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Estimation of Greenhouse Gas Emissions from Fogera Dairy Cattle Breeding Program at Andassa Livestock Research Center in Ethiopia Using Gleam-I Model

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Research Article

Keywords: Emission intensity, Fogera breed, Methane, Protein productivity, GHG

Posted Date: November 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11253320/v1

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Additional Declarations: No competing interests reported.

Estimation of Greenhouse Gas Emissions from Fogera Dairy Cattle Breeding Program at Andassa Livestock Research Center in Ethiopia Using Gleam-I Model

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***Running Title**: GHG Emissions from Fogera Cattle*

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Abstract

Greenhouse gas (GHG) emission from livestock systems is gaining more attention because of its potential impacts on climate change and food security. In this study, GHG emission from the Fogera dairy cattle breeding program of Andassa Livestock Research Center, Ethiopia, were estimated using a model called GLEAM-i and a potential mitigation option (scenarios) was evaluated. The study used data collected from 2014 to 2024 to estimate GHG emissions, quantity of proteins produced, and emission intensity. The overall emission was increasing from 538.6 to 896.03 t CO-eq over the study period mainly because of expanding herd size and productivity. Among the gases, CH_4 comprised the bulk of emissions (>80%). Although the overall emission was rising during the study period, the quantity of proteins produced increased from around 2,800 to nearly 8,000 kg while emission intensity showed a decreasing trend, indicating the efficiency of producing more proteins per unit of GHG emitted. Two scenarios were evaluated against the business-as-usual system. Scenario 1 increased the quantity of proteins produced by 19.99% and reduced emission intensity by 8.49%. Moreover, scenario 2 increased the quantity of proteins produced by 49.96% and decreased emission intensity by 22.38%. Even though the overall emission for the scenarios was slightly higher than the base, the increase in the quantity of proteins produced was considerably higher compared to the GHG emission. Improving feed quality, herd performance, and manure management would improve productivity and minimize emission per unit of milk produced. Scenario 2 resulted in the best performance and is a feasible option for climate-smart production in Ethiopia. So further, to reduce GHG emissions while increasing productivity, the study suggests scaling up Scenario 2 practices, with a focus on feed optimization, selective breeding, and better manure management.

Keywords: *Emission intensity, Fogera breed, Methane, Protein productivity, GHG*

1 Introduction

Livestock production is a crucial income source for many communities, especially in low- and middle-income countries, but it also contributes substantially to global greenhouse gas emissions. Cattle, buffalo, sheep, goats, pigs, and poultry emit an

estimated 7,516 million metric tons CO_2-equivalent annually about 18% of global greenhouse gas (GHG) emissions [1]. Reducing human-caused GHG is essential for climate mitigation; dairy cattle are a major agricultural source, largely because of methane (CH_4) from enteric fermentation [2]. Ruminant CH_4 is a major concern roughly 25% of global CH_4 emissions, with enteric CH_4 from the rumen accounting for nearly 90% of that. Nutritional strategies that optimize feed intake and improve feed and milk efficiency can reduce CH_4 emissions in some dairy cows, reflecting the established link between enteric CH_4 and dry matter intake [3, 4].

In Ethiopia, the livestock sector accounts for over 43% of national GHG emissions [5], significantly exceeding the global average of 14.5% [6]. GHG emissions from the livestock sector in Ethiopia and its study regions have shown a concerning upward trend over time, necessitating urgent mitigation measures. Without intervention, the sector's GHG emissions are expected to rise further due to increasing animal populations driven by the growing demand for animal protein. While this sector offers substantial economic benefits, it remains the primary source of emissions, primarily from enteric fermentation, manure management (CH_4 and N_2O), and direct and indirect nitrous oxide (N_2O) emissions from dung and urine on pastures, as well as carbon dioxide (CO_2) emissions from feed and fodder production [6]. Menghistu et al. [7] reported rising GHG emissions from 2003/04 to 2017/18, averaging an annual increase of 3.8 million tons CO_2e across cattle, sheep, goats, and chickens, and 3.3 million tons CO_2e from cattle alone in the dry land areas of Amhara, Tigray, and Afar regions. Berhe et al. [8] showed that combined feed, herd, and manure management can cut total GHG emissions by 20.72–30.33%, CH_4 by 23.57–29.83%, and N_2O by 21.11–32.95%. These measures also reduced milk emission intensity by 83.26% in pastoral, 78.80% in mixed crop–livestock, and 62.33% in urban systems. Emission intensity denotes GHGs emitted per unit of activity. It is essential to design mitigation interventions that preserve dairy and beef production and productivity in the region.

Fogera cattle are a promising Ethiopian breed, well suited to the Lake Tana plain in Amhara. They offer higher milk yields than other local breeds, larger body size, greater traction power, and better resistance to internal parasites, making them adapted to Fogera’s waterlogged plains [9]. Starting from the year 2000, the Andassa Livestock

Research Center has run conservation and selective-breeding programs to prevent Fogera's extinction and improve productivity. Over the past 25 years the center has implemented measures to increase milk production and efficiency, though the effects of these programs on greenhouse gas emissions remain under examined. Tesfa et al. [10] reported that milk production at ALRC rose from 2002 to 2017, prompting the development of a Fogera dairy cow production system aimed at lowering emission intensity without reducing milk yield.

To gain a clearer understanding of the environmental impact associated with the Fogera cattle dairy production system, it is essential to calculate GHG emissions from previous years to develop various future intensification scenarios. The GLEAM-i model assesses initial GHG emissions from various livestock systems [11], providing insight into their environmental impact and guiding climate-resilient livestock strategies. Data on greenhouse gas emissions from the livestock sector, especially for the Fogera dairy cattle breeding program are limited. This study therefore evaluates GHG emissions, emission intensity, and potential mitigation strategies for the Fogera breeding program at Andassa Livestock Research Center using data from 2014–2024 years.

2 Materials and Methods

2.1 Description of study area

The study utilized the data collected from the open-nucleus Fogera cattle breeding program conducted at the Andassa Livestock Research Center (ALRC) Northwestern Ethiopia (Fig.1). The center is located at an elevation of 1,730 meters above sea level, and situated at 11°29' North and 37°29' East, approximately 22 kilometers from Bahir Dar, the capital of Amhara region and 560 km from the national capital, Addis Ababa, along the road to Blue Nile Falls. The center receives an average annual rainfall of 1,150 millimeters, with temperatures ranging from 6.5 to 30 ^{o}C. The center was established on 1965 in the emperor regiom with the main objectives of milk production and conservation of the Fogera cattle. Since 2000 the center had upgraded to research center and starts selection program along with conservation of the breed [9].

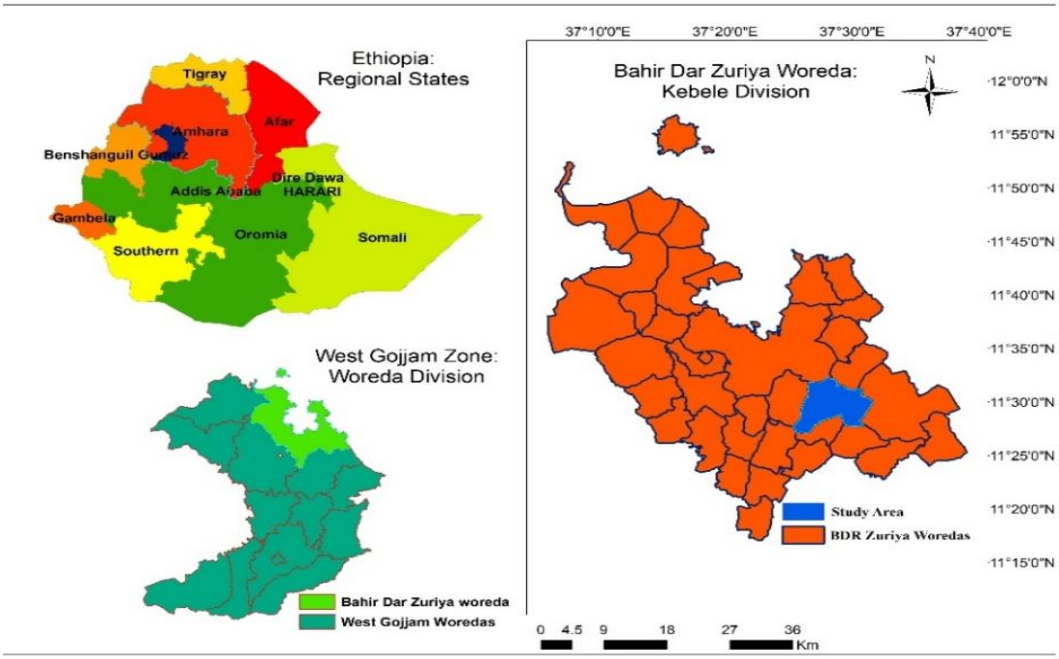

Fig. 1 Map of the study area

2.2 Animal management

The animal management practices in this study align with the breeding objectives of the center. The center typically maintains a stock of over 450 Fogera dairy cattle annually, organized into various groups based on age and sex. Housing for the pure Fogera cattle is segregated by herd group, with each group accommodated in pens featuring concrete floors and roofs made of iron sheets. During the dry season (October–May), cattle graze eight hours daily and receive supplemental feed natural pasture hay and concentrates for lactating cows. Herd water comes mainly from the Andassa River (a Blue Nile tributary); young and sick indoor animals receive tap water. Health management emphasizes prevention with vaccinations against blackleg, anthrax, and pasteurellosis, and internal and external parasites are treated twice yearly at the start and end of the rainy season. For the first four days after birth, pure Fogera cows nurse their calves to provide adequate colostrum [12].

2.3 Data sources and collection methods

Data to fit the GLEAM-i model modules viz. herd module, feed module, and manure module, was collected from the herd book of the center. To parameterize the entire

inputs, additional data were sources from published and unpublished secondary sources along with expert opinion. The analysis included a 10-year data collected from 2014 to 2024.

2.4 Source of data for each of Modules

2.4.1 Feed module

From 2014 to 2024, feeding of Fogera cattle at ALRC gradually moved to balanced systems (Table 1). The main changes were improved forages, rising from 5% to 7%, and concentrate feeds, increased from 5% to 8%. Feeding systems are steadily changing to improve Fogera cattle nutrition and productivity. Generally, the 10-year feed module has three phases spanning phase I (2014-2018), phase II (2019-2020) and phase III (2021-2024).

Table 1 Source of data for feed module

Feeding Options	Unit	Phase I	Phase II	Phase III
Grazing	%	70	67	64
Hay	%	20	20	21
Improved forage	%	5	6	7
Concentrate	%	5	7	8
Total		100	100	100

2.4.2 Herd module

The dataset for the herd module comprises the performance record from 2014-2024 from the ALRC (Table 2) including demographic, reproductive, and production metrics that are relevant to GHG estimation.

146 Table 2 Source of data for herd module

Parameters	Unit	Observation years										
		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	20
Milk yield	liter/year	384.3	292.8	268	222.7	176.9	540	817.4	744.2	787	960.8	99
Milk fat content	%	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Number of adult females	number	113	109	115	110	225	186	150	172	153	169	17
Milk protein content	%	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Number of adult males	number	6	5	6	5	14	10	16	11	8	5	5
Weight birth	Kg	25	25	21	20	20	20	21	22	22	22	23
Live weight of adult females	Kg	275	275	275	275	275	275	275	275	275	275	27
Live weight of Adult Males	Kg	350	350	350	350	350	350	350	350	350	350	35
Live weight meat female animals at slaughter	Kg	220	220	220	220	220	220	220	220	220	220	22
Live weight meat male animals at slaughter	Kg	300	300	300	300	300	300	300	300	300	300	30
Age at the first parturition	Month	51	51	51	51	51	51	51	51	51	51	51
Fertility rate of adult females	%	85	85	85	85	85	85	85	85	85	85	85
Death rate of young females	%	5.06	1.111	2.78	1.2	5.56	4.44	6.25	4.35	2.86	5	4.6
Death rate of young males	%	5.8	1.01	3.61	0.99	6.06	6	6	2.3	4.08	5	4.7
Death rate of adult animals	%	1.65	0	0	0	0	0.51	0	2.14	2.3	0.57	0

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2.4.3 Manure module

The manure management and disposal system adopted for the study periods was similar. They used two main methods: solid storage and pasture or paddock deposition. Solid storage made up 60% of the manure handling, and pasture or paddock accounted for the remaining 40%.

2.5 Developing mitigation scenarios

After estimating GHG emissions from the Fogera dairy cattle production system at ALRC, several mitigation approaches were evaluated for their potential to reduce emissions. These options were assessed for feasibility within the Fogera dairy production system at Andassa without interfering with the breed improvement program. Three mitigation scenarios: Business as Usual (BAS), Scenario 1 (S1), and Scenario 2 (S2) examined changes in feed, herd, and manure management were tested.

At the Andassa Livestock Research Center, we have mapped out three ways the Fogera cattle system could go: Business as Usual (BAS), Scenario 1 (S1), and Scenario 2 (S2) (Table 4). Each scenario looks at changes in feed, herd, and manure management. These mitigation scenarios push for a stronger approach, boost productivity, reduce CH_4 and N_2O, and make Fogera cattle farming friendlier to the environment in the next production years.

Table 3 Base line and mitigation scenario assumptions for the Fogera dairy cattle production

Module	Parameter	Mitigation scenarios		
		BAS	S1	S2
Feed	Grazing	70	50	30
	Hay	20	20	20
	Improved forage	4	15	30
	Concentrate mixture	6	15	20
Herd	Milk yield per lactation (Litter)	991.3	30% (1288.69)	50% (1486.95)
	Age at the first parturition	51	45	39

	Number of adult females	200	200	200
	Mortality rate	5	3	2
	Fertility rate	85	90	95
Manure	Pasture + paddock	40	30	20
	Solid storage	60	40	20
	Anaerobic digestion (pit, compositing)	0	30	60

BAS, baseline scenario; S1, mitigation scenario 1; S2, mitigation scenario 2.

2.6 Data analysis

The major feeding practices and manure disposal activities were changed to percentage of contribution to use as an input for the GHG estimation fit with the GLEAM model [6, 11]. After collecting and formatting all the necessary data, it was entered in the GLEAM-i version 2.0 software (Fig. 2). Once the analysis was completed, the result was exported into excel sheet and descriptive statistics and graphical interpretations were made.

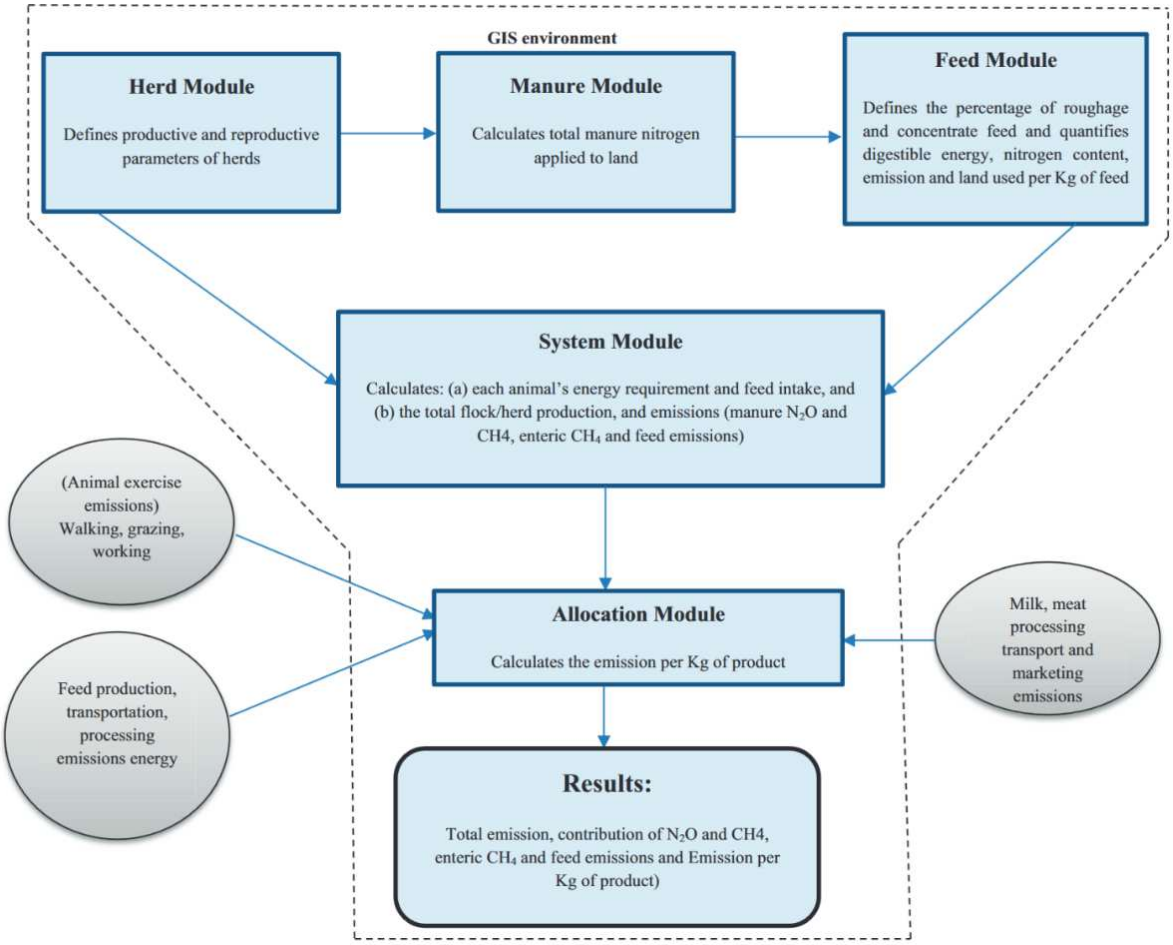

Fig. 2 Working flow under the GLEAM-i model (Source: Gerber et al., 2013b)

3 Results and Discussion

3.1 Absolute Greenhouse Gas Emission

The annual emissions in tons of total GHG and the individual gases (CH_4, N_2O, CO_2) trend from 2014 to 2024 is shown in (Fig. 3, Fig. 4). The results indicated that there was a total GHG emission increase from 538.6 t CO_2-eq in 2014 to 896.03 t CO_2-eq in 2024 with an increase of about 37.9 t CO_2-eq per year (R^2 = 0.5002), demonstrating a gradual increase with notable deviations, including a sharp rise in 2018, reflecting the expansion of the herd size and improved productivity. The average total GHG emissions in the period of 11 years are approximately 751.6 t CO_2-eq. This large increase matches findings from Ethiopia and similar developing-country livestock systems. It is mainly due to larger herd sizes and low milk productivity; even if individual cattle become more efficient, total emissions rise when animal numbers increase.

The notable rise that occurred in 2018 in GHG emission may relate to variations in herd size, management approaches, or temporary productivity changes, which aligns with a report from [13] stating that the yearly GHG variability was due to management variability. The comparatively stable N_2O emissions and slow increase of the CO_2 component suggest a shift toward more intensive management, including more energy, or feed processing, as noted in existing literature [14]. The GHG emissions history of the Fogera cattle-breeding program reflects the overall progress in livestock emissions associated with livestock product outputs in developing regions, where overall GHG emissions are increasing, with herd size and production improvements. Providing higher-quality feed usually raises intake and productivity, which can increase total greenhouse gas emissions per animal and sometimes expand herd size to exploit better performance [2, 6]. Yet better feed digestibility and nutrient balance improve feed efficiency, lower CH_4 emissions per unit of feed, and dilute maintenance-related emissions across more milk or meat produced [15, 16].



Fig. 3 Trends of Total Greenhouse gas emission from Fogera cattle across observation among years

3.2 Major sources of Emission

From emission sources, CH_4 is the dominant greenhouse gas with 87.95% share followed by N_2O and CO_2 (Fig. 4). The average CH_4 emission over the years was 29.5 tones, with total emissions increasing from 450 tones CO_2-eq to 850 tones CO_2-eq (R^2 = 0.468) (Fig. 5). Emissions of N_2O ranged between 70 tones and 130 tones, reflecting an annual increase of approximately 5.65 tones CO_2-eq (R^2 = 0.583). Carbon dioxide emissions, which were at lower levels of 10 tones CO_2-eq to 40 tones CO_2-eq, showed an average increase of 2.12 tones CO_2-eq (R^2 = 0.81) (Fig. 5).

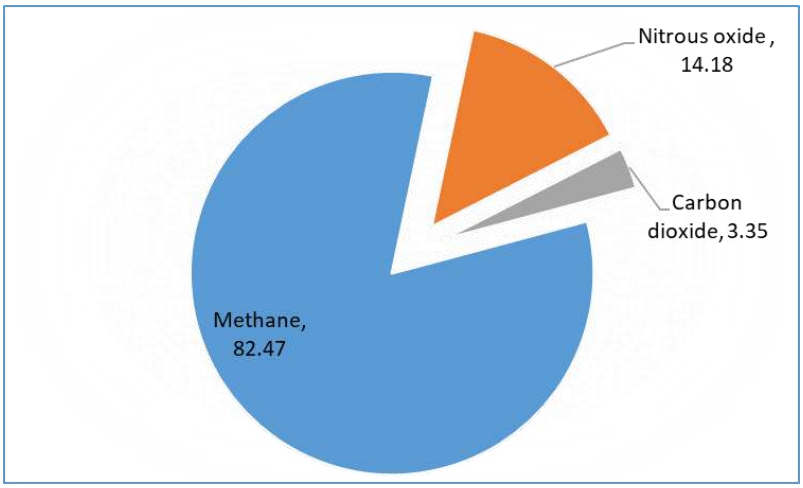

Fig. 4 Share of the major GHG gases in the Fogera dairy cattle production system at ALRC

The high CH_4 share aligns with previous Ethiopian and global studies showing enteric fermentation is the main livestock-related GHG source [6, 17]. Likewise, Tadesse et al. [18] and Mekonnen et al. [19] found CH_4 accounted for over 80% of total GHGs in indigenous cattle systems, due to low feed digestibility and long production cycles. The steady rises in N_2O and CO_2 observed here mirror global trends where intensified manure management slightly increases these emissions [14]. The higher R^2 for CO_2 (0.81) indicates a stronger time-related trend, likely reflecting gradual management intensification and greater energy or mechanization use.

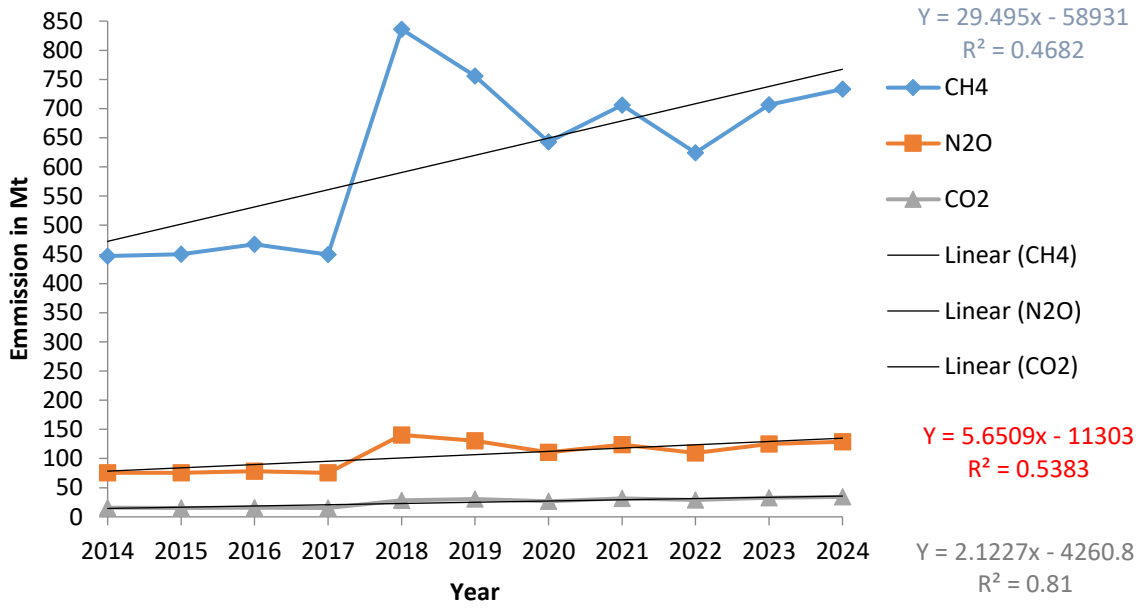

Fig. 5 Trends of key greenhouse gas Emissions from Fogera across Years

3.3 Total protein output Across Years

The total protein output (TPP) of Fogera cattle at ALRC indicated a definite and uniform rise throughout the period 2014-2024, escalating from around 2,800 kg protein to close to 8,000 kg protein (Fig. 6). The result demonstrated that TPP was increasing at the rate of approximately 531 kg per year, with a consistent upward trend. This large increase in protein yield infers that there were major gains in productivity regarding feeding systems, genetics, and herd management. The abrupt increase after 2018 corresponded to herd structuring basing the milk yield and slight increase in number of animals in the breeding nucleus herd. Studies highlighted that high-quality feed led to higher protein yield and lowered environmental footprint due to easily absorptions by the animal [6, 18, 19].

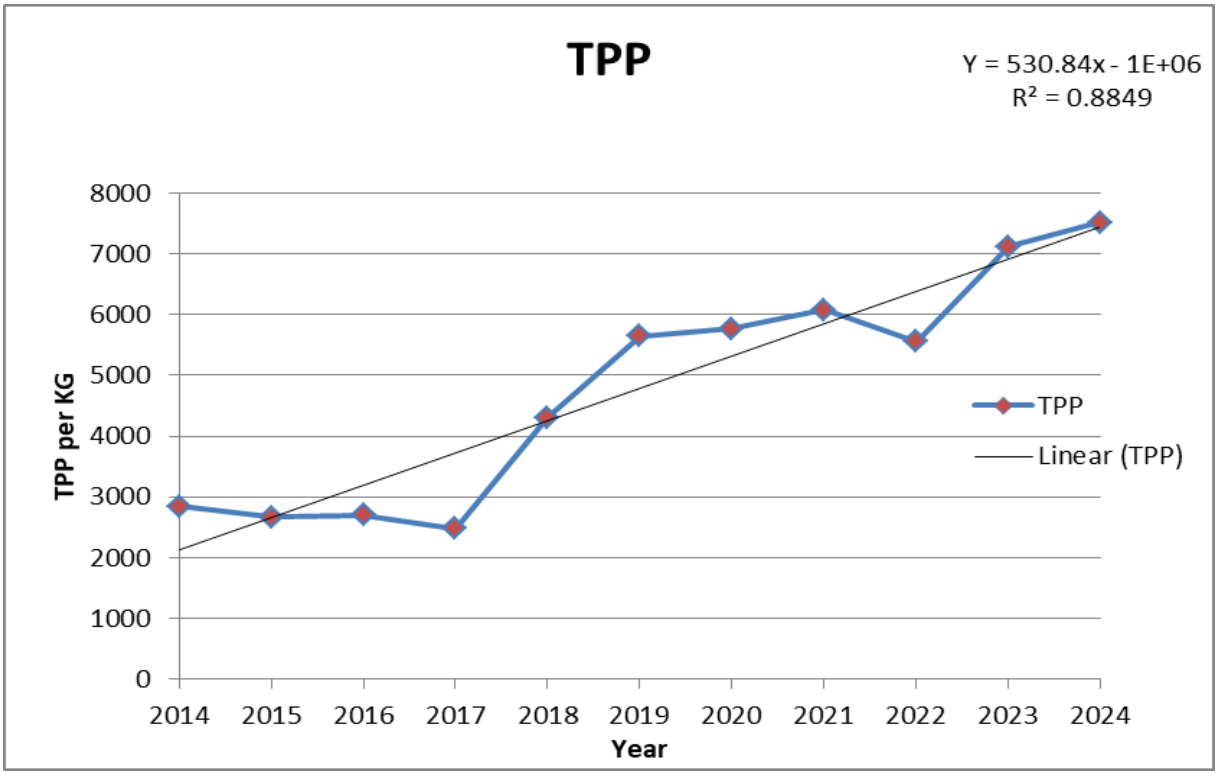

Fig. 6 Trends of Total protein production in the Fogera dairy cattle at ALRC

3.4 Trends of emissions intensity

The emission intensity (EI) from Fogera cattle at (ALRC) during the period of 2014 to 2024 has shown a notable reduction, from a range of about 190-200 tone CO_2-eq/protein output to averaged 120 CO_2-eq/protein output per year, even though there was a temporary increase in 2018 (Fig. 7). The trend suggests that although total GHG emissions increased during the study period, emissions per unit of product i.e. milk or mutton gain have decreased due to better production efficiency.

The observed decline in emission intensity (EI) despite increases in total GHG emissions highlights the improving production efficiency of the Fogera cattle breeding program and its progression toward a more climate-efficient livestock production system. This finding is consistent with studies from Ethiopia and elsewhere, which emphasize that enhancing livestock productivity and efficiency is one of the most effective pathways for reducing emission intensity in livestock systems [6, 18, 19].

Improved feeding practices, better-quality feed resources, enhanced productivity, and improved manure management have been identified by FAO [2] and IPCC [20] as key

interventions for substantially reducing CH_4 and N_2O emissions while supporting climate-smart livestock development. Importantly, although absolute emissions may remain stable or even increase as production expands, emission intensity measured as GHG emissions per kilogram of animal product typically declines when productivity per animal improves [6]. This distinction between absolute emissions and emission intensity is therefore essential when assessing the environmental benefits of productivity-enhancing interventions in livestock production systems [2]. The declining EI trend observed in Fogera cattle suggests that gains in production efficiency are beginning to offset increases in total emissions, representing a transitional stage toward climate-smart livestock production. Over time, sustained improvements in productivity are expected to further reduce emission intensity and enhance the environmental sustainability of the breeding program, enabling greater output with lower emissions per unit of product.

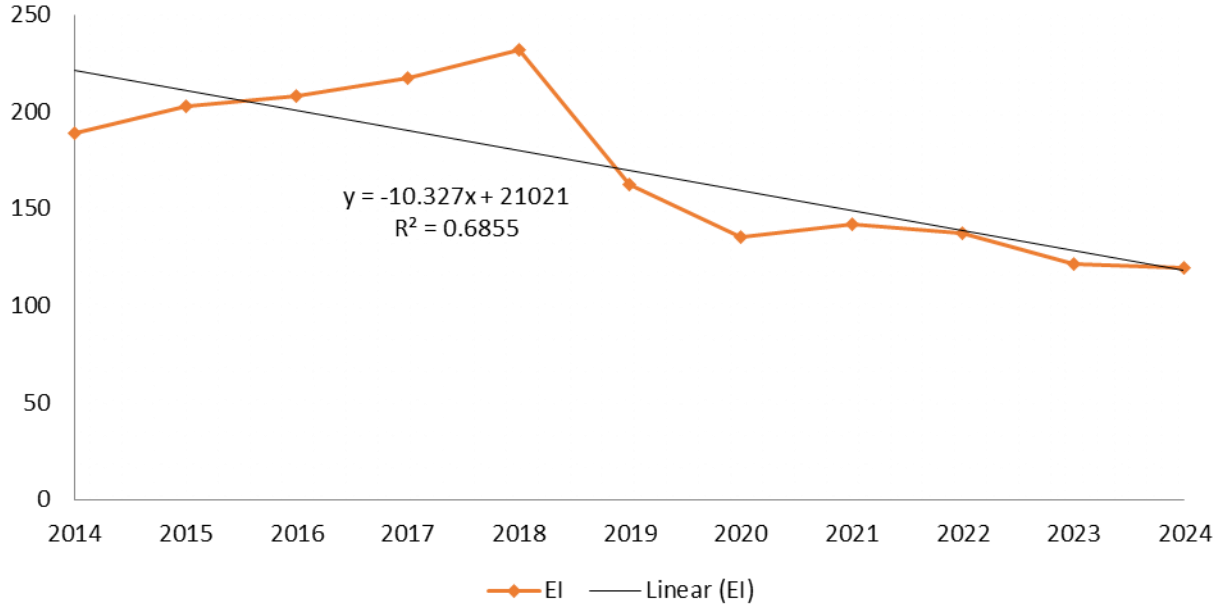

Fig. 7 Trends of emission intensity from the Fogera dairy cattle at ALRC

3.5 Mitigation Scenario Results

Table 4 reveals that the use of two mitigation approaches (S1 and S2) has implications for the level of GHG emissions, productivity, and emissions intensity. The total emissions under the Business-as-Usual (BAU) approach were 868.68 t CO_2-eq, while

these values reached 944.32 t CO_2-eq for S1 and 912.47 t CO_2-eq for S2. Compared with BAU, the emissions level under S1 upped to 8.71%, while the level of emissions under the second scenario S2 was lower by 5.04% compared with BAU scenario, whereas S2 released 3.37% fewer emissions compared with the first approach. The level of production in terms of protein was raised from 4,802 kg in BAU to 5,762 kg for S1 and 7,201 kg for S2. These growth figures show an increase of 19.99% for S1 and 49.96% for S2, while the second scenario provided the level of production higher by 24.97% compared with the first scenario. Emission intensity decreased from 78.34 metric tons of CO_2 equivalent produced per one unit of protein under business as usual (BAU) level to 71.69 metric tons of CO_2 equivalent under S1 scenario and to 60.81 metric tons of CO_2 equivalent in S2 scenario, which corresponds to reduction of emission intensity by 8.49% and 22.38%, respectively. Similarly, actual emission intensity (AE/PP) decreased from the value of 0.18 under BAU level to 0.16 in S1 scenario and to 0.13 in S2 scenario. These findings suggest that although there was a slight increase in overall emissions under mitigation scenarios, increase in production of protein was much greater, resulting in lower emissions per unit of production.

Proportional reductions in emission intensity due to increased productivity have been also found in Ethiopian dairy systems [21]. Moreover, this finding is in agreement with Tadesse et al. [18] and Mekonnen et al. [19], who indicated that through feed optimization and selective breeding, CH_4 emissions in the Ethiopian cattle systems could be reduced by 10–20% without losing the productivity. In the same vein, the FAO global assessment [6] suggested that enhancing feed conversion efficiency and animal performance not only reduces CH_4 intensity but also slightly increases the CO_2 from energy-related activities, a scenario which is also reflected in the Fogera data. In general, the findings prove that integrated mitigation measures, especially those that target feed utilization, breeding efficiency, and manure management, can yield significant GHG reductions in indigenous cattle systems. The trend of the Fogera cattle program in mitigation coincides with national and global conclusions, and it is conclusive that productivity-driven mitigation is indeed a possible path to livestock emissions reduction while at the same time supporting sustainable production growth

Table 4 Result of the mitigation scenario

Emissions	BAU	S1	S2	ΔS1BAU (%)	ΔS2BAU (%)	ΔS2S1 (%)
Absolute emission (tones CO_2- eq_)	868.677	944.32	912.468	8.71	5.04	-3.37
Protein production (kg)	4802	5762	7201	19.99	49.96	24.97
Emission intensity (tones CO_2-eq/protein output)	78.34	71.69	60.81	-8.49	-22.38	-15.18
Real EI (AE/PP)	0.18	0.16	0.13	-9.40	-29.95	-22.68

AE= absolute emission, EI= emission intensity, PP= protein production

3.6 Emissions intensity Across Senarios

Fig. 6 describes the shift in the emission intensity for the three scenarios. In terms of emission intensity, the highest emission intensity was experienced within the BAU scenario (78.34 t CO_2-eq per unit of protein), then followed by S1 scenario (71.69 t CO_2-eq per unit of protein), while the lowest emission intensity recorded was under S2 scenario (60.81 t CO_2-eq per unit of protein). In fact, the graph shows a decline from BAU scenario to S1 then to S2. Such a process means that greenhouse gas emissions were more effectively used in the production of livestock protein products. The large drop observed in S2 scenario indicates that productivity rise exceeds the increase in emissions occurred. The same trends were noted in Ethiopian dairy production process where feeding and management measures raised productivity and cut emissions per a unit of animal product [8, 21, 22].

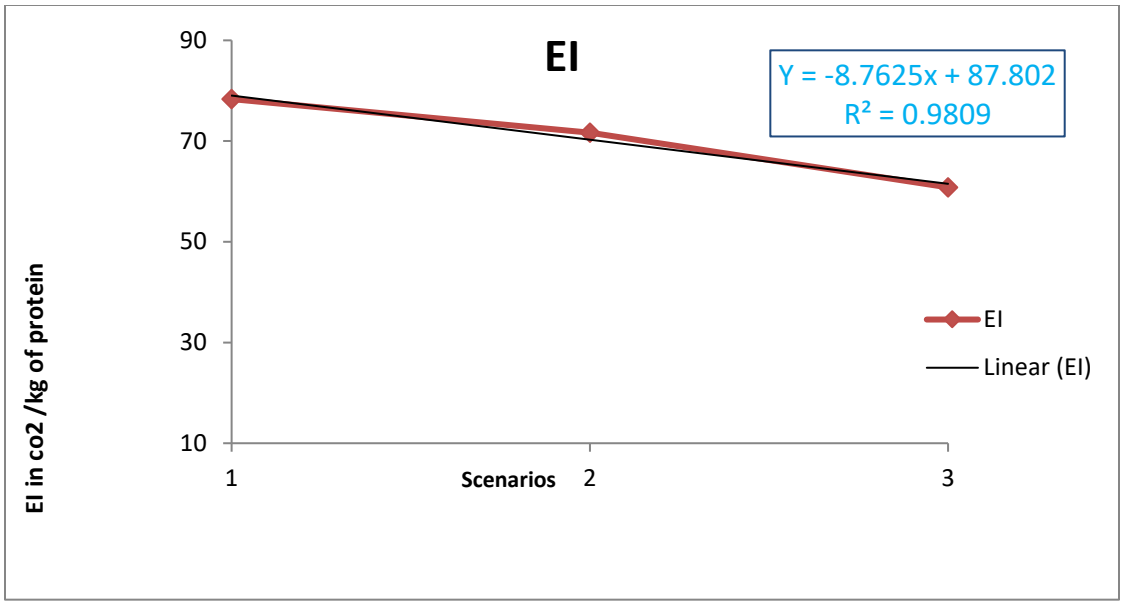

Fig. 6 Emission intensity (EI) across scenarios

3.7 Protein Production Across Senarious

The total amount of protein produced, as depicted in Fig. 7, was higher across three different emissions scenarios (BAU, S1, S2). Overall protein production rose from 4,802 kg under BAU through 5,762 kg under S1 to 7,201 kg under S2. In addition, the figure indicates that S2 has the maximum yield of protein, compared to all other cases. In contrast with BAU, protein production under S1 rose close to 20% while that under S2 increased by almost 50%. The significant leap in the yield of S2 indicates that the mitigation strategies played a more efficient role in boosting the effectiveness of dairy production compared to S1. Growth in protein production along with the fall in emission intensity is crucial for sustainable animal farming since it enables higher productivity with lower pollution. Unlike many conventional systems where productivity is flat, Fogera cattle show that implementing progressive production scenarios can significantly increase protein yield while at least decreasing environmental harms (diagram of EI). The association between growing productivity and diminished emissions indicates the potential for sustainable intensification in Fogera cattle production

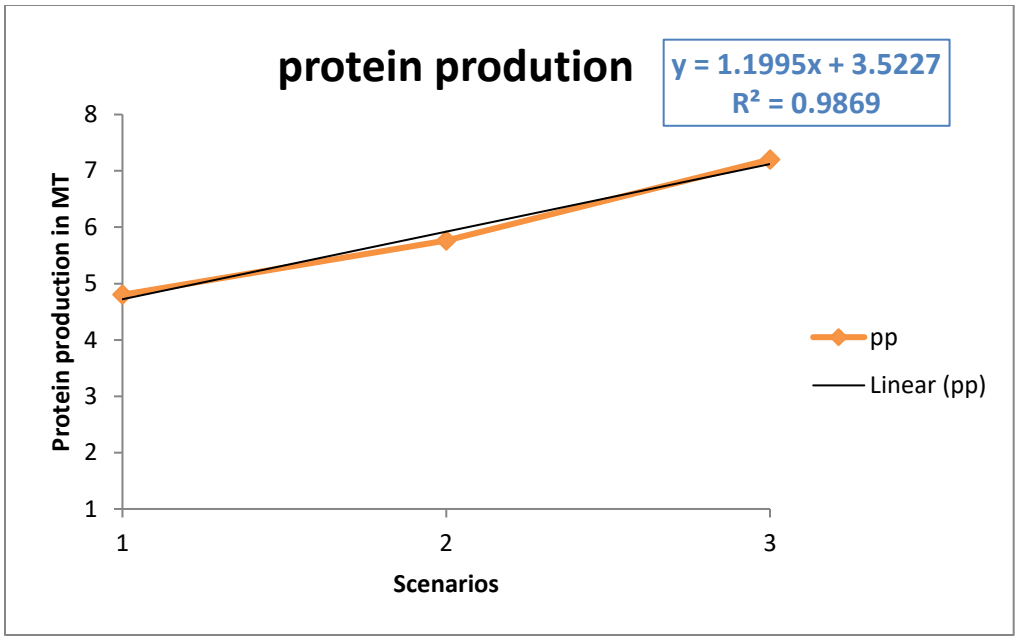

Fig. 7 Total protein prodcution across scenarios

4 Conclusions

The Fogera breeding program for dairy cattle had several increases in productivity from 2014 to 2024. Total greenhouse gas emissions rose at the same time as the herd size and milk production increased, with CH_4 accounting for the largest share of emissions. The increase in protein production was greater than the increase in emissions, which translated into a gradual decrease in emission intensity or the production system was getting more efficient. The mitigation analysis also indicated that by improving feeding, productivity, reproductive traits and manure management, the environmental efficiency of Fogera dairy cattle system can be further increased. Based on the options considered, the proposed Scenario 2 maximized protein production and minimized the emission intensity of protein production. The total emission under Scenario 2 was marginally higher than the baseline system and the emission per unit of protein produced was significantly higher.

The results indicate that interventions that focus on increased production can ensure climate-smart livestock development by producing more meat or milk with fewer emissions for each unit produced. The improvements in the feed base, herd management and manure utilization can support both productivity growth and environmental sustainability in Fogera dairy cattle production systems. Scenario 2's

feeding and management systems should be advocated for the Fogera dairy breeding program since they led to the highest protein yield and lowest emission intensity. Feed quality, milk yield, manure management, and improved dairy herd productivity should be optimized to enhance the sustainable production of livestock products while reducing the emissions intensity of milk production. Further work is also needed to validate GLEAM-i estimates under field conditions and in different Ethiopian dairy production systems.

Author contributions

BH: Conceptualization, methodology, investigation, data collection, data curation, GLEAM-i modeling, formal analysis, interpretation of results, visualization, and writing original draft preparation.. DK, AT, NB, ZA & TT: methodology, data collection, validation, interpretation of results, review and editing, MW & SM: investigation, review and editing, YA: data collection, review and editing, GZ, AWZ & SEW: methodology, validation, review and editing.

Funding

This study did not receive funding.

Data availability

The data used in this study can be available on request.

Declarations

Ethical compliance

Not applicable

Consent to publish

Not applicable

Consent to participate

Not applicable

Conflict of interest

The authors declare that they have no competing financial and/ or non-financial interests.

References

1. Steinfeld H, Gerber P, Wassenaar TD, Castel V, Rosales M, de Haan C. Livestock's Long Shadow: Environmental Issues and Options. Rome: Food and Agriculture Organization of the United Nations; 2006.
2. FAO. The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets. Rome: FAO; 2020.
3. Hristov AN, Kebreab E, Niu M, Oh J, Bannink A, Bayat AR, et al. Symposium review: Uncertainties in enteric methane inventories, measurement techniques, and prediction models. Journal of dairy science. 2018;101(7):6655–74.
4. Fischer H, van den Broek KL, Ramisch K, Okan Y. When IPCC graphs can foster or bias understanding: evidence among decision-makers from governmental and non-governmental institutions. Environmental Research Letters. 2020;15(11):114041.
5. FDRE: Ethiopia's climate-resilient green economy strategy. In. Addis Ababa; 2011: 1–130.
6. Gerber PJS, H. Henderson, B. Mottet, A. Opio, C. Dijkman, J. Falcucci, A. Tempio, G. Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities. Rome: Food and Agriculture Organization of the United Nations (FAO); 2013b.
7. Menghistu HT, Zenebe Abraha A, Mawcha GT, Tesfay G, Mersha TT, Redda YT. Greenhouse gas emission and mitigation potential from livestock production in the drylands of Northern Ethiopia. Carbon Management. 2021;12(3):289–306.
8. Berhe A, Bariagabre SA, Balehegn M. Estimation of greenhouse gas emissions from three livestock production systems in Ethiopia. International Journal of Climate Change Strategies and Management. 2020;12(5):669–85.

9. Tesfa A, Kumar D, Abegaz S, Mekuriaw G, Bimerew T, Kebede A, et al. Growth and reproductive performance of Fogera cattle breed at Andassa Livestock Research Center. Livestock Research for Rural Development. 2016;28(1):1–17.
10. Tesfa A, Bimerew T, Tilahune M, Kassahun D, Kebede A, Mengesha W. Evaluation of the breeding practices and population trend of the Fogera cattle breed in Ethiopia. Frontiers in Animal Science. 2022;3:998628.
11. FAO: Global livestock environmental assessment model – interactive – a tool for estimating livestock production, greenhouse gas emissions and assessing intervention scenarios. In.: Food and Agriculture Organization of the United Nations; 2017b.
12. Kassahun D, Tesema Z, Lakew M, Meseret M. Risk factors and genetic parameter estimates for preweaning survival of Fogera calves. Animal. 2023;17(11):100988.
13. Chalchissa FB, Diga GM, Tolossa AR. Modeling the responses of Coffee (Coffea arabica L.) distribution to current and future climate change in Jimma Zone, Ethiopia. SAINS TANAH-Journal of Soil Science and Agroclimatology. 2022;19(1):19–32.
14. Chadwick D, Cardenas L, Dhanoa M, Donovan N, Misselbrook T, Williams J, et al. The contribution of cattle urine and dung to nitrous oxide emissions: Quantification of country specific emission factors and implications for national inventories. Science of the Total Environment. 2018;635:607–17.
15. Hristov AN, Oh J, Firkins J, Dijkstra J, Kebreab E, Waghorn G, et al. Special topics—Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. Journal of animal science. 2013;91(11):5045–69.
16. Capper JL, Cady RA, Bauman DE. The environmental impact of dairy production: 1944 compared with 2007. Journal of animal science. 2009;87(6):2160–7.
17. Dangal SR, Tian H, Zhang B, Pan S, Lu C, Yang J. Methane emission from global livestock sector during 1890–2014: Magnitude, trends and spatiotemporal patterns. Global Change Biology. 2017;23(10):4147–61.

18. Tadesse M, Getahun K. Methane emission factors from indigenous cattle breed in smallholder livestock production systems in Ethiopia. Online Journal of Animal and Feed Research. 2021;11(4):145–50.
19. Mekonnen EF, Assefa MA, Ayele AG. Trends in rainfall and temperature extremes during 1954-2019 in Addis Ababa, Ethiopia. Journal of Agrometeorology. 2024;26(4):516–8.
20. IPCC. Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land-management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge: Cambridge University Press; 2019.
21. Feyissa AA, Senbeta F, Tolera A, Diriba D, Boonyanuwat K. Enteric methane emission factors of smallholder dairy farming systems across intensification gradients in the central highlands of Ethiopia. Carbon balance and management. 2023;18(1):23.
22. Feyissa AA, Senbeta F, Diriba D, Tolera A. Understanding variability in carbon footprint of smallholder dairy farms in the central highlands of Ethiopia. Tropical Animal Health and Production. 2022;54(6):411.