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Mitigating Greenhouse Gas Emissions in Kenya's Food System

Economic Interdependencies and Policy Opportunities

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ABSTRACT

Low- and middle-income countries worldwide share the common challenge of achieving sustainable economic development while reducing greenhouse gas (GHG) emissions. This challenge is complex due to the interconnectedness of economic activities, where policies targeting one industry can have ripple effects on others. Therefore, it is crucial to understand integrated GHG emissions and their relationships across industries within an economy to inform effective policy formulation. Kenya, as a middle-income country experiencing rapid economic growth, faces an urgent need to address this challenge. This study analyzes the economic relationships between agricultural production, the food industry, and other sectors of the economy in Kenya to identify key drivers of national GHG emissions from the food system. To accomplish this, an environmentally extended input-output (EEIO) table is employed to calculate both direct and indirect emissions for 38 activities of Kenya's economy, as well as emissions embodied in final goods. Direct emissions refer to those generated during the production process of an activity, while indirect emissions are produced by other activities that provide inputs to the activity of interest. The findings reveal that agriculture is the largest contributor to GHG emissions in Kenya, with the majority of emissions stemming from direct sources such as enteric fermentation and manure management in livestock production. Additionally, the study finds that total emission intensity in the manufacturing sector is considerably higher than in most agricultural activities, except for livestock production, primarily due to the significant level of indirect emissions associated with manufacturing processes. Within the agricultural sector, cereals and livestock production exhibit high levels of direct emissions, while export crops like coffee and tea, as well as vegetable cultivation, show relatively higher indirect emissions. Addressing GHG emissions from the livestock sector emerges as a crucial step in significantly reducing agricultural emissions in Kenya. The dairy sub-sector presents an opportunity for intensification and technological advancements, as climate-smart technologies have already demonstrated their potential to enhance productivity while reducing emissions. Conversely, mitigating GHG emissions in beef production, which is primarily concentrated in ecologically fragile areas, will require institutional innovations focusing on rangeland management, disease control, and scaling up livestock marketing efforts. While the intensification of dairy production can contribute to agricultural growth and development in Kenya, its impact on mitigating GHG emissions is expected to be limited at the national scale.

Keywords: Economic development**,** Food system, Greenhouse gas emissions, Input–output analysis, Kenya, Sub-Saharan Africa.

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ACRONYMS

ASAL	Arid and Semi-Arid Lands
CSA	Climate smart agriculture
EEB	Net embodied emissions of international trade
EEC	Emissions embodied in domestic consumption, *EEC*
EEIO	Environmentally extended input-output table
EEM	Emission embodied in imports
EEP	Direct and indirect emissions from domestic production
EEX	Emissions embodied in exports
GDP	Gross domestic product
GHG	Greenhouse gas
HICs	High-income countries
KCSAP	Kenya Climate Smart Agriculture Project
LMICs	Low- and middle-income countries
NAMA	Nationally Appropriate Mitigation Action
NDMA	National Drought Management Authority
NGO	Non-governmental organization
SDL	Sustainable Dairy Landscapes
SSA	Sub-Saharan Africa

1. INTRODUCTION

Greenhouse gas (GHG) emissions are the main cause of global warming, presenting a significant and shared challenge for humanity in the 21st century. Historically, efforts to address climate change have focused on reducing emissions from high-income countries (HICs) and major middle-income economies like China and India. Currently, many HICs have already reached their peak carbon emissions by adopting cleaner energy sources, improving energy efficiency, and restructuring polluting industries (Sun et al., 2022). In the coming decades, the focus of emission reduction efforts will shift to low- and middle-income countries (LMICs) in less developed regions, including Sub-Saharan Africa (SSA).

Most SSA countries are in the early stages of economic development and urbanization, where economic growth and emissions are closely linked. On one hand, population growth, rapid economic expansion, and improving living standards have resulted in a significant energy gap, changes in consumption patterns, and increased demand for food. On the other hand, SSA countries face challenges in reducing emissions in the medium term due to limited budgets and technological capabilities compared to HICs (Pueyo, 2018; Sun et al., 2022). Therefore, it is necessary for them to develop specific low-carbon strategies, implement strong mitigation measures, and seek international support.

In this context, LMICs worldwide face common challenges of understanding the impact of climate change on the economy and finding ways to achieve sustainable economic development while reducing GHG emissions. This challenge is particularly urgent for Kenya, a middle-income country, and the largest economy in East Africa. Kenya is experiencing high economic growth while relying heavily on rainfed agriculture, tourism, and natural resources, all of which are vulnerable to climate variability, change, and extreme weather events (Sun et al., 2022). Kenya's GHG emissions have been steadily increasing, averaging 4.4 percent per year between 2001 and 2019, which is almost the same growth rate as its Gross Domestic Product (GDP) during the same period (World Bank, 2023). While industry-specific policies can effectively reduce GHG emissions, they may also increase production costs and potentially hinder economic development to varying degrees. Economic activities are interconnected, and policies targeting one industry can impact the activities of other industries. Therefore, it is crucial to understand the integrated GHG emissions and emission relationships across all industries within a socio-economic system to support policy formulation.

This paper aims to enhance understanding of the key drivers of national GHG emissions from the food system in Kenya by analyzing the economic relationships between agricultural production, the food industry, and other sectors of the economy. It also explores opportunities for GHG mitigation actions considering economic development needs.

To accomplish this goal, we have developed an ecologically extended input-output (EEIO) model that facilitates an integrated analysis of GHG emissions. The EEIO analysis offers a straightforward and robust method for assessing the relationships between economic consumption activities and their environmental impacts. This approach has been extensively employed to examine the upstream factors that drive environmental impacts downstream, particularly in terms of consumption-based drivers and the environmental consequences associated with the goods and services consumed or exported by nations. For example, Chen and Zhang (2010) composed an inventory of GHG emissions associated with an input-output analysis for the Chinese economy in 2007 to reveal the emission embodiment in final consumption and international trade. Gallardo and Mardones (2013) used information from the input–output tables, national accounts, household survey, and environmental pollutant emissions to elaborate an environmentally extended social accounting matrix for Chile to determine the effects of sectoral demand shocks on economic development. Mangır and Şahin (2022) used an environmentally extended global multi-regional input–output analysis to calculate consumption and import based embodied emissions for the year 2015 for 26 sectors of Turkey's economy. Pal et al. (2012) construct an EEIO for the Indian economy in 2006-2007 to show the interrelationships between economic activities and their impact on GHG emissions, depletion of natural resources, and to analyze direct and indirect-induced impacts of growth in sectoral output on GHG emission. A EEIO model is developed by Liu et al. (2019) to investigate integrated GHG emissions and the emission relationships of various industries applied to the case study for the Province of Saskatchewan, Canada, to illustrate the potential benefits of its use in the formulation of industrially related legislation. Su and Thomson (2016) used a time-series extended input–output dataset to analyze China's carbon emissions embodied in both normal and processing exports at a detailed 135-sector level. Finally, Wang et al. (2018) included abatement cost, emission charge and abatement benefit into an EEIO for China to estimate the environmental efficiency and assess the effects of environmental policies on economy and environment.

The study aims to demonstrate the potential advantages of utilizing the EEIO analysis to inform policy formulation. To achieve this, the study calculates both direct and indirect GHG emissions for 38 sectors, estimates emissions associated with domestic consumption (EEC), exports (EEE), and imports (EEI), and examines the effects of different activities on growth, production, and GHG emissions. The analysis results yield insights into the implications of different growth trajectories for Kenya, considering the economic and environmental challenges at hand.

The paper is organized as follows: The next section presents the methodology and the main concepts behind the EEIO table. Section 3 describes the data used and the allocation of GHG emissions from different sources to the 38 sectors of the EEIO table. Section 4 presents the main results, while Section 5 discusses the implications of the results for the reduction of GHG emissions from agriculture in Kenya. The final section concludes.

2. METHODOLOGY

The environmentally extended input-output (EEIO) model based on the Leontief framework (Leontief, 1936), is a method for evaluating the relationship between economic activities and downstream environmental impacts. The model can be used to identify the economic drivers of any environmental impact, including the emission of pollutants, the degradation or harvest of natural resources, and the loss of biodiversity. In the environmental literature, EEIO is generally used to calculate the hidden, upstream, indirect, or embodied environmental impacts associated with a downstream consumption activity. It has been also used to calculate the amount of embodied environmental impact in goods traded between nations (Kitzes, 2013).

The economic accounting balance at the center of the Leontief approach is the starting point for the EEIO model and can be expressed following Chen and Zhang (2010) as

$$Y = A * Y + D - M \tag{2.1}$$

where Y is an $n \times 1$ vector of the total output of n sectors or economic activities; A is the $n \times n$ matrix of technology coefficients where each element a_{ij} is the input from sector i needed to produce one unit of output in sector j. The product of matrix A and the vector of total output (Y) captures the intermediate use of commodities as inputs in the production process; D is the matrix of final demand with columns including final consumption by households, government consumption, gross capital formation, exports, and changes in inventories. Finally, M is a vector of imports. From Eq. 2.1 the following expression is obtained, where I is the identity matrix

$$D - M = Y - A * Y = (I - A)Y \tag{2.2}$$

Equation 2.2 says that the final demand (D) for output of the n activities minus imports (M) of the respective commodities, equals the value-added in the production of those commodities (Gross Output minus intermediate use of output).

The original Leontief model in Eq. 2.2 is then linked to the environmental analysis of GHG emissions by introducing into the model the direct emissions E^d of each activity in the I-O table to obtain the emission flows among different sectors in the entire system, as shown in Eq. 2.3:

$$E^d + \varepsilon(A * Y) = \varepsilon Y \qquad 2.3$$

where ε represents the embodied emission coefficient matrix and $A*Y$ is the value flow matrix from Eq. 2.1 and 2.2. Assuming the same embodied emission intensity for both the import and domestic product associated with each sector[1] as in Weber et al. (2008), the GHG emission balance can be expressed as

$$E^d = \varepsilon(Y - AY) = \varepsilon(D - M) \qquad 2.4$$

From where the vector of embodied emission intensity coefficients is derived:

$$\varepsilon = \varepsilon^d * (I - A)^{-1} \qquad 2.5$$

In Eq. 2.5 ε^d is a row vector of direct emission intensity coefficients defined as emissions per unit of output of each sector. The embodied emission coefficient matrix ε can then be used to calculate the GHG emission flows among all sectors (*F*).

$$F = \varepsilon * Y = GY \qquad 2.6$$

$$G = diag(\varepsilon^d) * (I - A)^{-1} \qquad 2.7$$

Matrix G is the matrix of total emission intensities (direct and indirect), with elements g_{ij}. As in the original Leontief approach, matrix G is used to obtain demand-driven I-O multipliers to quantify the total impact of changes in exogenous expenditures (private demand, exports, investment). Broadly, what is called in the literature a Type I multiplier (Emonts-Holley et al. 2021) captures both the initial direct demand disturbance and subsequent supply-chain impacts or indirect effects. Applied to environmental impact using the EEIO table, matrix G is equivalent to the Type I Leontief inverse where the representative element of this matrix (g_{ij}) is the quantity of GHG emissions generated in sector *i* required to produce one unit of exogenous final demand in sector *j*. Summing the elements of column *j* in *G*, gives the Type I GHG emissions multiplier (EM) for sector *j*. The multiplier represents in this case, total

[1] This is assumed due to the lack of emission data for imported products and to the infeasibility of calculating those values as part of this study.

emissions across all domestic sectors associated with a unit increase in exogenous demand for the output of sector *j*. The GHG emissions multiplier, EM_j, for sector *j* can be obtained from matrix *G*.

$$EM_j = \sum_{i=1}^{n} g_{ij} \qquad 2.8$$

where g_{ij} represents the quantity of GHG emissions that sector *i* needs to generate for sector *j* to produce 1 unit of output.

The EEIO can be used also to quantify the total environmental impact of changes in demand. In this context, the indirect emission intensity coefficients are used to calculate emissions embodied in private consumption, gross capital formation, or government spending and measure the impact that changes in these variables have on GHG emissions. For example, the emissions embodied in exports ($EEX= \varepsilon X$), reflect the amount of GHG emissions generated to produce those exported goods.

Emissions embodied in domestic consumption, *EEC* (Chen and Zhang, 2010), include direct and indirect emissions from domestic production ($EEP=F + E^d$), exclude the emission embodied in exports but include the emission embodied in imports ($EEM= \varepsilon M$)

$$EEC = EEP + EEM - EEX \qquad 2.8$$

The net embodied emissions of international trade (*EEB*) can be obtained by combining embodied GHG emissions of domestic production and domestic consumption, (Chen and Zhang, 2010). A positive *EEB* (Eq. 2.9) means a trade surplus of embodied GHG emissions while a negative EEB means that other countries generate part of the emissions needed to satisfy the demand of goods and services in the importing country.

$$EEB = F + E^d - EEC = EEX - EEM = \varepsilon(X - M) \qquad 2.9$$

3. DATA

The input-output table contained in Kenya's 2003 Social Accounting Matrix (SAM) covering 50 sectors developed by Kiringai et al. (2006) is used as the main input to build the EEIO table. The original structure of the I-O table in the 2003 SAM was kept almost unchanged but gross production, value-added, intermediate use, expenditure, investment, and trade for the activities in the 2003 SAM were updated to 2019.

Most of the relevant data used to update values of the 2003 SAM were derived from recently issued official publications from the Kenya National Bureau of Statistics (KNBS), such as the Economic Survey 2022 (Kenya, National Bureau of Statistics, 2022), the Census of Industrial Production (CIP) 2018 (Kenya, National Bureau of Statistics, 2019b), the Kenya Integrated Household Budget Survey 2005/06 (Kenya, National Bureau of Statistics, 2006) containing information on agricultural production and the 2019 Kenya Population and Housing Census (Kenya, National Bureau of Statistics, 2019a). Data sources and values used to update the I-O table are briefly described.

Values of production, value-added, labor, capital, and intermediate use by industry at current prices in millions of Kenya Shillings (KSh Million) were available for the period, 2017-2021 from Kenya, National Bureau of Statistics (2022, and 2019b), including intermediate consumption, compensation of employees, operating surplus/mixed income, gross, value-added, and output at basic prices. Gross Domestic Product by activity, 2017 - 2021 at current prices (KSh Million) was also available for growing crops and animal production (Kenya, National Bureau of Statistics, 2022).

Value of expenditure on the Gross Domestic Product at current prices (KSh Million) was obtained also for the period 2017-2021, including, government final consumption, private final consumption expenditure, final consumption expenditure by NPISH2, gross fixed capital formation, changes in inventories, gross domestic expenditure, exports and imports of goods and services (Kenya, National Bureau of Statistics, 2022).

Available data on the Balance of Payments, and Balance of Merchandise Trade, 2017-2021 (KSh million) were complemented with values of principal exports and imports, 2017-2021 for 45 commodities including main agricultural exports and imports and trade from manufacturing and service sub-sectors. Information on production values, expenditure on materials and supplies for the Food sub-sector by Activity (KSh Million), and distribution of employees by type and Industry were available from the Census of Industrial Production (CIP) 2018 (Kenya, National Bureau of Statistics, 2019b)

The 50 sectors of the original 2003 SAM were merged into 38 sectors as described in Table A.1 in the Appendix. The reason for this is that availability of data on emissions imposed a constraint on how to aggregate the economic sectors for input-output analysis. For example, industries like Non-Metallic, Chemical Industries, Metals and Machines, generate carbon dioxide (CO_2) as a by-product of the final desired output, so they are kept separated from other industries like Textile & Clothing, Leather & Footwear, Wood & Paper, Printing and Publishing, for which emissions result mostly from the use of energy as an input in the production process. Information on emissions for these industries is available as "emissions from energy use in manufacturing." No attempt was made to allocate total emissions from energy use across these industries, so they were grouped together under "Light Manufacturing." The Food Industry falls within this category, but it was kept separated because of the focus of the analysis on the food system. Something similar occurs with livestock. In the case of Kenya, where the economic importance of poultry and pig production is relatively low compared to that of beef and dairy cattle and given that the most important source of emission is enteric fermentation and manure management that occurs in ruminants (cattle, sheep, and goats), beef and dairy cattle are kept as separate activities, grouping all other species under "Other Livestock." Most GHG emissions from this last group are produced by camels, goats, and sheep.

Data on GHG emissions were obtained from the Emissions Database for Global Atmospheric Research (Crippa et al., 2021; and EDGAR, 2022). EDGARv6.0 provides emissions of the three main greenhouse gases including CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases per sector and country. CO_2 emissions include all fossil CO_2 sources, such as fossil fuel combustion, non-metallic mineral processes (e.g., cement production), metal (ferrous and non-ferrous) production processes, urea production, agricultural liming, and solvent use. Large-scale biomass burning with Savannah burning, forest fires, and sources and sinks from land-use, land-use change, and forestry (LULUCF) are excluded. Table 3.1 shows GHG emissions for Kenya 2019, by source.

The original data from Table 3.1 were allocated to the 38 sub-sectors in the I-O table in several steps. Emissions for which there was a one-to-one correspondence with sub-sectors in the I-O table were allocated first as shown in Table 3.2.

Use of Fuels, Solid Fuels, Non-Energy Products from Fuels and Solvent Use, Manufacturing Industries and Construction. Allocation of emissions from these sources at the aggregated sectoral level (Agriculture, Industry, Transport) was based on data from the Kenya, National Bureau of Statistics (2022), Tables 9.3 and 9.11b on *Net Domestic Sales of Petroleum Fuels by Consumer Category*, *2017-2021*, and *Physical Energy Use, respectively.* Within sectors, emissions were allocated based on the share of each sub-sector in Gross Output.

Urea Application. Allocated across crops based on data on the use of nitrogen per hectare by crop in Kenya, available from Ludemann et al. (2022).

Manure Management, Enteric Fermentation. Allocated to cattle, sheep, goats, and camels, based on the number of heads of each species reported in Kenya, National Bureau of Statistics (2019a). The number of heads was then converted to Tropical Animal Units (AU) defining camels as 1 AU, indigenous cattle as 0.7 AU, sheep and goats as 0.15 AU, pigs as 0.3 AU, and poultry as 0.01 AU, while exotic cattle was defined as 2.5 AU using the carcass weight difference between Kenyan and European cattle from FAO (2022) as a proxy for animal size.[2] AU of indigenous and exotic cattle was increased by 20 percent to

[2] Livestock emissions from enteric fermentation were allocated based on AU which directly relates to the animal size or body mass. This approach could be overestimating emissions from camels which are not technically ruminants. A study by Dittmann et al. (2014) shows no significant difference between cattle and camels when methane emission was expressed relative to fiber intake. However, they found that camelids produced less methane expressed based on body mass when compared to literature data on domestic ruminants fed on roughage diets. The

represent the AU of dairy cows.

Direct and Indirect N_2O Emissions from Managed Soils. They were allocated to crop, and livestock sub-sectors based on Hergoualc'h et al. (2019). These emissions are mostly generated by the use of synthetic fertilizer (urea) and from urine and dung from grazing animals. The first step was to determine nitrogen (N) excreta per animal/year and the use of N from fertilizer. Default values for nitrogen excretion per animal head of the different species in the Africa region were obtained from Jun et al. (2002). This information was used to calculate the total amount of N used by crops and excreted by animals. Emissions were allocated proportionally to the quantities of N deposited on the soil by the different sub-sectors.

Emissions from biomass burning. These are emissions resulting from the burning of crop residues. The information is available from FAO (2022). Crop residues that are burned in Kenya include maize, rice, wheat, and sugarcane.

GHG emissions by sub-sector of the I-O table resulting from the allocation of emissions from the EDGAR dataset are presented in Table 3.3. EDGAR also provides emission grid maps at 0.1 x 0.1-degree resolution at the global level. Data from emission grid maps were obtained for Kenya and aggregated at the county level although the data was not used in the analysis at the national level.

Kenya Population and Housing Census (Kenya, National Bureau of Statistics, 2019a) shows a total population of 16 million heads of cattle and almost 5 million heads of camels, but the camel's body mass is significantly larger than the body mass of indigenous cattle in Kenya resulting in higher AUs per head.

Table 3.1–Sources of GHG emissions of the Kenyan economy, 2019 (Gg)

IPCC code[1]	Name	CO_2	CH_4	N_2O
3.A.2	Manure Management	0	36	1
3.A.1	Enteric Fermentation	0	1,378	0
3.C.7	Rice cultivations	0	4	0
3.C.3	Urea application	15	0	0
3.C.6	Indirect N_2O Emissions from manure management	0	0	0.0
3.C.5	Indirect N_2O Emissions from managed soils	0	0	3
3.C.4	Direct N_2O Emissions from managed soils	0	0	42
1.B.1	Solid Fuels	0	356	1
1.A.1.bc	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries	91	0	0
1.A.1.a	Main Activity Electricity and Heat Production	1,281	0	0
1.B.2	Oil and Natural Gas	0	0	0
2.A.3	Glass Production	2	1	0
1.A.2	Manufacturing Industries and Construction	3,495	0	0
2.A.2	Lime production	0	0 0	0
2.A.1	Cement production	2,320	0	0
3.C.2	Liming	5	0	0
2.C	Metal Industry	1	0	0
2.D	Non-Energy Products from Fuels and Solvent Use	283	0	0
2.A.4	Other Process Uses of Carbonates	281	0	0
2.G	Other Product Manufacture and Use	0	0	0
1.A.5	Non-Specified	114	0	0
3.C.1	Emissions from biomass burning	788	1	0
5.A	Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	0	0	3
1.A.4	Residential and other sectors	49,284	128	2
1.A.3.d	Water-borne Navigation	3	0	0
1.A.3.a	Civil Aviation	61	0	0
1.A.3.c	Railways	122	0	0
1.A.3.b_noRES	Road Transportation no resuspension	8,177	1	0
4.D	Wastewater Treatment and Discharge	0	238	1
4.A	Solid Waste Disposal	0	32	0
4.C	Incineration and Open Burning of Waste	1	0	0
	Total	**66,324**	**2,175**	**53**

Source: Crippa et al. (2021), and : EDGAR (2022).

Note: (1) Code corresponds to IPCC 2006 standard report

Table 3.2– Allocation of emissions for which there was a one-to-one correspondence between EDGAR database sources and sectors in the I-O.

	Name	Code	IPCC name
3	Rice	rice	Rice cultivations
22	Petroleum	petr	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries
23	Chemical industries	chem	Metal Industry
25	Nonmetallic products	nmet	Glass Production
			Cement production
			Lime production
			Liming
28	Water supply; sewerage, waste management	wate	Wastewater Treatment and Discharge
			Solid Waste Disposal
29	Electricity supply	sele	Main Activity Electricity and Heat Production
32	Transport	trans	Civil Aviation
			Railways
			Road Transportation no resuspension
			Water-borne Navigation

Source: Elaborated by authors based on Crippa et al. (2021), EDGAR (2022), and Kiringai et al. (2006).

Table 3.3– Gross Output (million KSh) and direct GHG emissions (CO_2eq) in Kenya, by activity, 2019

	Name	Gross Output	CO_2	CH_4	N_2O	CH_4eq	N_2Oeq	Total
1	Maize	161,955	741	1	2	32	451	1,224
2	Wheat	38,229	49	0	0	2	21	72
3	Rice	9,461	9	4	0	97	8	114
4	Cereals, other	41,570	6	0	0	0	78	84
5	Roots & tubers	187,211	26	0	0	0	105	132
6	Pulses & oil crops	127,434	20	0	1	0	235	254
7	Fruits	188,304	26	0	0	0	74	100
8	Vegetables	199,865	28	0	0	0	45	72
9	Cut flowers	120,101	20	0	1	0	419	439
10	Sugar cane	88,352	35	0	0	1	39	75
11	Coffee	29,617	4	0	0	0	31	35
12	Tea	254,376	35	0	0	0	67	102
13	Crops, other	11,740	2	0	0	0	14	16
14	Beef	207,105	28	448	16	11,188	4,692	15,908
15	Milk	358,007	49	302	10	7,538	2,916	10,503
16	Livestock, other	383,343	52	665	15	16,630	4,554	21,236
17	Fishing & aquaculture	69,541	9	0	0	0	0	10
18	Forestry & logging	101,939	14	0	0	0	0	14
19	Mining	141,313	278	0	0	0	2	280
20	Food industry	971,056	668	145	0	3,629	0	4,297
21	Light manufactures	368,425	254	55	0	1,377	0	1,630
22	Petroleum	172,909	210	26	0	646	0	856
23	Chemical industries	267,268	184	40	0	999	0	1,183
24	Metals and machines	153,572	107	23	0	574	0	680
25	Nonmetallic products	223,702	2,762	35	0	864	0	3,626
26	Other manufacturing	154,653	106	23	0	578	0	684
27	Construction	1,391,357	817	0	0	1	5	824
28	Water supply & waste mgt.	116,974	0	271	1	6,763	427	7,190
29	Electricity supply	159,209	1,281	0	0	2	4	1,287
30	Trade	1,601,688	201	0	0	0	0	201
31	Accommodation and food services	346,939	87	0	0	0	1	88
32	Transport	2,082,170	8,364	1	0	35	66	8,465
33	Information and communication	522,622	66	0	0	0	0	66
34	Financial and insurance activities	924,259	116	0	0	0	0	116
35	Real estate	1,035,989	130	0	0	0	0	130
36	Public administration	847,824	308	0	0	1	2	311
37	Health & education	967,269	121	0	0	0	0	121
38	Other services	714,542	90	0	0	0	0	90
	Total	**15,741,891**	**17,303**	**2,038**	**48**	**50,957**	**14,254**	**82,514**

Source: Elaborated by authors based on Crippa et al. (2021), EDGAR (2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

4. RESULTS

This section provides an overview of the main sources of GHG direct emissions in Kenya based on the results of the EEIO model and presents evidence of the importance of considering the economic links between activities when assessing emissions.

Direct Emissions

Total direct emissions and total Gross Output disaggregated by sector are shown in Table 4.1. The total direct emissions of the Kenyan economy amounted to 82,514 Gg of CO_2eq. The results show that agriculture is by far the largest emitter of GHG, accounting for 50,366 Gg of CO_2eq equivalent or 61 percent of total emissions. Within agriculture, 95 percent of total emissions were generated by livestock production, an amount equivalent to 58 percent of Kenya's total direct emissions. Emissions from cattle (beef and dairy) explain about 60 percent of total livestock emissions or equivalently 16 and 12 thousand Gg of CO_2eq, respectively. The rest, (24 thousand Gg) is produced by other livestock including, sheep, goats, camels, pigs, and poultry. Most emissions within this group are generated by ruminants (sheep, goats, and camels).

Direct emissions from crops represented only a small fraction of total direct emissions from agriculture. Maize was the crop with the highest levels of direct GHG emissions (1,224 Gg) but this represents only 1.5 percent of total emissions at the national level. Emissions from other crops are in all cases below 1 percent of Kenya's total direct GHG emissions. In a study that examined annual CO_2, CH_4 and N_2O emissions from 59 plots of low-input, rain-fed crop production, across different vegetation types, field types and land classes in western Kenya, Pelster et al. (2015) found that crop GHG emissions were low with no discernable difference between field types, land classes and crop types. On the other hand, they observed high intensity of GHG emissions because of the low yields obtained. Pelster et al. argue that the lack of differences between plots was likely due to the low input rates used.

Manufacturing contributes 16 percent of total GHG emissions in Kenya, one-third of them from the food processing industry. Manufacturing of non-metallic products, an industry that includes the production of cement, glass, and other activities that emit CO_2 not only because of energy use but as a by-product of the production process, is responsible for about 4 percent of total GHG emissions. Only two service activities are important in terms of direct emissions. These are transport and water supply and waste management. These activities generate 10 and 9 percent of the country's total GHG emissions, respectively.

There are notable variations in the types of emissions produced by agriculture and other sectors (Figure 4.1). In agriculture, CH_4 and N_2O emissions represent 70 and 27 percent of total emissions, respectively. Direct emissions of CO_2 embody 33 percent of emissions from manufacturing, increasing to 60 percent in services. While agriculture accounts for 15 percent of national Gross Output, it contributes with 7 percent of total CO_2 emissions, 70 percent of CH_4 emissions, and 96 percent of N_2O emissions (Figure 4.2).

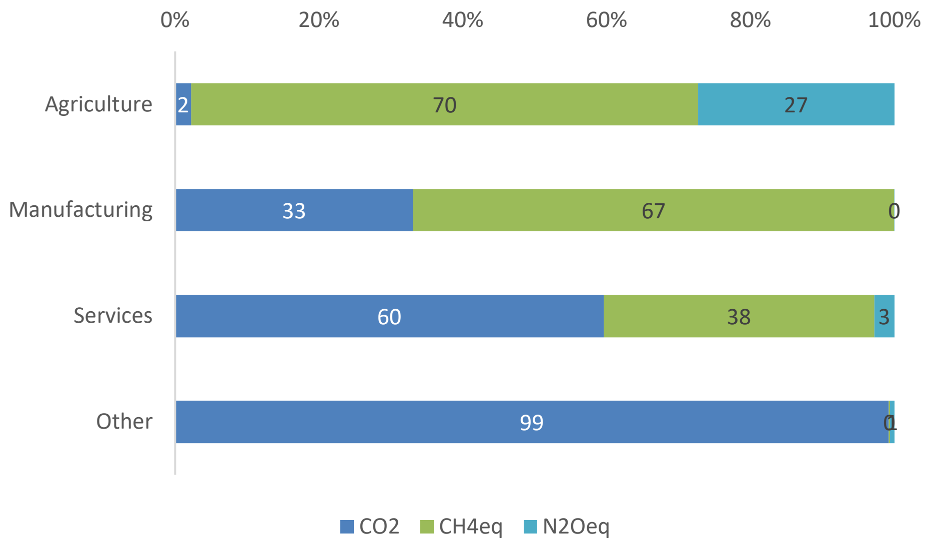
Differences in the mix of GHG emissions across sectors are caused by the specific sources of emissions in each sector. In agriculture, livestock farming, and manure management are the primary sources of emissions. In contrast, most emissions in manufacturing and services are due to the burning of fuels as a source of energy during the production process. The higher incidence of CH_4 emissions in manufacturing than in services results from the use of solid fuels in some industries. In addition to fuel combustion, certain industrial procedures, such as the smelting of ferrous metals, and the production of nonmetal mineral products and raw chemicals, can also result in significant CO_2 emissions.

Table 4.1– Output (in million KSh) and direct GHG emissions (in Gg of CO_2eq) by activity, 2019.

Activity	Gross output	Share	CO_2	CH_4eq	N_2Oeq	CO_2eq	Share
Maize	161,955	1.0	741	32	451	1,224	1.5
Wheat	38,229	0.2	49	2	21	72	0.1
Rice	9,461	0.1	9	97	8	114	0.1
Cereals, other	41,570	0.3	6	0	78	84	0.1
Roots & tubers	187,211	1.2	26	0	105	132	0.2
Pulses & oil crops	127,434	0.8	20	0	235	254	0.3
Fruits	188,304	1.2	26	0	74	100	0.1
Vegetables	199,865	1.3	28	0	45	72	0.1
Cut flowers	120,101	0.8	20	0	419	439	0.5
Sugar cane	88,352	0.6	35	1	39	75	0.1
Coffee	29,617	0.2	4	0	31	35	0.0
Tea	254,376	1.6	35	0	67	102	0.1
Crops, other	11,740	0.1	2	0	14	16	0.0
Beef	281,660	1.8	28	10,934	4,691	15,653	19.0
Milk	358,007	2.3	49	9,383	2,925	12,357	15.0
Livestock, other	308,788	2.0	52	15,039	4,546	19,636	23.8
Total agriculture	2,406,671	15.3	1,131	35,488	13,747	50,366	61.0
Forestry, fisheries & mining	312,793	2.0	302	0	2	304	0.4
Food industry	971,056	6.2	668	3,629	0	4,297	5.2
Light manufactures	368,425	2.3	254	1,377	0	1,630	2.0
Petroleum	172,909	1.1	210	646	0	856	1.0
Chemical industries	267,268	1.7	184	999	0	1,183	1.4
Metals and machines	153,572	1.0	107	574	0	680	0.8
Nonmetallic products	223,702	1.4	2,762	864	0	3,626	4.4
Other manufacturing	154,653	1.0	106	578	0	684	0.8
Total manufacturing	2,311,586	14.7	4,290	8,667	0	12,957	15.7
Construction	1,391,357	8.8	817	1	5	824	1.0
Water supply and waste management	116,974	0.7	0	6,763	427	7,190	8.7
Electricity supply	159,209	1.0	1,281	2	4	1,287	1.6
Transport	2,082,170	13.2	8,364	35	66	8,465	10.3
Other services	6,961,131	44.2	1,119	1	2	1,122	1.4
Total services	9,319,484	59.2	10,764	6,800	500	18,064	21.9
Total	**15,741,891**	**115**	**17,303**	**50,957**	**14,254**	**82,514**	**100**

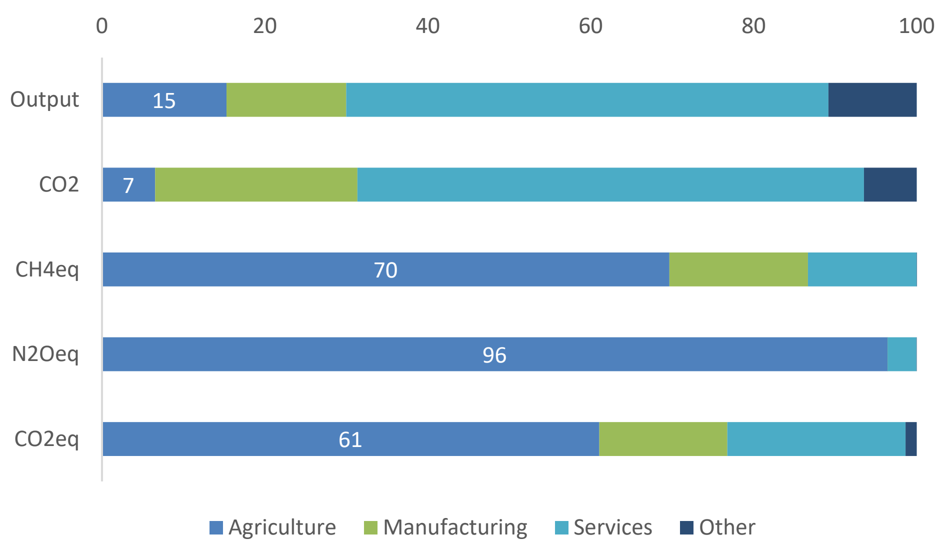
Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Figure 4.1. Composition of GHG emissions by major sector measured in CO2eq (percentage)



Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Figure 4.2. Contribution of major sectors to emissions of different GHG (percentage)



Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

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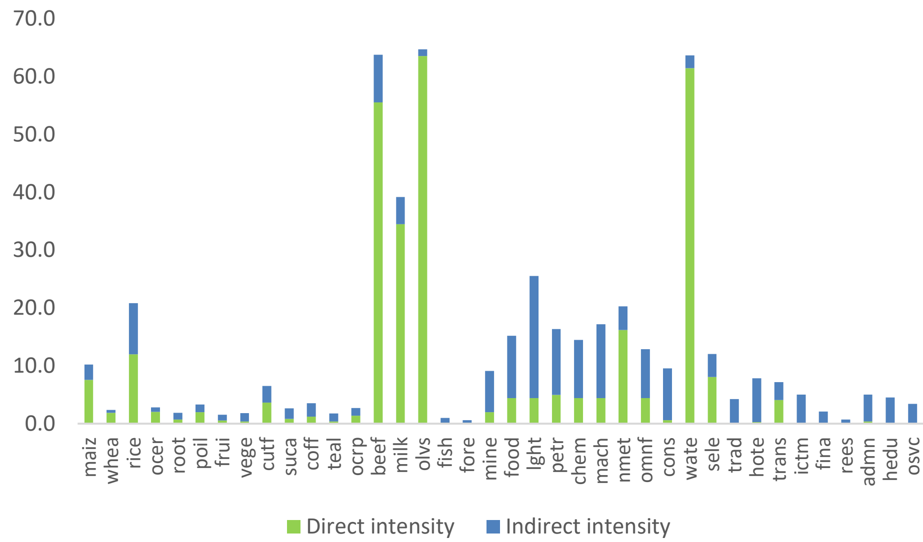
In sum, results so far show that agriculture is the most important source of GHG emissions in Kenya as it generates more than 60 percent of total emissions while producing 15 percent of the country's Gross Output. It is also the main source of CH_4 and N_2O emissions, mostly produced by enteric fermentation and manure management from livestock. As shown in Table 4.1, agriculture's CH_4 emissions measured in CO2eq (35,488 Gg) are larger than the total emissions of all GHG gases from manufacturing and services (31,021 Gg). The food industry, on the other hand, was the largest manufacturing sector in 2019, with a Gross Output of almost 1 billion KSh, followed at a distant second by industries grouped as "light manufactures" (textiles, apparel, leather, shoes, wood, paper, and publishing and printing) with total Gross Output of 0.36 billion KSh. Agriculture plus the food industry contribute with 22 percent of Kenya's Gross Output and 66 percent of total GHG emissions.

Indirect Emissions

The estimation of the EEIO allowed for the calculation of total emission intensity which includes the direct emission intensities of sector *j* and the indirect emission intensities that result from the use of inputs from other sectors by *j*. This is the multiplier discussed in Section 2 and represents total emissions across all domestic sectors associated with a unit increase in exogenous demand for the output of sector *j*. The direct and indirect emissions of CO_2, CH_4, and N_2O from different sources for the 38 sectors in Kenya's EEIO table are summarized in Figure 4.3.

Figure 4.3 Direct and indirect GHG emission intensity by sector, 2019 (tons of CO2eq/million KSh)

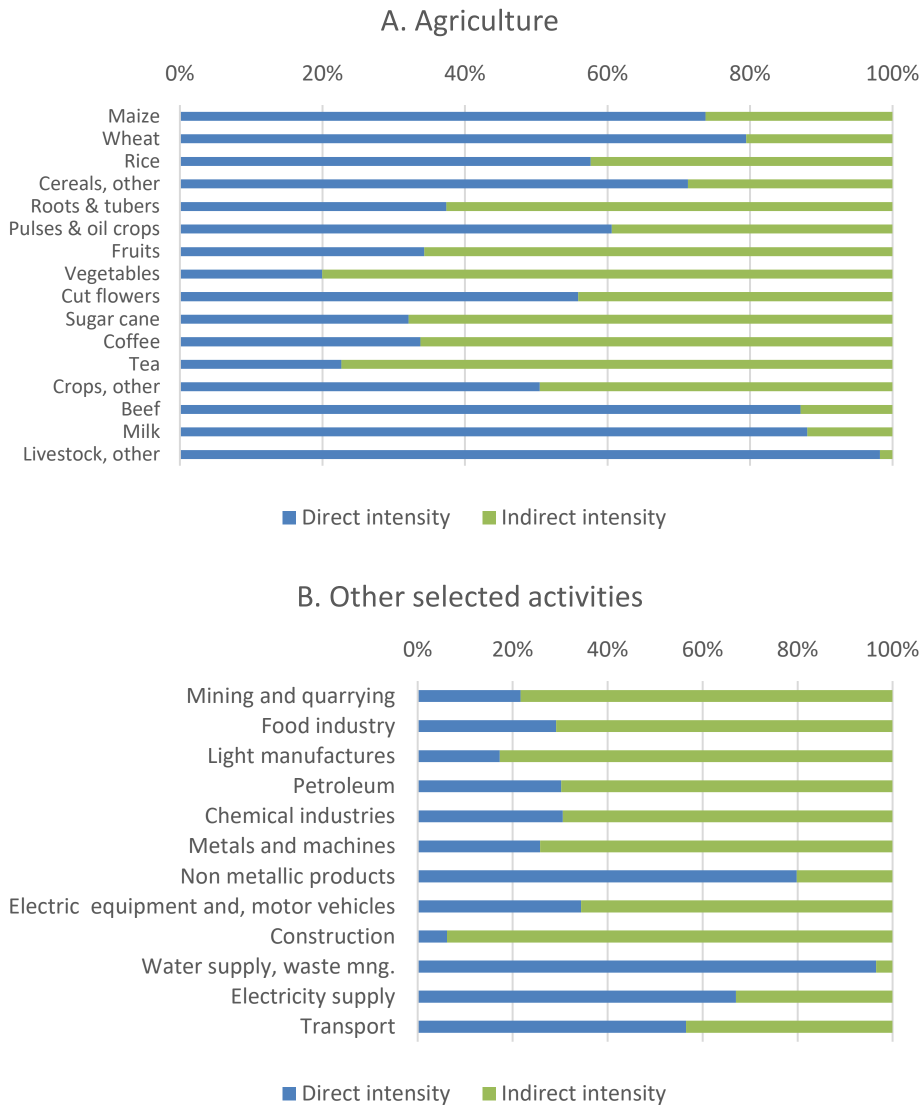


Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Figure 4.3 shows that the livestock sector has the highest total emission intensity among all sectors except for water supply and waste management which shows similar levels of emission intensity. For every million KSh of beef and meat of other livestock produced, these sectors generate about 65 tons of CO2eq. Among crops, rice and maize show the highest emission intensity with 20 and 10 tons per million KSh of output, respectively.

It is worth noting that the total emission intensity in manufacturing is much higher than in most agricultural activities except for livestock. This is the result of the relatively high level of indirect emissions generated by manufacturing. Figure 4.4 shows the importance of direct and indirect emissions in the different sectors. As noted by Liu et al. (2019), differences in the importance of indirect emissions are closely correlated to the specific characteristics of the production process of each sector. According to Liu et al. (2018), primary activities are more likely to generate direct GHG emissions, while indirect emissions are most likely to happen in manufacturing industries. There are also major differences in the importance of indirect emissions between agricultural activities. For example, direct emissions are high in cereals and livestock production and are relatively low in export crops like coffee and tea, and in intensive activities like vegetables.

Figure 4.4–Contribution of direct and indirect GHG emissions to total emission intensity (percentage)



Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Direct and indirect emission intensities were used to calculate total GHG emissions by sector. Results in Table 4.2 show that Kenya's total GHG emissions from production in 2019 were 162,237 Gg of CO2eq, with indirect emissions of 79,723 Gg at a similar level of direct emissions (82,514 Gg), revealing the significance of indirect emissions. However, in the case of agriculture, most emissions are still direct emissions from the livestock sector.

Table 4.2–Total direct and indirect emissions by production activity, 2019

	Direct Gg CO_2eq	Share %	Indirect Gg CO_2eq	Share %	Total Gg CO_2eq	Share %
Maize	1,224	1.5	435	0.5	1,659	1.0
Wheat	72	0.1	19	0.0	91	0.1
Rice	114	0.1	84	0.1	197	0.1
Cereals, other	84	0.1	34	0.0	118	0.1
Roots and tubers	132	0.2	221	0.3	353	0.2
Pulses and oil crops	254	0.3	165	0.2	420	0.3
Fruits	100	0.1	192	0.2	292	0.2
Vegetables	72	0.1	289	0.4	361	0.2
Cut flowers	439	0.5	347	0.4	786	0.5
Sugar cane	75	0.1	159	0.2	233	0.1
Coffee	35	0.0	70	0.1	105	0.1
Tea	102	0.1	348	0.4	450	0.3
Crops, other	16	0.0	16	0.0	31	0.0
Beef	15,653	19.0	2,321	2.9	17,974	11.1
Milk	12,357	15.0	1,681	2.1	14,037	8.7
Livestock, other	19,636	23.8	357	0.4	19,993	12.3
Food industry	4,297	5.2	10,448	13.1	14,745	9.1
Manufacturing	8,660	10.5	16,630	20.9	25,289	15.6
Water supply; sewerage, waste management	7,190	8.7	257	0.3	7,447	4.6
Electricity supply	1,287	1.6	633	0.8	1,920	1.2
Transport	8465	10.3	6510	8.2	14975	9.2
Other services	1122	1.4	24895	31.2	26017	16.0
Other	1,127	1.4	13,614	17.1	14,741	9.1
Total	**82,514**	**100**	**79,723**	**100**	**162,237**	**100**

Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Embodied Emissions in Final Consumption

The EEIO model was also used to estimate Kenya's GHG emission embodiments in 2019, that is, the emissions embodied in final goods consumed domestically or exported. Total GHG emissions were allocated to final domestic demand and exports. Final domestic consumption includes rural and urban consumption by households, government consumption, gross fixed capital formation, and changes in inventories. The embodiment results are shown in Table 4.3.

Table 4.3– Embodied emissions in final consumption, 2019 (Gg of CO2eq)

Activity	Domestic consumption						Exports
	Total	Rural	Urban	Government	Capital formation	Inventory change	
Maize	1,446	1,013	141	243	33	16	90
Wheat	206	125	19	24	4	33	20
Rice	409	189	207	11	2	1	0
Cereals, other	88	0	0	26	5	57	2
Roots & tubers	132	96	35	0	0	1	0
Pulses & oil crops	255	177	75	0	0	2	0
Fruits	93	66	26	0	0	1	7
Vegetables	63	33	30	0	0	1	9
Cut flowers	79	0	0	0	0	79	360
Sugar cane	85	0	0	0	0	85	5
Coffee	10	3	7	0	0	0	28
Tea	52	0	0	0	0	52	51
Crops, other	10	0	0	0	0	10	6
Beef	15,849	15,616	11	187	35	0	191
Milk	10,635	10,510	43	68	13	0	63
Livestock, other	21,140	20,725	166	209	40	0	213
Food industry	5,647	1,818	3,838	0	0	-9	643
Agriculture & Food Industry	**56,200**	**50,372**	**4,597**	**769**	**133**	**329**	**1,687**
Manufacturing & Construction	26,613	3,018	5,814	0	11,373	1,621	4,339
Water supply & waste	7,990	402	5,441	2,147	0	0	693
Transport	7,795	2,119	5,656	20	0	0	2,396
Other services	2,403	218	1,768	415	3	0	182
Other	1,082	18	5	21	805	233	55
Total	**102,083**	**56,147**	**23,282**	**3,372**	**12,314**	**2,183**	**9,352**

Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Results show that GHG emissions in Kenya were driven by final domestic consumption. In 2019, total goods consumed by rural households embodied 56,147 Gg of CO2eq emissions equivalent to 55 percent of emissions embodied in total final domestic consumption. Goods consumed by urban households resulted in emissions of 23,282 Gg of CO2eq, which brings emissions embodied in all goods consumed by households to 78 percent of emissions in final domestic demand. Gross capital formation explains only 12 percent of embodied emissions (12,314 Gg of CO2eq). On the other hand, emissions embodied in exports were only 9,352 Gg or about 9 percent of the emissions embodied in final domestic consumption.

The total GHG emissions embodied in Kenya's trade are shown in Table 4.4. Emissions embodied in imports were calculated using the same approach used for goods produced in Kenya given that no information on emissions generated in the countries of origin of imports was available. The total emissions in exports in 2019 were, as shown before, 9,297 Gg while imports of embodied emissions were three times bigger than emissions in exports (28,187 Gg), making Kenya a net importer of emissions from other countries.

Table 4.4– Total GHG emissions embodied in international trade, 2019 (Gg of CO_2eq)

	Exports	Imports	Balance
Maize	90	281	-191
Wheat	20	146	-127
Rice	0	296	-296
Cereals, other	2	5	-3
Roots & tubers	0	0	0
Pulses & oil crops	0	1	-1
Fruits	7	0	7
Vegetables	9	0	9
Cut flowers	360	0	360
Sugar cane	5	13	-8
Coffee	28	2	26
Tea	51	1	50
Crops, other	6	0	6
Beef	191	521	-330
Milk	63	171	-109
Livestock, other	213	583	-369
Food industry	643	1,756	-1,113
Total Agriculture & Food Industry	1,687	3,776	-2,089
Manufacturing & Construction	4,339	20,983	-16,644
Water supply & waste	693	1,390	-697
Transport	2,396	1,691	704
Other services	182	346	-164
Other	55	8	47
Total	**9,297**	**28,187**	**-18,890**

Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

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Most of the imported emissions are embodied in manufacturing goods (20,983 Gg in a total of 28,187 Gg), but food and agriculture are also net importers of emissions. As shown in Table 4.4, there are only five sub-sectors that have higher values of embodied emissions in exports than in imports, including fruits and vegetables, cut flowers, coffee, tea, and mining. Overall, Kenya is an importer of emissions embodied in agricultural goods and processed food with a trade balance of -2,089 Gg. About half of this trade balance is explained by net imports of emissions embodied in products from the food industry. The remaining half percent results from a similar negative trade balance of emissions in cereals and livestock products.

5. DISCUSSION

Results on direct and indirect emissions and embodied emissions in final consumption presented in the previous section are relevant when it comes to analyzing possible paths for reducing GHG emissions from agriculture and the food industry. The main findings are that emissions from livestock account for a large proportion of Kenya's total GHG emissions. These emissions are equivalent to the total emissions of manufacturing and construction while representing almost 85 percent of all emissions from agriculture and the food industry. The results also show that emissions from crops and from food manufacturing represent only 6 and 9 percent of total emissions from agriculture and the food industry, respectively. Adding to this, between 90 and 98 percent of the total emissions from the livestock sector are direct emissions.

Analyzing GHG mitigation policy impact for multiple industries from both production and consumption sides, Liu et al. (2019) found that direct and indirect emission analysis is essential to support GHG emission reduction policymaking. Their results show that for industries with predominantly direct emissions, Production-Based Policies lead to larger GHG reductions, while Consumption-Based Policies should be considered for those industries that cause indirect emissions that are located at the end of industrial chains. The results in Section 2 on GHG emissions from agriculture and the findings by Liu et al. (2019), seem to suggest that to reduce agricultural GHG emissions in Kenya, policymakers should target the livestock sector with production-based policies. However, according to the actual production condition of the livestock sector in Kenya, CH_4 emissions from enteric fermentation would be hard to regulate and could result in negative impacts on agricultural growth and livelihoods.

Adaptation, Mitigation, and Intensification

Thornton and Herrero (2010) argue that the greatest potential for reducing livestock GHG emissions in LMICs is through the implementation of different technologies and practices that also contribute to increasing productivity. These include improvements in feed quality, such as the use of improved or cultivated pastures, the use of supplements such as grains that increase the digestibility of the feed consumed, changes in pasture practices and land use, and the change of ruminant breeds.

The analysis of Thornton and Herrero (2010) shows that although methane gas production per animal consuming improved pastures is higher than that of cattle consuming natural pastures—38.7 compared to 31.2 kg of methane per year, respectively—milk production and live weight gain per animal per day are three times higher. This results in a significant reduction in emission intensity and total methane produced. As a result of these differences, the number of animals needed to meet demand is reduced under the option of improved pastures, in turn reducing pressure on natural resources. The adoption of deep-rooted tropical pastures such as *Brachiaria spp.* has the additional advantage of sequestering more carbon than natural pastures (see Fisher et al., 1994). According to Thornton and Herrero (2010), this option could result in the use of less land, as well as fewer animals to meet demand, which in turn could translate into more CO2 savings from avoided deforestation.

Another key factor for increasing productivity and reducing GHG emissions is land-use changes to increase carbon sequestration. Thornton and Herrero (2010) discuss two options that are commonly associated with high mitigation potential: carbon sequestration through the restoration of degraded grasslands, and the use of agroforestry practices. They conclude that restoration of degraded grasslands has the greatest potential for mitigation in areas where the magnitude of degradation is considerable, although they note that there may be problems associated with its implementation.

Next is the agroforestry option, which has the double benefit of improving the quality of livestock diet by the high nutritional value of agroforestry species while increasing the carbon sequestration of the atmosphere. According to Thornton and Herrero (2010), 28 percent of the plausible mitigation potential for this option comes from the possible reduction in the number of livestock (higher productivity) while 72 percent of the mitigation potential results from carbon sequestration.

Havlik et al. (2014) found that mitigation policies targeting emissions from land-use change are 5 to 10 times more efficient—measured in "total abatement calorie cost"—than policies targeting emissions from livestock only. They conclude that fostering transitions toward more productive livestock production systems in combination with climate policies targeting land-use change appears to be the most efficient lever to deliver desirable climate and food availability outcomes.

Finally, Thornton and Herrero (2010) found that the adoption of improved breeds with higher milk production potential and higher body weights results in modest reductions in the amount of CH_4 produced per ton of milk. This is because animals of improved breeds have a higher body weight than domestic breeds and therefore, with the same diets, will have higher intakes, which produce more GHGs. Emission intensity remains largely unchanged as improved breeds produce more milk and meat per animal, generally the same or more than the amount of GHG emissions they generate (Thornton and Herrero, 2010). While the impact of improved breeds on GHG emissions is modest, the increase in productivity and product quality, in the case of meat, is very significant.

Given the different agroecologies and the livestock systems associated with them, adaptation and mitigation solutions will need to be specific for the different production systems and regions. To increase milk yield, Kenya's Nationally Appropriate Mitigation Action (NAMA)[3] plan for the dairy sector identified various practices that consistently lead to significant increases in milk yields, such as adopting specialized dairy breeds, improving feeding and water supply, ensuring animal health through measures like tick control, and managing calf suckling. Particularly, altering feeding management, such as promoting the use of concentrate based on the lactation cycle, has been recognized as a crucial action for mitigating greenhouse gas (GHG) emissions in central Kenya (Mbae et al., 2021). Other suggested measures to improve environmental efficiency include the reduction of energy requirements in dairy cooperatives, addressing loss and waste in milk supply chains, and harmonizing dairy intensification with forest conservation to reduce agricultural expansion-induced forest loss (Mbae et al., 2021).

[3] Kenya's Updated Nationally Determined Contribution (NDC) to the Paris Agreement for Climate Change proposes Climate Smart Agriculture (CSA) practices to mitigate emissions in the agricultural sector, in line with the Kenya CSA Strategy (KCSAS) (Government of Kenya, 2018). The Updated NDC further identifies efficient livestock management systems as a priority under CSA, including the implementation of a Dairy NAMA, involving 267,000 households by 2030 (Government of Kenya, 2018).

Mitigation and adaptation measures in beef production are specific for the different production systems. Mbae et al. (2021) identify three major production systems: extensive grazing systems (both pastoralism and ranching), semi-intensive grazing (agro-pastoralism), and a small intensive (feedlot). The ASALs (Arid and Semi-Arid Lands) of Kenya, with a population of approximately 16 million people, is the primary location for cattle farming. However, these areas are highly susceptible to climate change and variability, resulting in widespread poverty, land degradation, and conflicts. Drought poses the most significant risk in these regions, profoundly impacting livelihoods, the economy, and the environment. Enhancing rangeland management stands out as a highly promising adaptation strategy for the ASAL region, as highlighted by Mbae et al. (2021). The degradation of natural pasture significantly hampers livestock production in these areas, making it imperative to address this limitation. To effectively cope with climate variability and uphold the health of vegetation and land, it is crucial to prioritize livestock mobility and implement sound grazing management practices, as emphasized by Mbae et al. (2021). Improved rangeland management has major mitigation co-benefits as it could increase carbon sequestration in soils and vegetation. In pastoralist regions, the achievement of this goal relies on establishing secure land and resource rights, such as communal land tenure, conservancies, and appropriate by-laws. Furthermore, locally tailored institutional arrangements should be developed to align with specific contextual needs and conditions. Other suggested measures for adaptation and mitigation are improved animal health and access to markets, and forage production in ASALs (Mbae et al., 2021). Improved access to markets and better animal health are particularly important for extensive systems, as they could lead to higher cattle off-take rates which implies less animals kept in stock per unit of output produced, reducing the GHG intensity of extensive production systems. Mbae et al. (2021) estimated that increasing the average off-take rate of 11 percent for cattle in Kenya by 10 to 13 percent would decrease GHG emissions per unit of protein produced by 6 percent.

We conclude this section with a brief reference to crop production. As discussed in previous sections, crop production contributes only a small proportion of total GHG emissions in Kenya, partly explained by the low levels of inputs used and its low productivity, which result in high intensity of emissions. Intensification in crop production is not important in terms of GHG mitigation but still key for economic development, food security, and adaptation to climate change. Bryan et al. (2013) identify enhanced soil nutrient management (combinations of inorganic fertilizer, mulching, and manure) as a key win-win strategy in the Kenyan context, increasing yields and revenues while providing a buffer against the negative impacts of climate change. According to Bryan et al., (2013) the benefits in terms of yield improvements far outweigh the costs of purchasing and applying fertilizers and manure in the study sites.

Scaling up

All these mitigation options have associated costs that determine the existence of a gap between what could potentially be achieved, and the mitigation achieved because of adopting these practices. According to Herrero et al. (2016), one option would be to improve the adoption rates of these strategies and other mitigation options, through investments that reduce transaction costs and provide services and incentives to farmers to adopt selected practices. These should be accompanied by GHG efficiency payment systems at the farm gate (such as payment of low emissions premiums per kilogram of animal product produced) and by setting restrictions on carbon emissions for the livestock sector.

According to Solymosi et al. (2016) silvopastoral systems[4] have shown promise in South America as evidenced by many studies conducted in the region and a series of successful enterprises. They argue that silvopastoral systems provide the benefits of land-use diversification, and contribute to biodiversity conservation and erosion control while, at the same time, reducing pressure on natural forests. The also offer a more balanced cash flow profile that reduces productive and economic risks and increases the resilience of producers in times of crisis and can make significant contributions in social terms, through job creation and promotion of a processing industry associated with the production of quality wood.

[4] Silvopastoral systems combine tree growing with the production of livestock, including pasture systems containing trees that are widely spaced or planted in clusters throughout the pasture. These systems have been proposed to increase efficiency while reducing the environmental burdens of extensive ranching systems. Intensive silvopastoral systems (ISPS) are a type of silvopastoral system that combine high-density cultivation of fodder shrubs with improved tropical grasses and tree species or palms that have the potential to deliver much more feed of higher quality (see Grebner et al. (2022).

Despite all the benefits associated with these systems described in the literature, the level of adoption remains low. Solymosi et al. (2016) admit that silvopastoral systems have been proven to be less profitable than forestry systems while Murgueitio et al. (2016) highlight three main barriers that hinder the multiplication of pastoral-forestry systems: the low availability of capital to invest in land-use changes in small and medium-sized producers; the need for appropriate technical assistance; and labor supply deficits in some regions. Herrero et al. (2016) argue that in many cases there would be a need to implement incentive policies for technology adoption such as GHG efficiency payment systems, establishing restrictions on carbon emissions for the livestock sector.

Kaimowitz and Angelsen (2008) have a more pessimistic view of the possibilities of intensification of livestock based on the adoption of improved pastures or silvopastoral systems. They argue that it will be difficult to get farmers to adopt capital- and labor-intensive techniques in areas that still have abundant land and forests. This is because relative price ratios not only suggest that extensive land systems will be more profitable in these circumstances, but local market imperfections may prevent farmers from obtaining enough labor and capital to invest in such techniques, even when they are profitable.

The dairy sub-sector is the best positioned to pursuit intensification and technical change given that it has received significant attention and interventions over the years to enhance productivity, with notable initiatives such as the Small-holder Dairy Project in the late 1990s. Climate-smart technologies for dairy production are well-documented, and the Kenya Climate Smart Agriculture Project (KCSAP) has provided valuable insights in this area. SDL (Sustainable Dairy Landscapes) has proposed the Dairy NAMA, which emphasizes an innovative financing strategy to attract private sector investment in low-emission and climate-resilient dairy development. This strategy leverages public funds, including technical assistance grants, low-interest loans, and loan guarantees (Mbae et al., 2021).

Not all livestock production systems in Kenya can be targeted for intensification. McDermott et al. (2010) argue that sustainable intensification of smallholder livestock systems must be targeted to those sectors and areas most likely to get positive social welfare returns and where natural resource conditions allow for intensification. For McDermott et al., targeting is critical to choosing which systems with livestock can be intensified. Extensive rain-fed systems could intensify with enabling policies and appropriate investments. In more fragile environments, deintensification is required to avoid irreversible damage to ecosystems.

This is likely the case of the ASALs regions, which requires a multifaceted approach to improve livelihood options given that the adoption of new technologies and improved productivity cannot play a major role as low population densities and high transport costs may discourage the intensification of livestock production. For example, a study carried out in Kajiado County in the Southern Maasai rangelands of Kenya (Omondi et al., 2012) revealed that access to livestock technologies and services was hampered by institutional, technological, environmental, and economic factors. Inadequate government staff, long distances to service providers, and weak institutional linkages were the most common problems encountered by pastoralists.

Institutional innovations seem to be more important for adaptation and mitigation in beef production. As reported by Mbae et al. (2021), various entities, including government agencies like the National Drought Management Authority (NDMA), NGOs, and county governments, are implementing several initiatives in these areas. Specialized efforts are directed towards rangeland management, disease control, and livestock marketing at a larger scale. Examples cited by Mbae et al. (2021) include the Northern Rangelands Trust and the International Union for Conservation of Nature (IUCN). Additionally, projects such as the "Restoration of degraded land for food security and poverty reduction in East Africa and the Sahel" led by the World Agroforestry Centre, focus on restoring degraded lands. Rangeland reseeding technologies have been developed by the Kenya Agriculture and Livestock Research Organization (KALRO) through various projects. Finally, Mbae et al. (2021) highlight Kenya’s undergoing reforms to its legal framework for animal health and livestock marketing through different bills. These reforms aim to align the animal health system with international standards, strengthen livestock marketing, vaccine production, and combat tsetse flies and trypanosomiasis, among other objectives.

To get a sense of the possibilities of intensification of livestock production, Figures 5.1 and 5.2 show the distribution of the stock of beef and dairy cattle, sheep and goats, and camels across counties with different proportions of land area in arid and very arid agroecologies. If regions with more than 80 percent of their land under arid and very arid conditions are in most cases fragile agroecologies with small potential for intensification, then 66 percent of beef cattle, 37 percent of dairy, and more than 70 percent of sheep and goats' stock cannot be targets for intensification. Given that sheep, goats, and camels are the dominant species in arid regions, the focus should then be on cattle. The most possibilities for further intensification and productivity growth appear to be in dairy production with 52 percent of its stock in regions with less than 50 percent of arid land. Only 22 percent of the stock of beef cattle is found in these regions while another 12 percent is in regions with 50 to 80 percent of arid agroecologies.

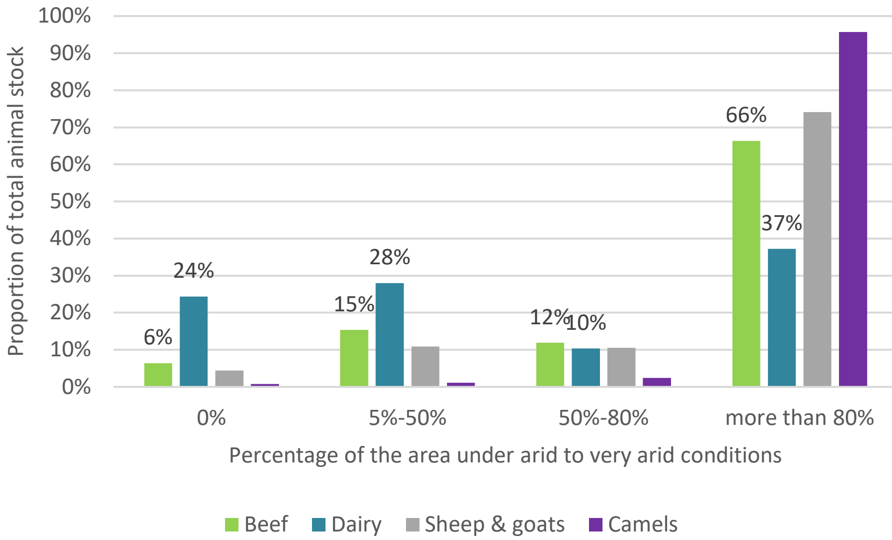
We conclude that because of constraints imposed by agro-ecologies and fragile natural resources, roughly 50 percent of the dairy stock and 22 percent of the beef cattle stock could be, in principle, targets of technology adoption and intensification to accelerate productivity growth and reduce the intensity of GHG emissions. Given the constraints for technology adoption faced by livestock keepers briefly discussed in this section, this could be thought of as a ceiling for livestock intensification. If this is the case, the impact of intensification of livestock production on mitigation of GHG emissions is expected to be very small but still relevant for the development of the dairy sector. The largest mitigation potential in the dairy sector seems to be related to promoting biogas on dairy farms and reducing fossil fuel use in dairy processing enterprises, although these changes are considered part of the changes needed in the energy sector (Mbae, 2021). Presented in this way, the contribution of the dairy sector to the mitigation targets is perceived as "not significant at national scale" (Mbae, 2021).

Finally, it is important to comment on the lack of intensification, low yields and low use of fertilizer in crop production that results in very low GHG emissions, high emission intensity and diminishes the country's capacity to increase resilience and adapt food crops to climate change. A recent study (Nin-Pratt, 2023) investigated the performance of agriculture in Kenya, comparing the total factor productivity (TFP) and technical efficiency of sub-counties in the Central Highlands, Rift Valley, and Western agro-ecologies. These regions collectively contribute to over two-thirds of Kenya's agricultural output. The study found that efficient sub-counties allocate more land to export and high-value crops, while dedicating a smaller portion to staple crops like maize. Efficient sub-counties also exhibited higher fertilizer and input usage per worker and per hectare of cultivated land and a higher proportion of irrigated land compared to inefficient sub-counties. Consequently, the efficient sub-counties generated approximately three times more output, land productivity, and labor productivity compared to the inefficient sub-counties.

The differences between efficient and inefficient sub-counties can be attributed to the presence of institutional frictions or rigidities that prevent unproductive farmers from exiting the agricultural market, as suggested by Gollin (2021). In a well-functioning market, less effective farmers would typically move out of agriculture and sell or rent their land to more skilled farmers. However, this reallocation process appears to be hindered in Kenya, resulting in a misallocation of labor, capital, and managerial effort, leading to overall inefficiency and reduced productivity.

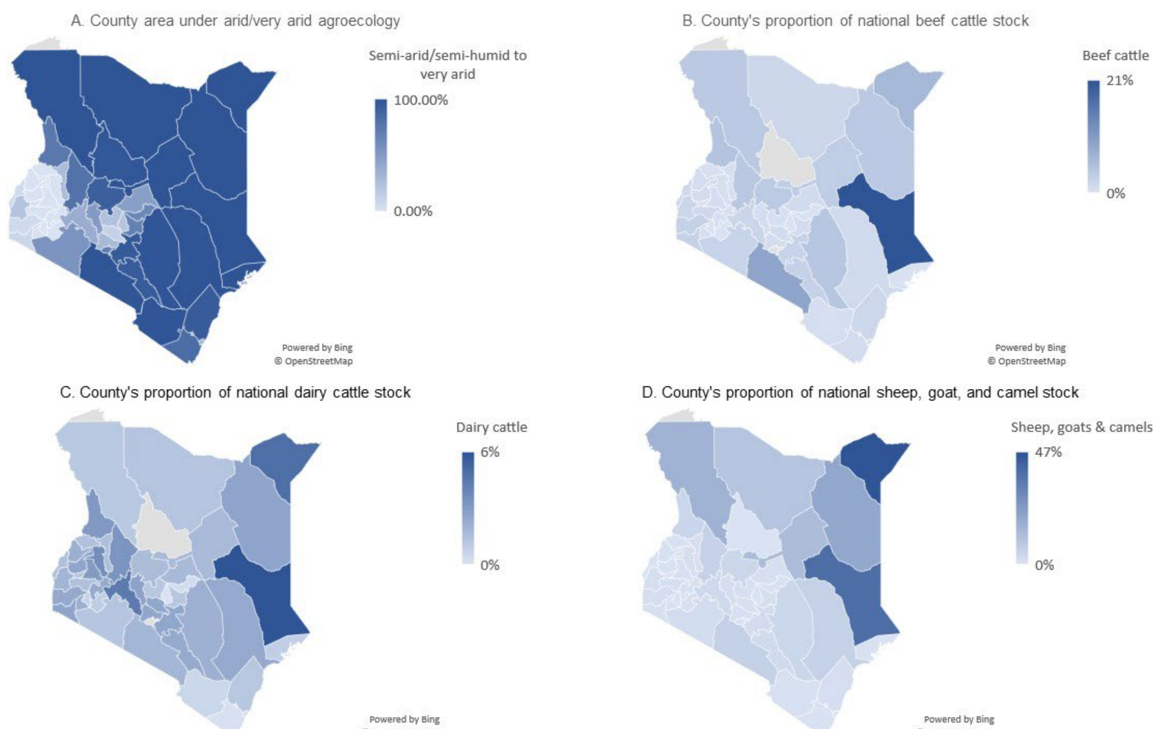
The presence of "land market frictions" has implications for investment and technical change in the agricultural sector and therefore for Kenya’s capacity to adapt crop production to climate change and increase food security. Limited access to land discourages investments in agronomic management and efficient fertilizer use. Vulnerable households tend to diversify their income from non-agricultural sources to minimize risks, rather than focusing on intensifying their production. In areas with abundant land, households are more likely to expand production by cultivating more land (extensification) rather than striving to increase productivity. Muraoka et al. (2015) highlight the importance of land rental markets in Kenya as a means for land-constrained rural households to access additional land for cultivation, suggesting that there is untapped potential in land rental markets to promote agricultural production and food security in rural Kenya.

Figure 5.1–Distribution of the stock of beef and dairy cattle, sheep and goats, and camels across regions with different proportions of land area in arid and very arid agroecologies



Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

Figure 5.2–Proportion of county's area under arid/very arid agroecology and proportion of total animal stock of different species by county.



Source: Elaborated by author based on Crippa et al., (2021), EDGAR, 2022), and Kenya, National Bureau of Statistics (2006, 2022, 2019a, 2019b).

6. CONCLUSIONS

This study contributes to the understanding of key drivers of national GHG emissions from the food system in Kenya using an environmentally extended input-output (EEIO) table. The EEIO is especially suited for this task as it allows the calculation of indirect emissions by sector and of emissions embodied in final goods. Direct emissions of activity *j* are those generated by j's production process while indirect emissions are those generated by other activities to produce the inputs used by activity *j*. Emissions embodied in final goods reflect the amount of GHG emissions generated to produce those goods. Results show that agriculture is by far the largest emitter of direct GHG emissions in Kenya, accounting for 61 percent of total emissions, mostly from enteric fermentation and manure management from livestock production. However, very different picture results when indirect emissions are accounted for. Indirect emissions represent only 12 percent of total emissions in agriculture, mostly explained by the low level of indirect emissions in livestock (between 90 and 98 percent of livestock emissions were direct emissions). The share of agriculture in overall indirect emissions was 8 percent and only 5 percent for livestock. This brings down the share of agriculture in total emissions (direct plus indirect) to 35 percent. Still, livestock activities show the highest levels of emission intensity among all sectors. For every million KSh of output produced, beef cattle generate about 65 tons of CO2eq. In comparison, the emission intensity of rice and maize, the crops showing the highest emission intensity, was low compared to that of livestock at only 20 and 10 tons per million KSh of output, respectively.

The measure of embodied emissions in final consumption goods shows that most GHG emissions in Kenya (including emissions embodied in imports) were generated to supply goods to final private consumption. Values of embodied emissions in export and import goods show that Kenya is an importer of emissions embodied in agricultural goods with about half of this trade balance explained by net imports of emissions embodied in products from the food industry. The remaining half percent results from a similar negative trade balance of embodied emissions in cereals and livestock products.

In this context, to reduce agricultural GHG emissions, Kenya will need to tackle emissions in the livestock sector. Past studies suggest that the greatest potential for reducing livestock GHG emissions is through the implementation of different technologies and practices that also contribute to increasing productivity, including improvements in feed quality, such as the use of improved or cultivated pastures, the use of supplements such as grains that increase the digestibility of the feed consumed, changes in pasture practices and land use, and the change of ruminant breeds.

The dairy sub-sector is the best positioned among livestock sub-sectors to advance intensification and technical change given that it has received significant attention and interventions over the years to enhance productivity and that climate-smart technologies for dairy production are well-documented. On the other hand, institutional innovations appear to be more important for climate adaptation and mitigation of GHG emissions in beef production, mostly located in the fragile agro-ecology of the ASALs, with efforts directed towards rangeland management, disease control, and livestock marketing at a larger scale.

Because of constraints imposed by agro-ecologies and fragile natural resources, roughly 50 percent of the dairy stock and 22 percent of the beef cattle stock could be, in principle, targets of technology adoption and intensification to accelerate productivity growth and reduce the intensity of GHG emissions. If this is the case, the impact of intensification of livestock production on mitigation of GHG emissions is expected to be very small but still relevant for the development of the dairy sector.

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APPENDIX

Table A1. Correspondence between sub-sectors of the 2019 I-O table and activities/commodities in the 2003 SAM

2019			2003		
	Activity/Commodity	Code	Activities	Commodities	Description
1	Maize	maiz	amaiz	cmaiz	Maize
2	Wheat	whea	awhea	cwhea	Wheat
3	Rice	rice	arice	crice	Rice
4	Other cereals	ocer	abarl	cbarl	Barley
			aogrn	cogrn	Other cereals
5	Roots & tubers	root	aroot	croot	Roots & tubers
6	Pulses and oil crops	puls	aoils	coils	Pulses & oil seeds
7	Fruits	frui	afrui	cfrui	Fruits
8	Vegetables	vege	avege	cvege	Vegetables
9	Cut flowers	cutf	acutf	ccutf	Cut flowers
10	Sugar cane	suca	asugr	csugr	Sugarcane
11	Coffee	coff	acoff	ccoff	Coffee
12	Tea	teal	atea	ctea	Tea
13	Crops, other	ocrp	acott	ccott	Cotton
			aocrp	cocrp	Others crops
14	Beef	beef	abeef	cbeef	Beef
15	Milk	milk	adair	cdair	Dairy
16	Livestock, other	olvs	apoul	cpoul	Poultry
			agoat	coliv	Sheep, goat and lamb for slaughter
			aoliv	cgoat	Other livestock
17	Fishing & aquaculture	fish	afish	cfish	Fishing
18	Forestry & logging	fore	afore	cfore	Forestry

Table A1. Correspondence between sub-sectors of the 2019 I-O table and activities/commodities in the 2003 SAM (continued)

	2019		2003		
	Activity/Commodity	Code	Activities	Commodities	Description
19	Mining and quarrying	mine	amine	cmine	Mining
20	Food industry	food	ameat	cmeat	Meat & dairy
			amill	cmill	Grain milling
			abake	cbake	Sugar & bakery & confectionary
			abevt	cbevt	Beverages & tobacco
			aomfd	comfd	Other manufactured food
21	Light manufactures	lght	afoot	cfoot	Textile & clothing
			awood	cwood	Leather & footwear
			aprnt	cprnt	Wood & paper
			apetr	cpetr	Printing and publishing
22	Petroleum	petr	atext	ctext	Petroleum
23	Chemical industries	chem	achem	cchem	Chemicals
24	Metals and machines	mach	amach	cmach	Metals and machines
25	Non metallic products	nmet	anmet	cnmet	Non metallic products
26	Electric & electronic equipment, motor vehicles & other	omnf	aoman	coman	Other manufactures
27	Construction	cons	acons	ccons	Construction
28	Water supply; sewerage, waste management	wate	awatr	cwatr	Water
29	Electricity supply	sele	aelec	celec	Electricity
30	Wholesale and retail trade; repairs	trad	atrad	ctrad	Trade
31	Accommodation and food service activities	hote	ahotl	chotl	Hotels
32	Transport	trans	atran	ctran	Transport
33	Information and communication	ictm	acomm	ccomm	Communication
34	Financial and insurance activities	fina	afsrv	cfsrv	Finance
35	Real estate	rees	arest	crest	Real estate
36	Public administration and defence	admn	aadmn	cadmn	Adminsitration
37	Health & education	hedu	aheal	cheal	Health
			aeduc	ceduc	Education
38	Other services	osvc	aosrv	cosrv	Other services

Source: Elaborated by authors based on Crippa et al. (2021), EDGAR (2022), and Kiringai et al. (2006).

Table A2. Emission intensity matrix (tons of CO_2eq/million KSh)

	code	maiz	whea	rice	ocer	root	poil	frui	vege	cutf
1	maiz	7.96	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.02
2	whea	0.00	1.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	rice	0.00	0.00	12.46	0.00	0.00	0.00	0.00	0.00	0.00
4	ocer	0.00	0.00	0.00	2.04	0.00	0.00	0.00	0.00	0.00
5	root	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00
6	poil	0.00	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00
7	frui	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00
8	vege	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00
9	cutf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.78
10	suca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	coff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	teal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	ocrp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	beef	0.04	0.01	0.04	0.02	0.02	0.02	0.01	0.02	0.04
15	milk	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.02
16	olvs	0.05	0.01	0.04	0.02	0.02	0.02	0.01	0.03	0.05
17	fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	fore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	mine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	food	0.15	0.03	0.13	0.05	0.07	0.08	0.05	0.08	0.15
21	lght	0.06	0.01	0.06	0.02	0.04	0.04	0.03	0.03	0.37
22	petr	0.18	0.04	0.19	0.07	0.13	0.11	0.08	0.09	0.19
23	chem	0.83	0.16	0.69	0.31	0.16	0.41	0.22	0.53	0.49
24	mach	0.35	0.07	0.31	0.12	0.17	0.18	0.26	0.19	0.41
25	nmet	0.14	0.03	0.13	0.05	0.06	0.07	0.04	0.08	0.15
26	omnf	0.25	0.03	0.15	0.05	0.22	0.11	0.04	0.08	0.08
27	cons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	wate	0.12	0.03	6.52	0.04	0.10	0.08	0.10	0.12	0.40
29	sele	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.03
30	trad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	hote	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	trans	0.06	0.02	0.04	0.02	0.10	0.05	0.11	0.13	0.33
33	ictm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	fina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	rees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	admn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	hedu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	osvc	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.00	0.01

Table A2. Emission intensity matrix (tons of CO2eq/million KSh) (continued)

	code	suca	coff	teal	ocrp	beef	milk	olvs	fish	fore
1	maiz	0.01	0.02	0.01	0.01	0.02	0.04	0.01	0.01	0.00
2	whea	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
3	rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	ocer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	root	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	poil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	frui	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	vege	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	cutf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	suca	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	coff	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	teal	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00
13	ocrp	0.00	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00
14	beef	0.02	0.04	0.02	0.02	59.50	0.09	0.02	0.02	0.01
15	milk	0.01	0.02	0.01	0.01	0.02	38.19	0.01	0.01	0.00
16	olvs	0.02	0.05	0.02	0.02	0.05	0.09	63.71	0.02	0.01
17	fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00
18	fore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
19	mine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	food	0.06	0.15	0.08	0.08	0.16	0.31	0.06	0.06	0.03
21	lght	0.03	0.07	0.03	0.04	0.04	0.01	0.01	0.08	0.04
22	petr	0.11	0.20	0.10	0.12	0.15	0.04	0.03	0.21	0.11
23	chem	0.25	0.84	0.48	0.37	0.57	0.11	0.06	0.10	0.05
24	mach	0.13	0.40	0.28	0.27	0.77	0.07	0.09	0.12	0.06
25	nmet	0.06	0.14	0.07	0.07	0.21	0.03	0.24	0.06	0.03
26	omnf	0.07	0.10	0.08	0.06	0.06	0.02	0.01	0.07	0.04
27	cons	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
28	wate	0.07	0.14	0.06	0.09	2.15	0.12	0.49	0.09	0.05
29	sele	0.03	0.02	0.01	0.02	0.03	0.01	0.01	0.01	0.00
30	trad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	hote	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	trans	0.82	0.07	0.07	0.12	0.04	0.06	0.01	0.01	0.01
33	ictm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	fina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	rees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	admn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	hedu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	osvc	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
	Total	**2.64**	**3.55**	**1.77**	**2.68**	**63.82**	**39.21**	**64.75**	**1.01**	**0.60**

Table A2. Emission intensity matrix (tons of CO2eq/million KSh) (continued)

	code	mine	food	lght	petr	chem	mach	nmet	omnf	cons
1	maiz	0.05	0.79	0.20	0.19	0.13	0.01	0.04	0.08	0.05
2	whea	0.01	0.18	0.05	0.04	0.03	0.00	0.01	0.02	0.01
3	rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	ocer	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	root	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	poil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	frui	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	vege	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	cutf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	suca	0.00	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00
11	coff	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	teal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	ocrp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	beef	0.12	1.73	0.45	0.41	0.28	0.02	0.08	0.17	0.11
15	milk	0.05	0.68	0.18	0.16	0.11	0.01	0.03	0.07	0.04
16	olvs	0.12	1.81	0.47	0.43	0.29	0.02	0.09	0.18	0.11
17	fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	fore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	mine	1.99	0.00	0.01	0.01	0.00	0.00	0.07	0.00	0.01
20	food	0.41	5.93	1.53	1.40	0.95	0.07	0.28	0.58	0.36
21	lght	0.30	0.22	6.83	0.42	0.30	0.02	0.09	0.20	0.21
22	petr	1.40	0.56	1.73	5.96	0.90	0.26	0.81	0.77	1.29
23	chem	0.90	0.85	2.09	2.28	6.98	0.11	1.08	1.00	0.81
24	mach	1.21	1.01	3.01	2.31	2.20	15.81	0.57	1.97	2.48
25	nmet	1.43	0.38	1.65	1.37	0.92	0.07	16.54	0.56	2.68
26	omnf	0.24	0.15	0.31	0.29	0.59	0.02	0.12	6.68	0.19
27	cons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
28	wate	0.51	0.55	6.59	0.68	0.50	0.37	0.17	0.35	0.36
29	sele	0.11	0.11	0.16	0.15	0.13	0.25	0.28	0.10	0.12
30	trad	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00
31	hote	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	trans	0.26	0.14	0.24	0.21	0.14	0.16	0.05	0.09	0.12
33	ictm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	fina	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.01	0.01
35	rees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	admn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	hedu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	osvc	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	Total	**9.14**	**15.18**	**25.55**	**16.37**	**14.48**	**17.20**	**20.31**	**12.85**	**9.57**

Table A2. Emission intensity matrix (tons of CO2eq/million KSh) (continued)

	code	wate	sele	trad	hote	trans	ictm	fina	rees	admn
1	maiz	0.01	0.04	0.03	0.15	0.02	0.03	0.01	0.00	0.03
2	whea	0.00	0.01	0.01	0.03	0.00	0.01	0.00	0.00	0.01
3	rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	ocer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	root	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	poil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	frui	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
8	vege	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9	cutf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	suca	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
11	coff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	teal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	ocrp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	beef	0.02	0.08	0.07	0.31	0.04	0.08	0.03	0.01	0.07
15	milk	0.01	0.03	0.03	0.36	0.02	0.03	0.01	0.00	0.04
16	olvs	0.02	0.09	0.08	1.70	0.05	0.08	0.03	0.01	0.14
17	fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	fore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	mine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	food	0.06	0.27	0.25	1.05	0.15	0.26	0.10	0.03	0.24
21	lght	0.02	0.13	0.27	0.23	0.08	0.33	0.25	0.08	0.16
22	petr	0.23	1.02	0.78	0.47	0.30	0.64	0.18	0.06	0.63
23	chem	0.13	0.48	0.53	0.60	0.48	0.71	0.23	0.07	0.54
24	mach	0.24	0.96	0.70	0.54	0.32	0.56	0.24	0.07	1.46
25	nmet	0.12	0.29	0.25	0.30	0.16	0.26	0.12	0.04	0.33
26	omnf	0.04	0.11	0.18	0.16	0.28	0.34	0.09	0.03	0.23
27	cons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	wate	62.74	0.22	0.44	0.78	0.17	0.84	0.42	0.13	0.55
29	sele	0.01	8.24	0.08	0.66	0.14	0.43	0.08	0.03	0.12
30	trad	0.00	0.00	0.13	0.01	0.01	0.01	0.01	0.00	0.00
31	hote	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.01
32	trans	0.02	0.07	0.39	0.17	4.96	0.23	0.13	0.04	0.08
33	ictm	0.00	0.00	0.01	0.00	0.00	0.14	0.01	0.00	0.00
34	fina	0.00	0.01	0.03	0.02	0.01	0.01	0.14	0.00	0.01
35	rees	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.13	0.01
36	admn	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.37
37	hedu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	osvc	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
	Total	**63.67**	**12.06**	**4.28**	**7.84**	**7.19**	**5.03**	**2.10**	**0.74**	**5.02**

Table A2. Emission intensity matrix (tons of CO2eq/million KSh) (continued)

	code	hedu	osvc
1	maiz	0.03	0.04
2	whea	0.01	0.01
3	rice	0.00	0.00
4	ocer	0.00	0.00
5	root	0.00	0.00
6	poil	0.00	0.00
7	frui	0.00	0.00
8	vege	0.00	0.00
9	cutf	0.00	0.00
10	suca	0.00	0.00
11	coff	0.00	0.00
12	teal	0.00	0.00
13	ocrp	0.00	0.00
14	beef	0.06	0.08
15	milk	0.04	0.03
16	olvs	0.15	0.08
17	fish	0.00	0.00
18	fore	0.00	0.00
19	mine	0.00	0.00
20	food	0.22	0.27
21	lght	0.22	0.21
22	petr	0.48	0.58
23	chem	0.43	0.43
24	mach	0.59	0.53
25	nmet	0.80	0.19
26	omnf	0.16	0.13
27	cons	0.01	0.00
28	wate	0.96	0.50
29	sele	0.16	0.05
30	trad	0.00	0.00
31	hote	0.01	0.00
32	trans	0.07	0.15
33	ictm	0.00	0.00
34	fina	0.00	0.01
35	rees	0.01	0.00
36	admn	0.01	0.00
37	hedu	0.13	0.00
38	osvc	0.00	0.13
	Total	**4.56**	**3.44**

Source: Elaborated by authors based on Crippa et al. (2021), EDGAR (2022), and Kiringai et al. (2006).

Table A3. Embodied emissions in final consumption, 2019 (Gg of CO2eq)

	code	Exports	Imports	Final domestic	Rural HH	Urban HH	Gov	Cap. Formation	Inventory change
1	maiz	90	281	1,446	1,013	141	243	33	16
2	whea	20	146	206	125	19	24	4	33
3	rice	0	296	409	189	207	11	2	1
4	ocer	2	5	88	0	0	26	5	57
5	root	0	0	132	96	35	0	0	1
6	poil	0	1	255	177	75	0	0	2
7	frui	7	0	93	66	26	0	0	1
8	vege	9	0	63	33	30	0	0	1
9	cutf	360	0	79	0	0	0	0	79
10	suca	5	13	85	0	0	0	0	85
11	coff	28	2	10	3	7	0	0	0
12	teal	51	1	52	0	0	0	0	52
13	ocrp	6	0	10	0	0	0	0	10
14	beef	191	521	15,849	15,616	11	187	35	0
15	milk	63	171	10,635	10,510	43	68	13	0
16	olvs	213	583	21,140	20,725	166	209	40	0
17	fish	0	0	10	6	4	0	0	0
18	fore	0	0	14	12	1	0	1	0
19	mine	54	6	233	0	0	0	0	233
20	food	643	1,756	5,647	1,818	3,838	0	0	-9
21	lght	551	841	1,993	778	1,215	0	0	0
22	petr	513	2,873	3,389	426	1,342	0	0	1,621
23	chem	888	3,459	4,142	1,711	2,431	0	0	0
24	mach	1,201	8,756	8,627	72	579	0	7,975	0
25	nmet	387	1,311	4,786	0	0	0	0	0
26	omnf	799	3,740	3,676	31	247	0	3,398	0
27	cons	1	2	825	0	0	21	803	0
28	wate	693	1,390	7,990	402	5,441	2,147	0	0
29	sele	139	299	1,474	89	1,385	0	0	0
30	trad	0	0	0	0	0	0	0	
31	hote	0	0	88	29	59	0	0	0
32	trans	2,396	1,691	7,795	2,119	5,656	20	0	0
33	ictm	10	4	60	16	44	0	0	0
34	fina	14	24	129	15	114	0	0	0
35	rees	1	6	135	3	129	3	0	0
36	admn	1	1	311	1	1	310	0	0
37	hedu	0	0	121	9	15	98	0	0
38	osvc	17	11	85	56	22	4	3	0
	Total	**9,352**	**28,193**	**102,083**	**56,147**	**23,282**	**3,372**	**12,314**	**2,183**

Source: Elaborated by authors based on Crippa et al. (2021), EDGAR (2022), and Kiringai et al. (2006).

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