, like the capybara, can thrive (Ingweye and Kalio, 2020) [55]. Using locally adapted micro livestock can reduce the pressure on biodiversity hence less environmental foot print that can drastically alter the environment to accommodate conventional livestock production, reducing the need for significant environmental changes.

5. Nexus between Gender, Climate Change, and Animal Agriculture (Micro livestock Farming): Understanding Gender Roles, Responsibilities, and Opportunities in Methane Reduction

The relationship between animal agriculture and climate change is complex due to the gendered nature of the agricultural sector (Assan, 2014) [5]. Climate change affects men and women differently, and they have distinct roles in livestock production systems (Njuki and Sangina, 2013) [79]. Climate change impacts micro livestock production, which contributes less GHG to climate change than beef and dairy cattle. The gender dynamics influencing animal management, ownership, and benefit distribution are evident in small-scale livestock farming. Women often control micro livestock, while men typically have authority over larger animals (Akter, *et al*. 2017) [2]. The rights and responsibilities associated with livestock and their products should be examined within their cultural context, as these can vary based on the specific setting (Verhart, *et al*. 2016) [105]. In many developing regions, women are the primary caretakers of micro livestock, such as poultry, small ruminants, and rabbits, which are low greenhouse gas emitters (Misra *et al*. 2024) [74]. Therefore, women are likely to spearhead initiatives addressing climate change impacts in micro livestock as a potential mitigation strategy.

Climate-smart animal husbandry can reduce methane emissions by considering gender disparities in ownership, management styles, and preferences in agriculture (Singh *et al*. 2012) [95]. This can lead to superior offspring and potentially lower greenhouse gas emissions. Gender dynamics in micro livestock production can contribute to lower greenhouse gas emissions (Assan, 2015) [6]. Recognizing the rights of both genders in methane reduction is crucial for developing countries. Women's role in micro livestock production, particularly in developing nations, is significant (Assan, 2021) [7]. Their specialized knowledge and experience can significantly contribute to climate mitigation efforts in sustainable animal agriculture (Misra *et al*. 2024) [74]. Recognizing the role of gender in climate mitigation is crucial for achieving global net-zero emissions.

Gender inequality results in missed opportunities for increased overall small-scale agriculture productivity (Mahato, 2023) [71], including climate mitigation efforts. To ensure an effective, equitable, and sustainable response to climate change in micro livestock farming, women's active involvement in decision-making is necessary. Addressing the impact of climate change on micro livestock production and promoting low methane emissions at community and household levels requires gender equality and women's empowerment. Promoting gender equality in micro livestock farming enhances food security and animal output for impoverished households, reduces vulnerability, and initiates a process to overcome poverty while addressing environmental concerns (Assan, 2021) [7]. To ensure long-term environmental sustainability and reduced methane production in micro livestock farming, gender-sensitive approaches to climate change mitigation must be implemented. Gender inequalities both within and outside the household threaten micro livestock farming productivity. Gender mainstreaming in animal agriculture is a crucial method for increasing output, achieving gender equality, and protecting the environment (Assan, 2014) [5]. This approach recognizes that increasing micro livestock production is vital for addressing adaptation and resilience challenges in the face of growing climate change concerns (Alidu, *et al*. 2022) [3].

In developing countries, agroforestry systems support micro livestock farming, with increasing recognition of women's crucial role in implementing climate-smart technologies and ensuring food security (Gélinas *et al*. 2015). These systems provide high-quality feed for livestock and help reduce methane emissions from ruminants. Women excel in cultivating fodder trees, which can supply animal feed during dry periods (FAO, 2013). Promoting fodder production is essential to combat feed shortages and establish efficient climate-smart micro livestock systems. The focus on addressing gender inequalities in livestock farming has grown, with women now central to initiatives aimed at enhancing productivity through climate mitigation practices (Franzel and Wambugu, 2007) [43]. Women can improve micro livestock nutrition, decrease methane emissions from goats and sheep, and mitigate fodder scarcity caused by climate change. Supporting women in establishing specialized fodder browses within agroforestry is vital for addressing methane emissions.

Addressing stereotypes about micro livestock farming, such as viewing small ruminants, poultry, and rabbits as "women's animals," is essential for successful climate action, as it indirectly exacerbates vulnerability in small-scale farming systems (Phiri *et al*. 2016) [85]. The initiative aims to promote low methane emission animal production systems that reduce emissions while offering equal opportunities for both genders. The study explores environmentally friendly and gender-inclusive micro livestock farming practices that do not contribute to climate change effects. The strategic outputs focus on indirect methane reduction through the promotion of low emitters, gender equality promotion, and sustained animal productivity (Assan, 2021) [7]. Women's involvement in micro livestock husbandry is vital in tropical regions for mitigating climate change impacts and boosting output. To enhance gender equality and climate resilience in micro livestock farming, women must be equipped with necessary resources to act as adaptation and resilience agents in the changing environment (Nsengiyumva, *et al*. 2022) [80].

Gender inclusivity is social aspect of addressing climate change - all we need is a gender responsive climate action plan. A gender-focused reform climate action is required in developing countries in order to successfully address greenhouse gas emissions in livestock production systems. Methane production from livestock is impacted by a complex interplay between gender, animal production practices, and climate change. Based on this, it is evident that work has to be done to address gender disparities in climate change and to raise livestock in a way that will result in an efficient climate-smart livestock system for long-term reduction of methane. Doing so will help livestock production systems combat the scourge of climate change and boost animal output over the long run while reducing the release of GHGs into the atmosphere. The inability to promote climate smart livestock systems is due to the negative effects of climate change, gender inequality, and/or a lack of women's full participation in livestock programs, among other issues (Vijalakshmy *et al*. 2023) that contribute to food insecurity, a persistently low livestock output in developing countries and increased contribution GHG emission that drive global warming. Gender sensitive and participatory methodologies are effective to identify and prioritize climate smart livestock production practices and gender relations in livestock systems in order to address methane production.

The implementation of a micro livestock-targeted methane reduction program should be a community-led approach, focusing on coordination, reflective learning, and local community support. Measuring progress and adapting strategies is crucial, and the approach should be flexible to address both anticipated and unforeseen situations. Regular reflection is essential to evaluate the effectiveness of interventions and assess their impact. The increase in methane emissions from ruminant animals contributes to global climate change, necessitating a refocus on promoting low methane emitters in mitigation strategies without compromising the nutritional and economic benefits for resource-poor small-scale farmers in developing countries. Gender gap analysis and participatory gender audits can identify disparities in resource access and decision-making in micro livestock farming, which has implications for climate mitigation. Climate-smart micro livestock agriculture can serve as a foundation for promoting low-emitter animal species and can be implemented within the holistic approach of climate-smart agriculture through gender-inclusive training on optimal animal management practices.

6. Future of micro livestock and strategies for promoting environmental sustainability

The significance of micro livestock (encompassing small ruminants, poultry, and rabbits) and other less common animal species (like snails, rodents, and insects) is anticipated to increase due to population growth, limited forage cultivation space (Hardouin 1995), and the environmental impact of large ruminants, particularly their methane emissions (Kumari *et al*. 2020) [64]. This aligns with the growing preference for micro livestock, which contribute to sustainable farming by utilizing local feed resources, thereby reducing dependence on industrial feed production, a major source of greenhouse gas emissions (Chisoro *et al*. 2023) [23]. These smaller animals also support biodiversity conservation by using diverse food sources and maintaining ecosystem services, while offering economic opportunities for rural communities. Developing nations possess a wide array of indigenous micro livestock and poultry breeds (Assan, 2022) [8], which have long supported local food production and can be integrated into strategies addressing climate change issues related to livestock farming in rural areas.

Small-scale farmers, who dominate livestock production systems in developing countries and manage most ruminant and non-ruminant populations (Kapari *et al*. 2023) [60], should be involved in efforts to reduce methane production. Many of these farmers already face limitations in pastureland for large ruminants due to population pressure (Touch *et al*. 2024) [99]. Micro livestock are positioned to play a crucial role in meeting animal protein demand while remaining environmentally friendly (Ingweye and Kalio, 2020) [55]. Their potential extends to urban settings in developing countries, where land scarcity makes conventional livestock farming challenging. Urbanization has increased the need for animal protein while causing environmental degradation and pollution (Liang and Wang, 2019) [69].

Developing countries should prioritize the development and promotion of micro livestock, allocating more scientific effort to address climate change through this approach (SAPA, 2012; Skapetas and Bampidis, 2016) [96]. Research should focus on evaluating and enhancing the productivity of micro livestock and other lesser-known animal species (Hardouin 1995). In a changing climate, improving efficiency, survivability, and manageability of micro livestock is essential. Enhancing feed-use efficiency in egg, meat, and milk production is crucial for reducing greenhouse gas emissions (Connor, 2015) [25]. Micro livestock production should be incorporated into rural development initiatives addressing climate change (Ingweye and Kalio, 2020) [55]. Experiment stations should develop and promote climate change mitigation-focused methods and materials for micro livestock rearing. Donors, development institutions, planners, and policymakers should recognize the potential of micro livestock and their socioeconomic and environmental benefits, including climate mitigation (Assan, 2013) [4]. Micro livestock present a promising approach to reducing methane emissions and fostering sustainable farming practices.

By providing training and capacity-building programs, policy support, market development, and research and development, farmers can adopt micro livestock production and management practices (Kalimba and Culas, 2020) [59]. This can contribute to achieving net-zero GHG emissions, mitigating climate change, improving livelihoods, and promoting biodiversity conservation. Markets for micro livestock products, such as meat, dairy, and eggs, can provide economic incentives for farmers (Hardouin 1995). Micro livestock will be a key component of sustainable farming and net zero GHG emissions. As the world strives to achieve net zero greenhouse gas (GHG) emissions and mitigate climate change, sustainable farming practices are gaining prominence. Micro livestock, such as small ruminants, poultry, and rabbits, can play a vital role in reducing methane emissions and promoting environmentally friendly agriculture (Ingweye and Kalio, 2020) [55].

Study Highlights

The study underscores the transformative potential of micro livestock farming as a pivotal force in bolstering food security, curbing methane emissions, and advancing gender equality in developing nations. Consider these compelling arguments:

- Micro livestock, such as goats, poultry, and rabbits, exert a significantly smaller environmental footprint compared to large ruminants, positioning them as a cornerstone of sustainable agriculture.
- By championing micro livestock farming, we can decisively slash methane emissions, boost agricultural productivity, and tackle gender inequality head-on.
- Women are indispensable to the success of micro livestock farming, and their active participation is vital for effective climate action.
- A gender-inclusive approach to micro livestock farming is not just beneficial but essential for achieving Sustainable Development Goal 5 (Gender Equality) and catalyzing progress across other SDGs.
- The diverse array of products derived from micro livestock—eggs, milk, meat, and fiber—provides sustainable and ethical food sources that are crucial for a resilient food system.
- Replacing large ruminants with micro livestock is a strategic move to drastically reduce methane production and combat climate change.

The study calls for an urgent, comprehensive, and gender-inclusive strategy to elevate micro livestock farming and mitigate methane emissions.

Conclusion

In conclusion, micro livestock farming emerges as a beacon of hope, offering a robust solution to enhance food security, combat climate change, and promote gender equality in developing countries. By embracing a holistic and gender-inclusive approach to micro livestock production, we can significantly reduce methane emissions, enhance productivity, and champion sustainable agriculture. This strategy holds immense potential to drive progress toward the Sustainable Development Goals, particularly SDG 5 on gender equality. As the global community confronts the pressing challenges of climate change and food insecurity, promoting micro livestock farming is not just an option but a necessity for forging a sustainable and equitable food system for developing countries. It is imperative to acknowledge that climate change strategies successful in developed countries cannot be indiscriminately applied to developing nations. To achieve meaningful climate mitigation in these regions, it is essential to implement tailored approaches that meticulously consider the unique sociocultural, economic, and environmental contexts. Furthermore, integrating region-specific technological and policy frameworks is not just beneficial but crucial. By doing so, we can ensure that climate strategies are not only effective but also sustainable and equitable, ultimately leading to a more resilient global response to climate change.

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Conflict of interest

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