IFAD

Dairy Interventions for Mitigation and Adaptation (DaIMA)

Funding Proposal

Annex 22: Assessment of GHG emission reductions

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Summary

Regarding emissions from dairy cattle, analysis shows a GHG emissions reduction of 4.01% (266,564 tCO_2 eq.) compared to the situation without the project (WOP) for the 20 years project capitalization. The enteric methane emissions are expected to decrease by 4.61% with DaIMA compared to the situation without the project. An average annual GHG emissions decrease of 13,328 tCO_2 eq/year is expected. *See sections A, B and C of this Annex*.

Country	WOP (tCO_2 eq.)	With DaIMA (tCO_2 eq.)	Annual GHG emissions with DaIMA (tCO_2eq./yr)	Total GHG emissions reduction (tCO_2 eq.)	Annual GHG emissions reduction (tCO_2 eq./yr)	Percentage of GHG reduction
Rwanda	590,818	534,311	26,716	56,507	2,825	-9.56%
Uganda	1,579,242	1,496,870	74,844	82,372	4,119	-5.22%
Tanzania	1,400,985	1,335,267	66,763	65,718	3,286	-4.69%
Kenya	3,069,483	3,007,516	150,376	61,967	3,098	-2.02%
DaIMA	**6,640,528**	**6,373,964**	**318,698**	**266,564**	**13,328**	**-4.01%**

Regional DaIMA					
GHG emissions in tCO2 equivalence	**Baseline**	**WOP**	**With DaIMA**	**% change**	**Annual emissions reductions**
CH4 from enteric fermentation	4,180,958.8	5,436,354.3	5,185,672.7	-4.61%	12,534
CH4 from manure management	376,796.9	491,591.3	462,434.2	-5.93%	1,458
N2O Emissions	292,239.3	380,257.8	402,175.8	5.76%	1,096
CO2 Emissions	250,791.5	332,323.7	323,681.4	-2.60%	432
Total GHG emissions	**5,100,786.5**	**6,640,527.21**	**6,373,964.19**	**-4.01%**	**13,328**

At mid-term, the project is expected to achieve a reduction in CH_4 enteric emissions estimated at 37,602 tCO_2eq, CH_4 manure emissions reduction of 4,374 tCO_2eq, CO_2 emissions reduction of 1,296 tCO_2eq, and an increase in N_2O emissions of 3,288 tCO_2eq. At the final year, the project is expected to achieve a CH_4 enteric emissions reduction of 75,204 tCO_2eq (250,682 tCO_2eq over 20 years), CH_4 manure emissions reduction of 8,747 tCO_2eq (29,157 tCO_2eq over 20 years), CO_2 emissions reduction of 2,593 tCO_2eq (8,642 tCO_2eq over 20 years), and an increase in N_2O emissions of 6,575 tCO_2eq (21,918 tCO_2eq over 20 years).

The project interventions improving herd and feed parameters will increase the milk production by 34% while reducing the milk emission intensity by 29%, and the total feed intake by 5.23% compared to the situation without the project.

	Protein production (t protein/year)			**Milk production (t/year)**		
	WOP	With DaIMA	Delta	WOP	With DaIMA	Delta
Rwanda	5,549	8,318	50%	89,505	154,679	73%
e	10,042	13,358	33%	206,446	269,200	30%
Tanzania	9,386	12,143	29%	164,713	223,288	36%
Kenya	32,336	41,135	27%	798,387	1,042,801	31%
DaIMA	**57,313**	**74,954**	**31%**	**1,259,051**	**1,689,968**	**34%**
	Total protein emission intensity (tCO_2eq/t protein)			**Milk emission intensity (tCO_2 eq/t milk)**		

	WOP	With DaIMA	Delta	WOP	With DaIMA	Delta
Rwanda	106	64	-40%	4.6	2.3	-50%
Uganda	157	112	-29%	5.2	3.5	-33%
Tanzania	149	110	-26%	5.6	4.0	-29%
Kenya	95	73	-23%	2.9	2.1	-28%
DaIMA	**116**	**85**	**-27%**	**3.7**	**2.6**	**-29%**

The total area of pastures and rangelands for rehabilitation is estimated at 178,362 ha in the four countries. Over the 20-year capitalization period of the project, the carbon sequestration increase in rehabilitated rangeland soils is expected to be 222,058 tC or 814,214 tCO_2 eq. compared to the without project situation (with an average annual increase of 11,103 tC or 40,711 tCO_2 eq.). *See section D of this Annex*.

		Soil C sequestration increase in 20 years	
Country	Area for rehabilitation (ha)	in tC	in tCO_2 eq.
Rwanda	51,773	64,457	236,341
Uganda	27,443	34,166	125,276
Tanzania	46,758	58,213	213,448
Kenya	52,388	65,222	239,149
DaIMA	**178,362**	**222,058**	**814,214**

Together, carbon sequestration (40,711 tCO_2 eq./year) and **reduced emissions from dairy cattle** (13,328 tCO_2 eq/year), lead to 54,039 tCO_2 eq./year, i.e. 1,080,780 tCO_2 eq. over 20 years.

Furthermore, over the 20 years, the **total annual emissions savings** from renewable energy solutions is 1,088,705 tCO2eq. *See section E of this Annex*.

As a result, for 20 years of project capitalization, the ex-ante analysis shows a **mitigation potential of 2,169,485 tCO_2 eq. for the whole programme**.

A. Methodology for GHG emissions assessment

The Global Livestock Environmental Assessment Model-interactive (GLEAM-i) developed by FAO was used to estimate the impact of the DaIMA project on GHG emissions. GLEAM-i is a publicly available and free tool specific to estimating the GHG emissions from different livestock species and production systems from all countries in the world. The livestock species covered in GLEAM-i are four ruminant species (cattle, buffalo, sheep and goat); and two monogastric species (chicken and pigs). The production systems embedded in the tool are grassland-based and mixed for ruminants; backyard, broiler and layers for chicken; and backyard, intermediate and industrial for pigs (FAO, 2017; MacLeod et al., 2017). The sources of emissions covered by the tool are listed in 19, and the details regarding the background calculations in GLEAM-i can be found in the GLEAM manual (FAO, 2017). The project implementation phase is 5 years of actual implementation, and the capitalization phase is assumed to be 20 years.

GLEAM-i has an embedded herd dynamic model that estimates animal numbers based on demographic parameters such as age at first parturition, fertility and mortality rates and replacement rates. In addition, GLEAM-i estimates feed requirements for each animal species, system and cohort based on their weights, activity, reproduction status and level of production. Direct emissions resulting from the consumption of these feed resources (enteric methane and emissions from manure) are based on their digestibility and nitrogen content. Indirect emissions coming from the production of these feed resources depend on their origin and nature (e.g. pastures, crop residues, grains, and their by-products, produced domestically or imported) (See Table 1).

Table 1: Sources of emissions covered in GLEAM-i[1]

Sources of emissions		Description
Feed CO_2[1]	field operations	CO_2 emissions arising from the use of fossil fuels during field operations
	fertilizer production	CO_2 emissions from the manufacture and transport of synthetic nitrogenous, phosphate and potash fertilizers
	pesticide production	CO_2 emissions from the manufacture, transport and application of pesticides
	processing and transport	CO_2 generated during the processing of crops for feed and the transport by land and/or sea
	blending and pelleting	CO_2 arising from the blending of concentrate feed
Feed LUC[2] CO_2	soybean cultivation	CO_2 emission due to LUC associated with the expansion of soybean
	palm kernel cake	CO_2 emission due to LUC associated with the expansion of palm oil plantations
	pasture expansion	CO_2 emission due to LUC associated with the expansion of pastures
Feed N_2O[3]	applied and deposited manure	Direct and indirect N_2O emissions from manure deposited on the fields and used as organic fertilizer
	fertilizer and crop residues	Direct and indirect N_2O emissions from applied synthetic nitrogenous fertilizer and crop residues decomposition
Feed CH_4[4]	Rice production	CH_4 emissions arising from the cultivation of rice used as feed
Enteric fermentation CH_4		CH_4 emissions caused by enteric fermentation
Manure management CH_4		CH_4 emissions caused by manure management
Manure management N_2O		N_2O emissions arising from manure storage and management
Direct energy use CO_2		CO_2 emissions arising from energy use on-farm for ventilation, heating, etc.
Embedded energy use CO_2		CO_2 emissions arising from energy use during the

[1] https://gleami.apps.fao.org/

	construction of farm buildings and equipment

[1] Carbon dioxide [2] Land use change [3] Nitrous oxide [4] Methane

B. Data Sources

The same assumptions as for the economic and financial analysis (EFA) conducted with the Livestock Sector Investment Policy Toolkit (LSIPT) were considered to define activity data and translated into input parameters used for GLEAM-i in the situations without the project (WOP) and with the project (WP). The growth rates used in WOP and WP situations for the GLEAM-i analysis were the same as calculated from LSIPT, which used realistic herd parameters for each livestock model.

The assumptions used to translate the project interventions into input parameters for GLEAM-i were based on realistic values informed by national and international experts' perspectives and partners such as ILRI. These estimations were derived from data collected throughout the project design process, from the feasibility study to cross-checks with advanced literature review, data from other ongoing projects in the different countries, and from the latest data provided by the National GHG inventories. Additional feedback was obtained from experts' consultations conducted during stakeholder engagement workshops (e.g. Nairobi 2024), providing valuable insights into the assumptions used in the analysis.

Uganda

The analysis considered five production systems as defined and conducted with LSIPT:

- Small scale intensive system with cross breed cattle
- Small scale intensive system with cross breed and exotic animals
- Semi-intensive system with local breed
- Agropastoral systems with local breed
- Pastoral systems with local breed

Grassland and mixed production systems are oriented for milk production. The project will support the access to better animal health care services, vaccination campaigns, better access to veterinary services and medicines. The project will also support the access and better results of artificial Insemination. The herd growth in the WP scenario was assumed to be slightly lower than for WOP due to the improvements in productivity from DaIMA interventions.

The project will also support the access to better feed, as the access to concentrates for small scale intensive systems, and better access to pasture increasing the proportion of fresh mixture of grass and legumes, and hay or silage from grass and legumes in the diet for the other systems. Biogas units will be implemented in the small-scale intensive system assuming that 50% of manure initially managed in solid storage will be used for biogas production.

The assumptions for herd and feed parameters for the WP scenario compared to the WOP were aligned with analysis conducted with LSIPT and presented in *Table 2*, *Table 3*, and *Table 4*.

Table 2: Herd parameters used in GLEAM-i for small scale intensive systems in Uganda.

		SMALL SCALE INTENSIVE SYSTEMS					
		Cross breed			Cross & exotic breed		
Parameter	Unit	Baseline	WOP	WP	Baseline	WOP	WP
Age at the first parturition	months	45	45	39	45	45	39
Death rate of adult animals	%	6%	6%	5%	6%	6%	5%
Death rate of young females	%	9%	9%	7%	9%	9%	7%
Death rate of young males	%	9%	9%	7%	9%	9%	7%
Fertility rate (adult female)	%	68%	68%	74%	68%	68%	74%
Live weight (Adult Females)	kg	400	400	441	435	435	480
Live weight (Adult Males)	kg	400	400	441	435	435	480

Live weight of animal at slaughter (Meat Females)	kg	277	277	306	299	299	330
Live weight of animal at slaughter (Meat Males)	kg	277	277	306	299	299	330
Milk fat content	%	4	4	4	4	4	4
Milk protein content	%	3.5	3.5	3.5	3.5	3.5	3.5
Milk Yield	kg	1870	1870	2787.26	2475	2475	3804.18
Number of animals (Adult Females)	#	556	839	676	303	432	372
Number of animals (Adult Males)	#	132	199	160	45	64	55
Replacement rate of adult females	%	12%	12%	12%	12%	12%	12%
Weight at birth	kg	28	28	28	32.5	32.5	32.5

Table 3: Herd parameters used in GLEAM-i for semi-intensive, agropastoral, and pastoral systems in Uganda.

		Semi-intensive local breed			**Agropastoral systems**			**Pastoral systems**		
Parameter	Unit	Baseline	WOP	WP	Baseline	WOP	WP	Baseline	WOP	WP
Age at the first parturition	months	57	57	45	54	54	45	57	57	49
Death rate of adult animals	%	6%	6%	5%	7%	7%	4%	6%	6%	5%
Death rate of young females	%	9%	9%	7%	10%	10%	6%	9%	9%	7%
Death rate of young males	%	9%	9%	7%	10%	10%	6%	9%	9%	7%
Fertility rate (adult female)	%	60%	60%	64%	60%	60%	64%	59%	59%	64%
Live weight (Adult Females)	kg	350	350	348.275	322	322	355.005	322	322	355.005
Live weight (Adult Males)	kg	350	350	348.275	322	322	355.005	322	322	355.005
Live weight of animal at slaughter (Meat Females)	kg	204	204	221	204	204	225	204	204	225
Live weight of animal at slaughter (Meat Males)	kg	204	204	221	204	204	225	204	204	225
Milk fat content	%	4	4	4	4	4	4	4	4	4
Milk protein content	%	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Milk Yield	kg	720	720	1019.24	400	400	546	270	270	356

Number of animals (Adult Females)	#	82408	127379	100077	211,503	267,146	257,176	15,762	19,393	18,951
Number of animals (Adult Males)	#	13862	21426	16834	13,221	16,699	16,076	708	872	852
Replacement rate of adult females	%	13%	13%	13%	13%	13%	13%	13%	13%	13%
Weight at birth	kg	21.5	21.5	25.8	21.5	21.5	25.8	21.5	21.5	25.8

Table 4: Feed parameters used in GLEAM-I for Uganda

Systems	Assumptions for feed parameters
Small scale intensive system -cross breed	Better feed by increasing the proportion of concentrate in the diet for adult females reducing the proportion of crop residues, and incorporating legumes to improve the feed basket: - Increase of the proportion of dry by-product from grain industries (brans of maize, wheat, and rice) from 2% in WOP to 10% in WP; -Increase of the proportion of fresh mixture of grass + legumes from 9 to 19% and the hay or silage from grass and legumes from 5 to 15% in WOP to WP; - Decrease of the proportion of crop residues from maize, millet, rice, sorghum, sugarcane, wheat, and other grains from 36% in WOP to 16% in WP.
Small scale intensive system -cross & exotic breed	Better feed by increasing the proportion of concentrate in the diet for adult females reducing the proportion of crop residues, and incorporating legumes to improve the feed basket: - Increase of the proportion of dry by-product from grain industries (brans of maize, wheat, and rice) from 2% in WOP to 10% in WP; -Increase of the proportion of fresh mixture of grass + legumes from 9 to 19% and the hay or silage from grass and legumes from 5 to 15% in WOP and WP; - Decrease of the proportion of crop residues from maize, millet, rice, sorghum, sugarcane, wheat, and other grains from 36% in WOP to 16% in WP.
Semi-intensive system - Local breed	Better access to pasture improving the feed basket by incorporating more legumes from pasture in the diet, reducing the proportion of crop residues and fresh grass: -Increase of the proportion of fresh mixture of grass + legumes from 9 to 19% and the hay or silage from grass and legumes from 5 to 15% in WOP and WP situations, reducing the proportion of crop residues of 15% and fresh grass of 5%.
Agro-pastoral systems - Local breed	Better access to pasture improving the feed basket of adult females and meat animals (non-feedlot) by incorporating more legumes in the diet, reducing the proportion of crop residues, fresh grass, and hay from adjacent area: -Increase of the proportion of fresh mixture of grass + legumes from 5 to 25% -Decrease of the proportion of crop residues from 26% to 14%, fresh grass from 60 to 55%, and hay from adjacent area from 5% to 2%
Pastoral mix systems - Local breed	Better access to pasture improving the feed basket of adult females and meat animals (non-feedlot) by incorporating more legumes in the diet, reducing the proportion of fresh grass, and hay from adjacent area: -Increase of the proportion of fresh mixture of grass + legumes from 2 to 27% -Decrease of the proportion of fresh grass from 90 to 70%, and hay from adjacent area from 4% to 1%

Tanzania

The analysis considered three production systems as defined and conducted with LSIPT:

- Small-scale commercial system – crossbreed
- Traditional system - local breed
- Traditional system - cross breed

Grassland and mixed production systems are oriented for milk production. The project will support the access to better animal health care services, vaccination campaigns, better access to veterinary services and medicines. The project interventions will also improve the access and better results of artificial Insemination. The herd growth in the WP scenario was assumed to be slightly lower than for WOP due to the improvements in productivity from DaIMA interventions.

The project will also support the access to better feed, such as concentrates for the small-scale commercial system, and better access to pasture increasing the proportion of fresh mixture of grass and legumes, and hay or silage from grass and legumes in the diet for all the other systems.

Biogas units will be implemented in the small-scale commercial system assuming that 14% of manure initially managed in solid storage will be used for biogas production.

The assumptions for herd and feed parameters for the WP scenario compared to the WOP were aligned with analysis conducted with LSIPT and presented in *Table 5* and *Table 6*.

Table 5: Herd parameters used in GLEAM-I for Tanzania

		Small-scale commercial - crossbreed			**Traditional local breed**			**Traditional cross breed**		
Parameter	**Unit**	Baseline	WOP	WP	Baseline	WOP	WP	Baseline	WOP	WP
Age at the first parturition	months	39	39	39	45	45	40	45	45	38
Death rate of adult animals	%	4	4	3	6	6	5	6	6	5
Death rate of young females	%	4	4	3	6	6	5	6	6	5
Death rate of young males	%	4	4	3	6	6	5	6	6	5
Fertility rate (adult female)	%	65	65	68	55	55	57	55	55	65
Live weight (Adult Females)	kg	250	250	276	200	200	221	200	200	252
Live weight (Adult Males)	kg	350	350	386	350	350	386	350	350	386
Live weight of animal at slaughter	kg	146	146	161	146	146	161	146	146	184

(Meat Females)										
Live weight of animal at slaughter (Meat Males)	kg	263	263	290	263	263	290	263	263	290
Milk fat content	%	4	4	4	4	4	4	4	4	4
Milk protein content	%	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Milk Yield	kg	1925	1925	2502.5	315	315	459.8	684	684	1014
Number of animals (Adult Females)	#	18451	25,560	23,319	246,828	308,456	299,883	21,463	26,822	26,671
Number of animals (Adult Males)	#	3469	4,806	4,384	83,205	103,980	101,090	7,235	9,041	8,990
Replacement rate of adult females	%	12%	12%	12%	13%	13%	11%	13%	13%	10%
Weight at birth	kg	73	73	80	73	73	80	73	73	92

Table 6: Feed parameters used in GLEAM-I for Tanzania

LPS	Assumptions for feed parameters
Small-scale commercial - crossbreed	Better feed by increasing the proportion of concentrate in the diet for adult females and incorporating legumes to improve the feed basket, reducing the proportion of crop residues and forage of less quality in the diet - Increase of the proportion of dry by-product from grain industries (brans of maize, wheat, and rice) from 5% in WOP to 10% in WP; -Integrating 10% of fresh mixture of grass + legumes and 10% of silage from grass and legumes in the diet of adult females and replacement animals in the WP situation; - Decrease of the proportion of crop residues from maize and rice, as well as the fresh grass of less quality.
Traditional local breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 15% of fresh mixture of grass + legumes and 10% of hay or silage from grass and legumes in the diet in the WP situation.
Traditional cross breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 20% of fresh mixture of grass + legumes and 10% of hay or silage from grass and legumes in the diet in the WP situation.

Kenya

The analysis considered four production systems as defined and conducted with LSIPT:

- Small scale intensive system - Cross and exotic breeds
- Semi-intensive system - Cross breed
- Semi-intensive system -Local breed
- Extensive system: Local breed

Grassland and mixed production systems are oriented for milk production. The project will support the access to better animal health care services, vaccination campaigns, better access to veterinary services and medicines. The project interventions will also improve the access and better results of artificial Insemination. The herd growth in the WP scenario was assumed to be slightly lower than for WOP due to the improvements in productivity from DaIMA interventions.

The project will also support the access to better feed, such as concentrates for the small-scale intensive system, and better access to pasture increasing the proportion of fresh mixture of grass and legumes, and hay or silage from grass and legumes in the diet for all the other systems.

Biogas units will be implemented in the small-scale intensive system assuming that 5% of manure initially managed in solid storage will be used for biogas production.

The assumptions for herd and feed parameters for the WP scenario compared to the WOP were aligned with analysis conducted with LSIPT and presented in *Table 7*, *Table 8*, and *Table 9*.

Table 7: Herd parameters for small scale intensive and semi-intensive cross breed systems - Kenya

		Small scale intensive - cross breed			**Semi-intensive system - cross breed**		
		Baseline	WOP	WP	Baseline	WOP	WP
Herd Module							
Age at the first parturition	months	32.4	32.4	30	32	32	30
Death rate of adult animals	%	6	6	5	7	7	6
Death rate of young females	%	7	7	6	7	7	6
Death rate of young males	%	7	7	6	7	7	6
Fertility rate (adult female)	%	75	75	79	60	60	62
Live weight (Adult Females)	kg	366	366	436	261	261	295
Live weight (Adult Males)	kg	310	310	369	241	241	311
Live weight of animal at slaughter (Meat Females)	kg	182	182	217	139	139	155
Live weight of animal at slaughter (Meat Males)	kg	146	146	174	163	163	180
Milk fat content	%	4.033	4.033	4.033	4.1425	4.1425	4.1425

Milk protein content	%	3.341	3.341	3.341	3.185	3.185	3.185
Milk Yield	kg	2043.5	2043.5	2684	762.5	762.5	1494.5
Number of animals (Adult Females)	#	120667	154809	145778	154120	205738	183826
Number of animals (Adult Males)	#	13823	23063	21718	18874	25182	22500
Replacement rate of adult females	%	12%	12%	10%	13%	13%	10%
Weight at birth	kg	29	29	35	21	21	24

Table 8: Herd parameters for semi-intensive and extensive local breed - Kenya

		Semi-intensive- Local breed			**Extensive Local breed**		
		Baseline	WOP	WP	Baseline	WOP	WP
Herd Module							
Age at the first parturition	months	42	42	37.8	45.6	45.6	36.48
Death rate of adult animals	%	7	7	6	10	10	8
Death rate of young females	%	7	7	6	11	11	7
Death rate of young males	%	7	7	6	11	11	7
Fertility rate (adult female)	%	60	60	62	60	60	62
Live weight (Adult Females)	kg	261	261	285	259	259	283
Live weight (Adult Males)	kg	256	256	280	241	241	264
Live weight of animal at slaughter (Meat Females)	kg	139	139	151	139	139	153
Live weight of animal at slaughter (Meat Males)	kg	163	163	178	164	164	181
Milk fat content	%	4.1	4.1	4.1	4.0	4.0	4.0
Milk protein content	%	3.2	3.2	3.2	3.6	3.6	3.6
Milk Yield	kg	762.5	762.5	976	324	324	378
Number of animals (Adult Females)	#	222464	299091	271300	246677	299699	296335
Number of animals (Adult Males)	#	27244	36628	33225	36545	44400	43902
Replacement rate of adult females	%	13%	13%	10%	13%	13%	10%
Weight at birth	kg	21	21	23	21	21	23

Table 9: Feed parameters used in GLEAM-I for Kenya

LPS	Assumptions for feed parameters
Small scale intensive - cross breed	Better feed by increasing the proportion of concentrate in the diet for adult females and incorporating legumes to improve the feed basket, reducing the proportion of crop residues and forage of less quality in the diet -5 % Increase of the proportion of dry by-product from grain industries (brans of maize, wheat, and rice) in WP compared to the WOP -20% increase of fresh mixture of grass + legumes and 15% of hay or silage from grass and legumes in the diet of adult females and replacement animals in the WP situation; - Decrease of the proportion of crop residues from maize as well as the fresh grass of less quality.
Semi-intensive system - cross breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 25% of fresh mixture of grass + legumes and 20% of hay or silage from grass and legumes in the diet in the WP situation.
Semi-intensive-Local breed	-Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 15% of fresh mixture of grass + legumes and 10% of hay or silage from grass and legumes in the diet in the WP situation.
Extensive Local breed	-Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 25% of fresh mixture of grass + legumes in the diet in the WP situation.

Rwanda

The analysis considered five production systems as defined and conducted with LSIPT:

- Zero grazing system - cross breed
- Zero grazing system - exotic breed
- Semi-grazing system - cross breed
- Semi-grazing system - local breed
- Grazing system - local breed

Grassland and mixed production systems are oriented for milk production. The project will support the access to better animal health care services, vaccination campaigns, better access to veterinary services and medicines. The project interventions will also improve the access and better results of artificial Insemination. The herd growth in the WP scenario was assumed to be slightly lower than for WOP due to the improvements in productivity from DaIMA interventions.

The project will also support the access to better feed and concentrates for zero-grazing systems (cross breed and exotic cows), and access to improved pasture increasing the proportion of fresh mixture of grass and legumes, and hay or silage from grass and legumes in the diet for all the different production systems.

Biogas units will be implemented in the small-scale intensive system assuming that 10% of manure initially managed in solid storage will be used for biogas production.

The assumptions for herd and feed parameters for the WP scenario compared to the WOP were aligned with analysis conducted with LSIPT and presented in *Table 10*, *Table 11*, *Table 12*, and *Table 13*.

Table 10: Herd parameters for local breed cattle in Rwanda

		Grazing system - local breed			Semi-grazing system - local breed		
Parameters	**Unit**	**Baseline**	**WOP**	**WP**	**Baseline**	**WOP**	**WP**
Age at the first parturition	months	34	34	30	34	34	30
Death rate of adult animals	%	6	6	5	6	6	5
Death rate of young females	%	9	9	6	9	9	6
Death rate of young males	%	9	9	6	9	9	6
Fertility rate (adult female)	%	60	60	63	63	63	70
Live weight (Adult Females)	kg	300	300	330	300	300	330
Live weight (Adult Males)	kg	350	350	386	350	350	386
Live weight of animal at slaughter (Meat Females)	kg	195	195	215	195	195	215
Live weight of animal at slaughter (Meat Males)	kg	231	231	254	231	231	254
Milk fat content	%	3.24	3.24	3.24	3.24	3.24	3.24
Milk protein content	%	3.56	3.56	3.56	3.56	3.56	3.56
Milk Yield	kg	361	361	440	483	483	598
Number of animals (Adult Females)	#	1311	1632	1581	2563	3306	3125
Number of animals (Adult Males)	#	33	42	40	65	84	80
Replacement rate of adult females	%	13%	13%	10%	13%	13%	10%
Weight at birth	kg	25	25	30	25	25	30

Table 11: Herd parameters for cross breed cattle in Rwanda

		Semi-grazing system cross breed			Zero grazing system cross breed		
Parameters	**Unit**	**Baseline**	**WOP**	**WP**	**Baseline**	**WOP**	**WP**
Age at the first parturition	months	32	32	30	32	32	30
Death rate of adult animals	%	6	6	5	6	6	5
Death rate of young females	%	9	9	6	9	9	6
Death rate of young males	%	9	9	6	9	9	6
Fertility rate (adult female)	%	63	63	70	70	70	77
Live weight (Adult Females)	kg	300	300	345	300	300	345
Live weight (Adult Males)	kg	350	350	403	350	350	403
Live weight of animal at	kg	195	195	224	195	195	224

slaughter (Meat Females)							
Live weight of animal at slaughter (Meat Males)	kg	231	231	266	231	231	266
Milk fat content	%	3.24	3.24	3.24	3.24	3.24	3.24
Milk protein content	%	3.56	3.56	3.56	3.56	3.56	3.56
Milk Yield	kg	483	483	850	483	483	850
Number of animals (Adult Females)	#	4,700	6,064	5,689	116,176	156,638	138,391
Number of animals (Adult Males)	#	157	203	190	3,896	5,248	4,637
Replacement rate of adult females	%	13%	13%	10%	12%	12%	10%
Weight at birth	kg	30	30	35	30	30	35

Table 12: Herd parameters for exotic breed cattle in Rwanda

		Zero grazing system exotic breed		
Parameters	**Unit**	**Baseline**	**WOP**	**WP**
Age at the first parturition	months	32	32	30
Death rate of adult animals	%	6	6	5
Death rate of young females	%	9	9	6
Death rate of young males	%	9	9	6
Fertility rate (adult female)	%	70	70	77
Live weight (Adult Females)	kg	300	300	384
Live weight (Adult Males)	kg	350	350	448
Live weight of animal at slaughter (Meat Females)	kg	195	195	250
Live weight of animal at slaughter (Meat Males)	kg	231	231	296
Milk fat content	%	3.24	3.24	3.24
Milk protein content	%	3.56	3.56	3.56
Milk Yield	kg	483	483	1764
Number of animals (Adult Females)	#	13,678	18,082	16,806
Number of animals (Adult Males)	#	328	433	402
Replacement rate of adult females	%	12%	12%	10%
Weight at birth	kg	30	30	35

Table 13: Feed parameters used in GLEAM-I for Rwanda

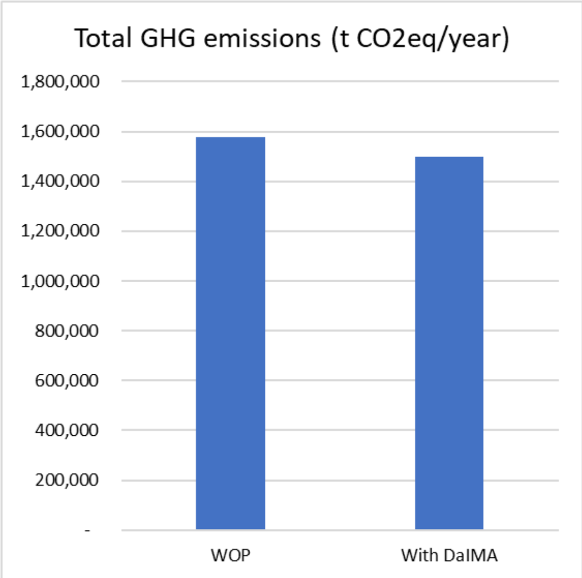
LPS	Assumptions for feed parameters
Zero grazing system - exotic breed	Better feed by increasing the proportion of concentrate in the diet and incorporating legumes to improve the feed basket, reducing the proportion of crop residues and forage of less quality -Increase of 5 % of dry by-product from grain industries (brans of maize, wheat, and rice), 3% of grains and 2% of maize in WP compared to the WOP. -20% increase of fresh mixture of grass + legumes and 15% of hay or silage from grass and legumes in the diet of adult females and replacement animals in the WP situation; - Decrease of the proportion of crop residues from maize, sorghum, millet and other grains, and reduction of the proportion of the fresh grass of low quality.
Zero grazing system - cross breed	Better feed by increasing the proportion of concentrate in the diet and incorporating legumes to improve the feed basket, reducing the proportion of crop residues and forage of less quality -Increase of 5 % of dry by-product from grain industries (brans of maize, wheat, and rice), 2% of grains and 1% of maize in WP compared to the WOP. -20% increase of fresh mixture of grass + legumes and 15% of hay or silage from grass and legumes in the diet of adult females and replacement animals in the WP situation; - Decrease of the proportion of crop residues from maize, sorghum, millet and other grains, and reduction of the proportion of the fresh grass of low quality.
Semi-grazing system - cross breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 30% of fresh mixture of grass + legumes and 15% of hay or silage from grass and legumes in the diet in the WP situation.
Semi-grazing system - local breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Increasing 15% of fresh mixture of grass + legumes and 10% of hay or silage from grass and legumes in the diet in the WP situation.
Grazing system - local breed	Better access to pasture improving the feed basket by incorporating more legumes in the diet, reducing the proportion of crop residues and fresh grass of low quality -Integrating 30% of fresh mixture of grass + legumes

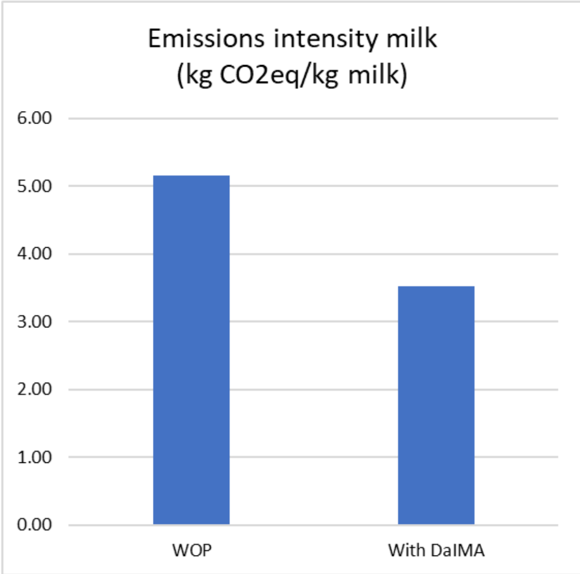
C. Results for GHG emission assessments

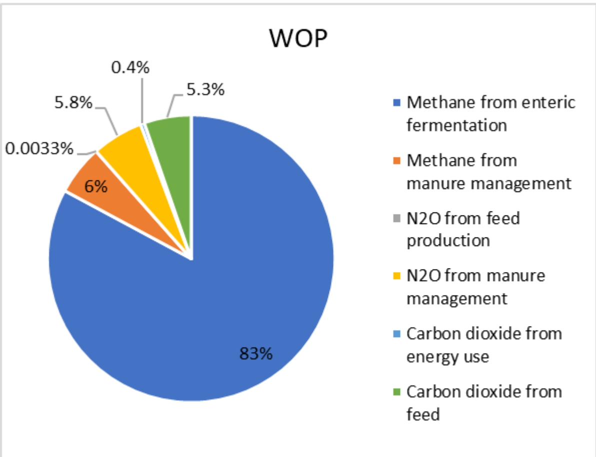
Uganda

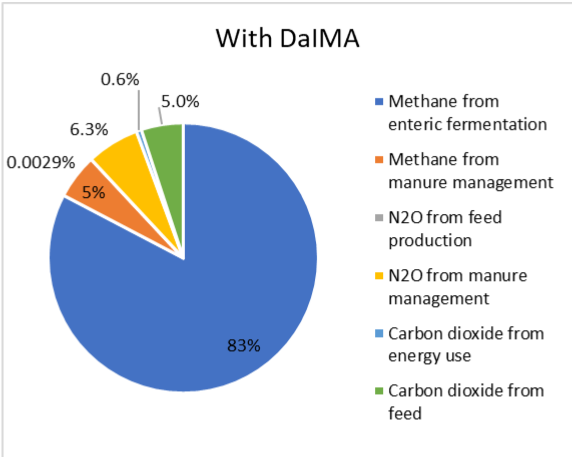
In Uganda, there is a reduction in total GHG emissions by 5.22 % (-82,372 tCO2-eq) in the 20 years and annual decrease of 4,118 tCO2-eq. The enteric methane emissions are expected to decrease by 5.4% with DaIMA compared to the situation without the project. Methane (CH_4) emissions from manure management and carbon dioxide (CO_2) emissions from energy use along the supply chain are projected to decrease by 9.46% and 6.8%, respectively. The nitrous oxide (N_2O) emissions are expected to rise by 3.12% over 20 years due to the increased use of concentrates and enriched protein diet, which contribute to higher N_2O emissions from feed supply chain and manure.

The project interventions improving herd and feed parameters led to an increase in milk production by 30% and a reduction in milk emission intensities by 31.76%. The total feed intake is expected to decrease by 4.62% in the situation with the project.







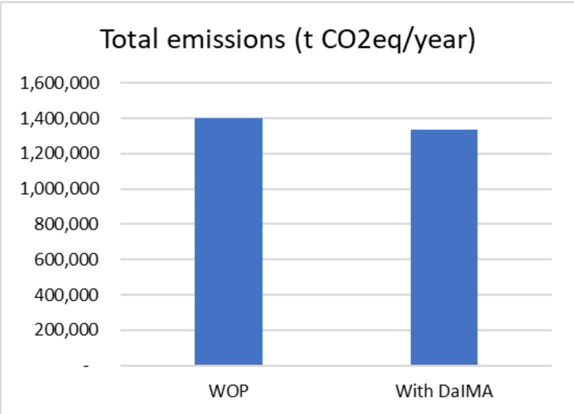


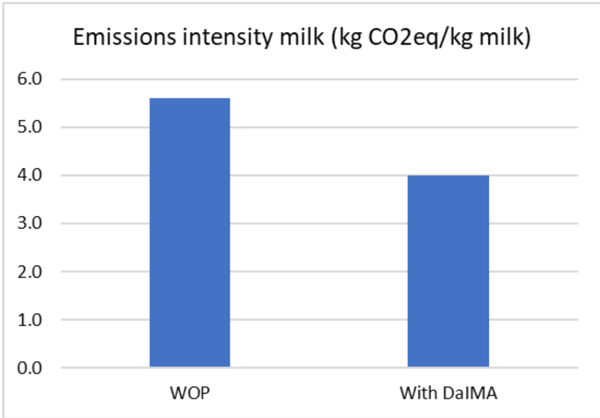
GHG emissions in tCO2 equivalence	**Baseline**	**WOP**	**With DalMA**	**% change**
CH4 from enteric fermentation	976,324	1,308,245	1,237,587	-5.40%
CH4 from manure management	66,309	88,820	80,419	-9.46%
N2O Emissions	68,285	91,426	94,282	3.12%
CO2 Emissions	66,458	90,751	84,581	-6.80%

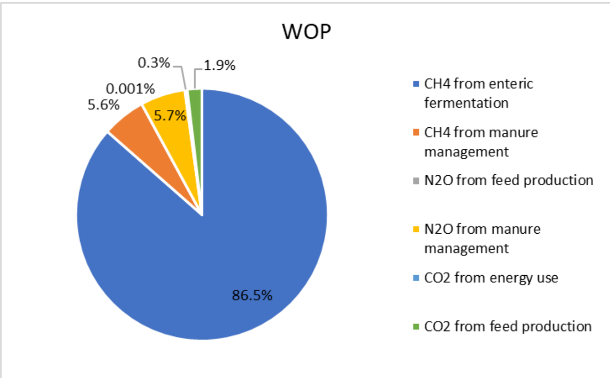
Total GHG emissions	1,177,377	1,579,242	1,496,870	-5.22%

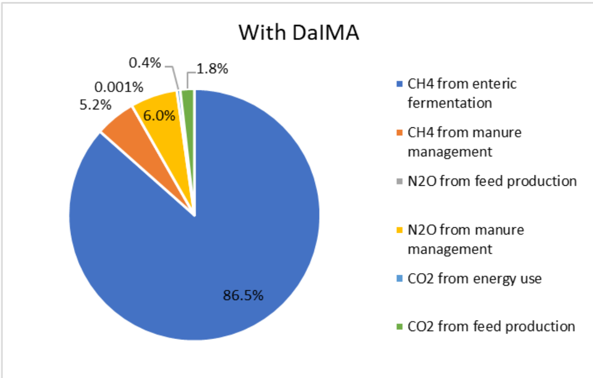
Tanzania

In Tanzania, there is a reduction in total GHG emissions by 4.7 % (-65,718 tCO_2-eq) in the 20 years and annual decrease of 3,286 tCO_2-eq. The enteric methane emissions are expected to decrease by 4.62% with DalMA compared to the situation without the project. The project interventions improving the herd and feed parameters led to an increase in milk production by 36% and a reduction in milk emission intensities by 28.9%. The total feed intake is expected to decrease by 4.85% in the situation with the project.







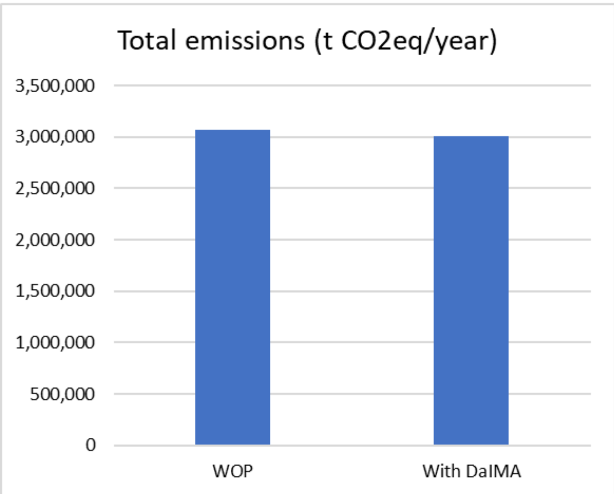


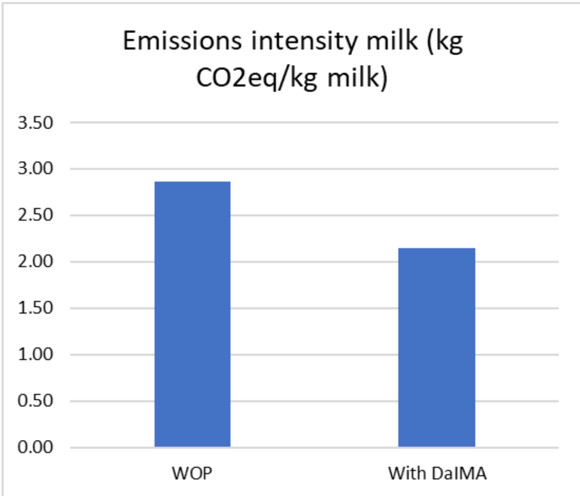
GHG emissions in tCO2 equivalence	Baseline	WOP	With DalMA	% change
CH4 from enteric fermentation	962,848	1,211,516	1,155,568	-4.62%
CH4 from manure management	62,215	78,228	69,431	-11.25%
N2O Emissions	64,022	80,491	80,394	-0.12%
CO2 Emissions	24,170	30,750	29,873	-2.85%

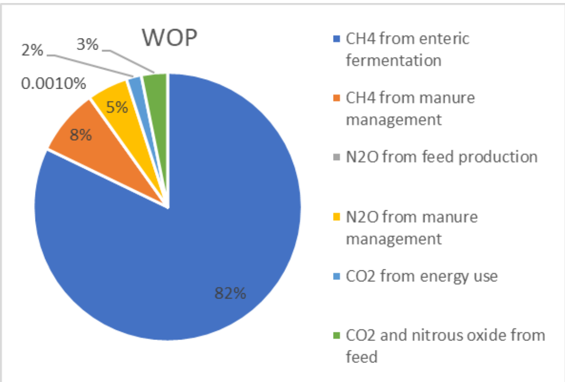
Total GHG emissions	1,113,255	1,400,985	1,335,267	-4.69%

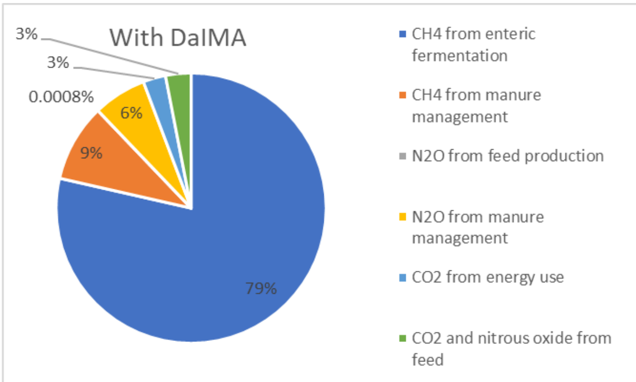
Kenya

In Kenya, there is a reduction in total GHG emissions by 2.02 % (-61,967 tCO2-eq) in the 20 years and annual decrease of 3,098 tCO2-eq. The enteric methane emissions are expected to decrease by 2.88% with DalMA compared to the situation without the project. The project interventions improving the herd and feed parameters led to an increase in milk production by 31% and a reduction in milk emission intensities by 24.94%. The total feed intake is expected to decrease by 2.42% in the situation with the project. The emission of CH_4 from manure and CO_2 from energy use along the supply chain are projected to decrease by 1.75% and 2.19%, respectively. The nitrous oxide (N_2O) emissions are expected to rise by 9.76% over 20 years due to the increased use of concentrates in the diet and enriched protein diet, which contribute to higher N_2O emissions from feed supply chain and manure management.









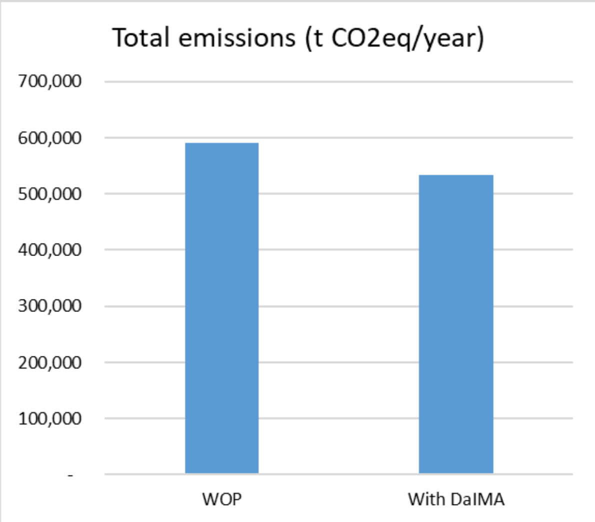
GHG emissions in tCO2 equivalence	**Baseline**	**WOP**	**With DalMA**	**% change**
CH4 from enteric fermentation	1,881,222	2,432,743	2,362,573	-2.88%

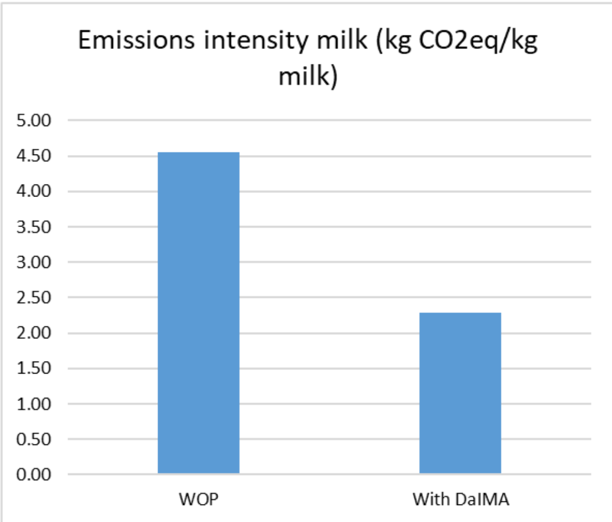
CH4 from manure management	218,460	284,651	279,671	-1.75%
N2O Emissions	135,030	174,932	192,001	9.76%
CO2 Emissions	135,124	177,157	173,272	-2.19%
Total GHG emissions	2,369,835	3,069,483	3,007,516	-2.02%

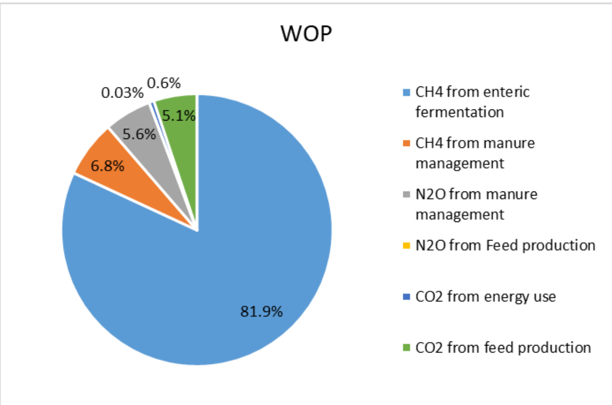
Rwanda

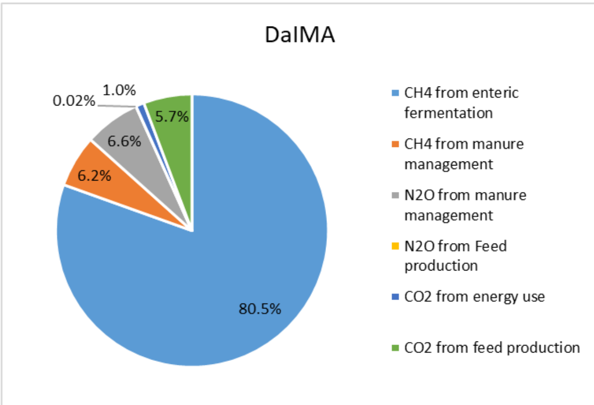
In Rwanda, there is a reduction in total GHG emissions by 9.56 % (-56,506 tCO2-eq) in the 20 years and annual decrease of 2,825 tCO2-eq. The enteric methane emissions are expected to decrease by 11.14% with DalMA compared to the situation without the project. The increase proportion of concentrates in the animal diet will result in the increase of N_2O emissions from feed supply chain and manure, as well as the CO_2 emissions from fossil energy use in the supply chain.

The project interventions improving the herd and feed parameters led to an increase in milk production by 72% and a reduction in milk emission intensities by 49%. The total feed intake is expected to decrease by 12% in the situation with the project.









GHG emissions in tCO2 equivalnce	**Baseline**	**WOP**	**With DalMA**	**% change**

CH4 from enteric fermentation	360,565	483,851	429,944	-11.14%
CH4 from manure management	29,812	39,893	32,914	-17.49%
N2O Emissions	24,902	33,409	35,498	6.25%
CO2 Emissions	25,040	33,666	35,955	6.80%
Total GHG emissions	440,319	590,818	534,311	-9.56%

D. Methodology and results for soil carbon sequestration assessment in improved and rehabilitated pastures and rangelands

Methodology. The estimation of the area of rangeland to be rehabilitated was based on the annual amount of biomass (fresh mixture and hay or silage of grass and legumes) required to meet the animal feed intake for improved diet in the situation with the project. The calculation considered the biomass yields of natural rangelands and improved pastures in East Africa context. Tessema and Emojong (2004), and Mwangi et al. (2015) estimated the average biomass yield of natural rangelands at 2.147 tDM/ha. Depending on the types of rehabilitation and improved practices implemented, the biomass yield can reach 5 to 10 tDM/ha. Improved practices include reseeding and integration of legumes with grasses in natural pastures, such as glycine *(Neonotonia wightii*), siratro (*Macroptilium atropurpureum*), dolichos (*Lablab purpureus* cv. Rongai), velvet bean (*Mucuna pruriens*) and shrubby stylo (*Stylosanthes scabr*a cv. seca), fertilization, and grazing management to improve the quality and quantity (seasonal availability) of natural pastures (Macharia et al., 2010; Koech et al., 2016). The total area for rehabilitation is estimated at 178,362 ha for the DaIMA project (Table 14**Error! Reference source not found.**).

The carbon sequestered in pasture and rangeland soils was estimated based on the increased carbon input returned into the soil as the result of biomass yield increase after the implementation of improved management practices under the project. The increase in biomass yield is attributed to interventions under the project, such as adopting better grazing practices, integration of legumes and soil management techniques. A detailed literature review specific to East Africa was conducted to estimate biomass yield improvements resulting from various management practices. This regionalized approach ensures that the method accounts for the unique environmental and ecological conditions of East African rangelands. Soil carbon inputs are estimated using below-ground biomass contributions (e.g., roots) and their root-to-shoot ratios based on studies like Snyman (2005). IPCC (Intergovernmental Panel on Climate Change) coefficients are applied to convert biomass into carbon values, ensuring consistency with global standards. The feasibility study on pasture and rangeland rehabilitation carried out for the design of the funding proposal provided average values on soil carbon sequestration potential of pasture and rangeland for each country if improved practices are implemented and degraded rangelands are properly restored. The same study provided a literature review on the main improved practices adapted to East Africa and was used as reference to this analysis to advance in the literature review and link with potential increase in biomass yield under improved managements and practices.

Results: under the project situation, it was estimated an average soil C sequestration of 0.1tC/ha/year, representing 18 to 20% of the potential of soil carbon sequestration in pasture and rangeland soils while around 0.04tC/ha/year in the without project situation.

Over the 20-year capitalization period of the project, the carbon sequestered in rehabilitated rangeland soils is expected to be 222,058 tC or 814,214 tCO2 eq. compared to the without project situation (average annual increase of 11,103 tC or 40,711 tCO2 eq.) (cf. Table 14).

Table 14: Proposed area of rehabilitation and soil organic carbon sequestration

		WOP		**With DalMA**		**Difference DalMA - WOP**	
Country	Area for rehabilitation (ha)	Soil carbon sequestered in tC (20 years)	Soil carbon sequestered in tCO2 eq. (20 years)	Soil carbon sequestered in tC (20 years)	Soil carbon sequestered in tCO2 eq. (20 years)	Soil carbon sequestered in tC (20 years)	Soil carbon sequestered in tCO2 eq. (20 years)
Rwanda	51,773	42,268	154,984	106,725	391,325	64,457	236,341
Uganda	27,443	22,405	82,151	56,571	207,427	34,166	125,276
Tanzania	46,758	38,174	139,971	96,387	353,419	58,213	213,448
Kenya	52,388	42,770	156,825	107,993	395,974	65,222	239,149
DalMA	178,362	145,618	533,931	367,676	1,348,146	222,058	814,214

Monitoring process.
For the monitoring of rangeland restoration interventions, M&E activities will include:

- On site ground-truthing. It will consist in collecting data at site level where rangeland restoration activities were implemented. Data to be collected will include: (i) GPS coordinates of rangelands under intervention, and areas of rangelands where improved practices were implemented, (ii) surveys on species composition and improved biomass yield, (iii) the type of improved grazing management applied at the community level (rotational grazing, agroforestry, improved pasture management, management of grazing intensity etc.). Additional information includes (iv) the quantity and type of legume seeds used, date of planting or reseeding. Ground truthing will be under the responsibility of the PCU M&E experts at local level (county/ district-coordination levels);
- Combined with on-site ground truthing, remote sensing analysis will be carried out, through high resolution satellite images (using e.g. normalized difference vegetation index - NDVI) to monitor the rangelands under restoration. Remote sensing analysis will be under the responsibility of the M&E/GIS experts in the PCU.
- Data will be collected through the M&E system, in particular through surveys (baseline at project start, mid-term at year 3, and impact at year 6) and stored in the MIS.

For monitoring soil carbon sequestration in areas under rehabilitation, M&E activities will include:

- Performing modeling for estimating the impact of management practices. Using baseline information on soil carbon stocks, soil texture, carbon inputs from vegetation and manure, as well as climate (all collected through the baseline survey), process-based models (e.g. RothC) will be employed. Other Tier 2 methodologies using IPCC default equations could be considered, such as the FAO Ex-ACT (Environmental Externalities Accounting Tool). Modeling will be under the direct responsibility of the Environment and Climate Change Experts in each PCU;
- The M&E team will also leverage data from the MRV systems enhanced under output 1.3. Tier 2 data generated from the MRV system will be used to estimate sequestration in each country, based on the hectares of rangelands restored. Estimations will rely on Tier 2 sequestration factors generated under sub-activity 1.3.1.1 (e.g. flux towers such as Eddy Covariance Towers – see FS for more details). The Environment and Climate Change Experts in each PCU will be collecting these data.

E. Methodology and results for calculating impact from energy generation and access

Defined System Boundaries. The methodology began by establishing the system boundaries of the project, focusing on the substitution of grid electricity and diesel electricity with biogas-generated electricity and solar photovoltaic (PV) systems.

Data Collection. Data was gathered first from the number of units and their respective capacities, that will be financed by the project in each country.

Analyzed Technical Specifications. Technical data sheets for relevant equipment, such as coolers, pasteurization units, biodigesters, and gas engines was reviewed. Details on capacities, efficiencies, and other technical data necessary for the calculations were captured.

Calculated Electricity Consumption. Utilizing the collected data, the grid electricity displaced in milk collection centers and processing units was computed. From this, the electricity displaced and calculated emission savings was estimated, under three possible scenarios: (i) Scenario 1: Grid electricity substitution, (ii) Scenario 2: Diesel electricity substitution and (iii) Scenario 3: Grid/diesel electricity substitution, according to each country grid electricity access shares. These calculations involved the use of a grid electricity emission factor per country, diesel emission factor and on-grid electricity access shares. Emission factors (e.g. country electricity EF) and technical data were derived from CDM-approved sources (UNFCCC, 2021) and other authoritative references, such as the FAO (2017), World Bank (2022), and peer-reviewed scientific journals (Rotich, I.K., Chepkirui, H. & Musyimi, P.K. 2024).

Estimated Biogas Production and generated electricity. Technical information and yield data from technical sheets was used to estimate biogas production. The conversion of biogas to electricity via gas engines was assessed, which allowed for further calculations of electricity displaced.

Aggregated Annual Emission Savings. The annual emission savings from all interventions for all three scenarios were combined to obtain the annual emission savings per country, and total annual saving per country, i.e. (i) Intervention 1: Solar power for milk collection centers, (ii) Intervention 2: Solar energy for processing units, and (iii) Intervention 3: Biogas to electricity.

Results. Results for scenario 3 are summarized below:

Table 16: Emission savings per year from various RE-powered technologies

Parameter	Unit	Tanzania	Uganda	Rwanda	Kenya	Total
Solar powered MCC	tCO2eq/yr	613	734	383	242	1,971
Solar powered Processing units	tCO2eq/yr	1,404	9,412	4,910	3,101	18,828
Biogas to electricity	tCO2eq/yr	10,598	19,026	529	3,483	33,636
Total annual savings	tCO2eq/yr	12,615	29,171	5,823	6,826	54,435

To obtain the values needed to fill the GCF MRA 1 indicator. it was necessary to convert the emission savings to net savings by computing them over three (mid-term), six (end of Programme), and twenty years (end of total lifespan period) to showcase results across the four countries. Over the 20 years, the total annual emissions savings is 1,088,705 tCO2eq. The obtained for scenario 3 results are summarized as follows:

Table 17: emission savings over 3, 6 and 20 years

Parameter	Unit D	Tanzania	Uganda	Rwanda	Kenya	Total
Total Savings mid-term (after 3 years)	tCO2eq (3-years)	37,846	87,514	17,468	20,478	163,306
Total Savings final (after 6 years)	tCO2eq (6-years)	75,692	175,028	34,936	40,956	326,612
Total Savings lifetime (after 20 years)	tCO2eq (20-years)	252,305	583,426	116,453	136,520	1,088,705

Bibliography used for the calculation is detailed below and in the Excel file with calculations.

References

For GLEAM-i and soil carbon sequestration analysis:

1. A.H. Kassam, H.T. van Velthuizen, P.H. Sloane, G.W. Fischer and M.M. Shah 1991. Agro-ecological land resources assessment for agricultural development planning-a case study of Kenya Resources data base and land productivity. Technical annex 5. Livestock productivity. Accessed from https://www.fao.org/3/t0828e/T0828E00.htm#TOC
2. FAO. 2017. Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome.
3. Macharia, P. N., Kinyamario, J. I., Ekaya, W. N., Gachene, C. K. K., Mureithi, J. G., & Thuranira, E. G. (2010). Evaluation of forage legumes for introduction into natural pastures of semi-arid rangelands of Kenya. *Grass and Forage Science*, *65*(4), 456-462.
4. MacLeod, M.J., Vellinga, T., Opio, C., Falcucci, A., Tempio, G., Henderson, B., Makkar, H., Mottet, A., Robinson, T., Steinfeld, H. and Gerber, P.J., 2018. Invited review: a position on the global livestock environmental assessment model (GLEAM). animal, 12(2), pp.383-397.
5. Mwangi, D. M. (2015). Grassland and Livestock Production: The East African Case. International Grassland Congress Proceedings
6. Selemani, I. S., Eik, L. O., Holand, Ø., Ådnøy, T., Mtengeti, E., & Mushi, D. (2013). The effects of a deferred grazing system on rangeland vegetation in a north-western, semi-arid region of Tanzania. African Journal of Range & Forage Science, 30(3), 141–148. https://doi.org/10.2989/10220119.2013.827739
7. Snyman, H. A. (2005). Rangeland degradation in a semi-arid South Africa—I: influence on seasonal root distribution, root/shoot ratios and water-use efficiency. *Journal of Arid Environments*, *60*(3), 457-481.

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8. Cecchinato, L., Corradi, M., & Minetto, S. (2010). Energy performance of supermarket refrigeration and air conditioning integrated systems. *Applied Thermal Engineering*. https://doi.org/10.1016/j.applthermaleng.2010.04.019
9. United Nations Climate Change. 2021. IFI TWG - List of methodologies List of harmonized GHG accounting standards/approaches and guidelines developed. Available at: https://unfccc.int/climate-action/sectoral-engagement/ifis-harmonization-of-standards-for-ghg-accounting/ifi-twg-list-of-methodologies. Accessed 14 January 2025.
10. IEA. 2024. An introduction to biogas and biomethane – outlook for biogas and biomethane: Prospects for organic growth – analysis. Available at: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane. Accessed 14 January 2025.
11. World Bank Group. 2022. New Ida Financing to add one million connections to the electricity grid in Tanzania. Available at: https://www.worldbank.org/en/news/press-release/2022/09/26/new-ida-financing-to-add-one-million-connections-to-the-electricity-grid-in-tanzania#:~:text=Despite%20Tanzania's%20impressive%20progress%20in,%2Fconnectivity%20rate%20(38%25). Accessed 15 January 2025.
12. International Trade Organization. 2024. Uganda - Energy. Available at: https://www.trade.gov/country-commercial-guides/uganda-energy#:~:text=In%20urban%20areas%2C%2057.2%25%20of,will%20not%20renew%20the%20concession. Accessed 15 January 2025.
13. Rwanda Electricity Group. 2024. Rwanda on-grid electricity access. Available at: https://www.reg.rw/what-we-do/access/ongrid/#:~:text=As%20of%20November%202024%2C%20the,over%20the%20last%2020%20years. Accessed 15 January 2025.
14. Rotich, I.K., Chepkirui, H. & Musyimi, P.K. 2024. Renewable energy status and uptake in Kenya. Energy Strategy Reviews, 54: 101453.
15. FAO GACSA, 2017, Solar-Powered Irrigation Systems: A clean-energy, low-emission option for irrigation development and modernization. https://www.fao.org/fileadmin/user_upload/gacsa/docs/GACSA_Practice_brief_SolarIrrigation_v5.pdf