



Article Effective Mainstreaming of Agricultural Emissions into Climate Action Agenda: The Case of Institutions and Smallholder Dairy Production Systems, Western Kenya

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Abstract: Small-scale farming production systems are integral drivers of global sustainability challenges and the climate crisis as well as a solution space for the transition to climate compatible development. However, mainstreaming agricultural emissions into a climate action agenda through integrative approaches, such as Climate Smart Agriculture (CSA), largely reinforces adaptationmitigation dualism and pays inadequate attention to institutions' linkage on the generation of externalities, such as Greenhouse Gas (GHG) emissions. This may undermine the effectiveness of local-global climate risk management initiatives. Literature data and a survey of small-scale farmers' dairy feeding strategies were used in the simulation of GHG emissions. The effect of price risks on ecoefficiencies or the amount of GHG emissions per unit of produced milk is framed as a proxy for institutional feedbacks on GHG emissions and effect at scale. This case study on small-scale dairy farmers in western Kenya illustrates the effect of local-level and sectoral-level institutional constraints, such as market risks on decision making, on GHG emissions and the effectiveness of climate action. The findings suggest that price risks are significant in incentivising the adoption of CSA technologies. Since institutional interactions influence the choice of individual farmer management actions in adaptation planning, they significantly contribute to GHG spillover at scale. This can be visualised in terms of the nexus between low or non-existent dairy feeding strategies, low herd productivity, and net higher methane emissions per unit of produced milk in a dairy value chain. The use of the Sustainable Food Value Chain (SFVC) analytical lens could mediate the identification of binding constraints, foster organisational and policy coherence, as well as broker the effective mainstreaming of agricultural emissions into local-global climate change risk management initiatives. Market risks thus provide a systematic and holistic lens for assessing alternative carbon transitions, climate financing, adaptation-mitigation dualism, and the related risk of maladaptation, all of which are integral in the planning and implementation of effective climate action initiatives.

Keywords: agricultural emissions; adaptation–mitigation dualism; carbon transitions; climate smart agriculture; effectiveness; greenhouse gases; institutions; small-scale farmers; shifting vulnerabilities

1. Introduction

Greenhouse gas (GHG) emissions create common pool problems that transcend geographical boundaries and political and economic agents [1]. As passive flows, GHGs impact the occurrence and magnitude of extreme disaster events, i.e., droughts and floods [2,3]. This undermines the realisation of sustainable development objectives across nations [4], as well as amplifies the vulnerability of individuals and communities to already existing and new disaster risks [5]. The increased risks and vulnerability are reflected in the increased cost of mitigating climate-related disasters, such as droughts [6,7], as well increased need for adaptation among already vulnerable people [8]. However, economic instruments,



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). such as carbon taxes [9], have largely failed to achieve target reductions in GHG emissions [10,11]. This suggests the need for innovative alternative transitions [11,12], as well as effective multilevel environmental governance systems [1]. Some of the transformative approaches towards effectiveness include addressing adaptation–mitigation dualism [8]. Implicitly, effective transitions largely revolve around risk perception and incentives [12].

As part of a cooperative effort to mitigate global warming and adjust to climate change, countries document their plans to reduce emissions and/or sequester carbon as Nationally Determined Contributions (NDCs). This follows the 2015 United Nations Framework Convention on Climate Change (UNFCCC) climate agreement, herein referred to as the Paris Climate Agreement (PAAC). In accordance with the PAAC, NDCs communicate progress made, as well as resource gaps needed to meet the set ambitions [6]. NDCs signal the global resolve to adjust to emerging climate change-related risks while taking advantage of embedded opportunities, building better and addressing underlying socio-economic drivers that predispose humanity to disaster risks [6,13,14]. Such a strategy is predicated on voluntary collective action to halve current emission levels by 2050 and stabilise global climate [6]. Intuitively, the achievement of carbon neutral trajectories by 2050 [6] is underpinned by collective action and frameworks that identify as well as address interlinked Social-ecological System (SES) challenges [9,15].

Among other measures, this encompasses changes in processes, practices, structures, and institutions at an individual, organisational, and technological level [8,9]. Technological innovations, institutional and behavioural changes, and responsive social systems influence effectiveness in carbon capture and storage initiatives [16]. This highlights the importance of local contexts and aspirations in sustainability initiatives [15,17–19]. Local contexts increasingly provide opportunities for learning, innovation, and transformation.

Broadening climate action areas has great potential for immediate scaling mitigation and the closing of GHG emission gaps [5,20–22]. Promoting climate friendly policies at a community level is especially critical in reducing emission gaps [23]. Land use sectors [7,9], and food systems in particular, have been identified as critical in carbon transitions and capturing feedbacks [24]. In particular, Agriculture, Forestry, and Land Use (AFOLU), which accounts for at least 23% of global emissions [7,25,26], has emerged as a pivotal sector for intervention. AFOLU is thus expected to play a critical role in NDCs, as well as the multiple Sustainable Development Goals [27,28]. Though the cumulative contribution of small-holder farmers on GHG emissions is potentially significant, it is not prioritised in carbon transition initiatives.

A risk chain can be visualised in terms of shocks, internal and external drivers, their management, and outcomes [29]. This is relevant to understanding the linkage of management practices, GHG emissions, and the design of effective mitigation practices [24]. The logic has direct bearing on maladaptive practices in Agriculture, Forestry, and Land Use (AFOLU), which directly account for about 23% of the annual global emissions. Since maladaptive practices in AFOLU could exacerbate GHG effect [7], they emerge as a critical sector in climate action. Maladaptation increases the predisposition of ecosystems, economic activities, and social groups to secondary risks [30].

Decision making plays a significant role in global initiatives such as GHG emissions mitigation initiatives [7,9,31]. It is particularly critical in land use-based adaptation planning in developing countries where small-scale production agriculture is the main economic and livelihood activity [32]. The potential impact of small-scale farmer production systems on global resource use, environmental services, food security, and environmental externalities is particularly significant in sustainability initiatives [30].

Institutional dimensions, such as financing and market power, are critical in the upscaling of eco-efficient agricultural value chains and the mainstreaming of agricultural emissions into a global climate action agenda [33]. This underscores the need to capture institutional and economic processes and incentive systems for the management of externalities [34]. The role of institutions in the integration of adaptation and mitigation pathways, in particular, requires nuanced attention [35]. A focus on institutional interactions, such as price risks, is posited to play a transformative role in global initiatives, such as the green fund and climate adaptation fund. However, nuanced analysis of institutional interactions on shifting vulnerabilities and the amplification of GHG effect has not been a focus of most policy and research discourses.

Agricultural systems have the potential to narrow GHG emission gaps, play a significant role in NDCs, as well as address adaptation–mitigation dualism [26]. Exploiting this potential is invariably through CSA technologies. CSA approaches enhance synergies between productivity, resilience, and mitigation objectives [36]. Formal and informal institutional arrangements are known to mediate most of the GHG mitigation policy objectives [32]. Paucity of knowledge on the interaction between local level decision making and adaptation governance at global level [8] however exist. For instance, though some studies have analysed the role of risk in adoption of adaptation technologies e.g., [37], there is paucity of knowledge on how risk mediate social costs such as GHG emissions during adaptation.

Effective local responses [6,7,21], as well as global GHG emission mitigation strategies [38,39], encompass increased policy attention on local-level constraints that hinder the integration of international decisions into local climate change mitigation. They also include a focus on the role of incentives and innovative climate financing to scale up innovations [5,30]. Addressing the risk of maladaptation [5,30,40] is equally an urgent research and policy problem area [30].

Maladaptation occurs when adaptation action/ investment increases vulnerability of systems, sectors, or social groups to other risks. The bearing of risks by individuals and communities who are not party to their production, referred to as shifting vulnerabilities [30] is particularly given low attention. The article assesses and adopt the interplay between price risks and methane emissions in dairy cattle feeding as an innovative lens for effective local-global climate action initiatives. An illustration is made through a case study from western Kenya. The analytical lens could inform policy, research, and practice on the integration of shifting vulnerabilities and optimization of adaptation-mitigation synergies.

The novelty of this study lies in its ability to integrate the interplay of socio-economic and environmental dimensions in climate governance. This is one of the existing gaps in the narrowly focused carbon transition discourses. Further, it addresses intertwined market and production risk. Integrating the intertwined risk lenses is integral to the operationalisation of broader adaptation planning frameworks [40]. In essence, the analytical framework suggested herein has the potential to enhance the design and implementation of alternative carbon transitions and inclusive climate financing interventions for resource-constrained small-scale farmers, as well as advance the mainstreaming of agricultural emissions into global GHG mitigation initiatives. In exploring this relationship, we sought to answer the following questions:

- Is local decision making at microlevel in smallholder farmer agricultural production critical to the effectiveness of existing local–global GHG mitigation strategies?
- Do price risks have an influence on environmental footprints, such as methane emissions?

Following the introduction, Section 2 provides the background to the study. Section 3 gives the data collection and analysis methods, while Section 4 provides the results. Section 5 discusses the findings and concluding remarks.

2. Background of the Study

2.1. Adaptation–Mitigation Dualism

Though external and internal drivers are responsible for the adoption and diffusion of adaptation and mitigation polices [18,19], there is a lack of a commonly agreed core goal [41,42]. This tends to wrongly frame adaptation as a local initiative [19], hence low consideration for spillovers, such as GHG emissions [43,44]. Until recently, policy framing has considered adaptation as a local disaster reduction response. Accordingly, most climate financing focuses on mitigation at the expense of adaptation [45]. This underscores the need to address the simplistic dualism between adaptation and mitigation [8]. Several

reasons support this position. Foremost is the risk of maladaptation [30,40] and increased evidence of spillover effect from adaptation across geographical jurisdictions [46]. This is underpinned by a growing concern that adaptation–mitigation dualism undermines resilience objectives [8,47].

Given that climate change amplifies the exposure and sensitivity of humans and ecosystems to harm, it increases the importance of adaptation action [8,47]. Importantly, climate crisis disproportionately impacts resource-constrained vulnerable segments, such as small-scale farmers [8]. This observation is critical in developing nations where the dominant small-scale farming production systems have the potential to deliver about 21–40% of the direct emissions mitigation targets [32]. This partly explains the increasing focus by developing nations on adaptation–mitigation co-benefits to meet their NDC ambitions [28]. Specifically, the lagged relationship between GHG emissions and current and future impacts being evident calls for timely attention on adaptation [8].

Local–extra level institutions are critical in climate action initiatives in general and adaptation planning [18,19]. In most cases, extra local institutions influence carbon transition visions or lock-ins [48]. Lock-ins in turn inform and justify the technological, institutional, policy, and behavioural choices [49,50]. The effect of lock-ins is thus multifaceted. Firstly, they could undermine innovation and bias policy choice efforts on generic yet locally irrelevant alternatives. Secondly, institutional lock-ins by default may overlook critical transition pathways that provide opportunity for widespread upscaling of GHG mitigation. Finally, institutional lock-ins may constrain individual capacity to adopt management choices that positively impact effectiveness in climate action. The understanding of institutional–human behaviour interplay [49] is thus critical in overcoming lock-ins and fostering alternative innovative decarbonisation trajectories [50].

2.2. Risk, Institutions, Micro-Level Decision Making, and Environmental Externalities

Institutions are formal and informal mechanisms that mediate the behaviour of various agents in an economic system [51]. Institutions influence access to resources and markets, shape (dis)incentives, as well act as channels for external interventions within which individual and collective action can be realised [18]. Institutional interplay is thus critical in the planning and implementation of effective climate interventions [52], more so the integration and scaling up of CSA pillars [53,54], as well as policy coherence [2]. According to [2], institutions either incentivise or constrain the primary agents, such as small-scale farmers and the production of environmental goods and services.

Policy coherence refers to the extent to which a suite of selected policy options and incentives converge to impact effectiveness [55]. Implicitly, policy coherence mediates the optimisation of synergies and co-benefits in climate action [45]. Since adaptation is a decision making process [56], there is need to appreciate the influence of incentive system on farmer decision making and its impact on environmental spill overs [57]. Key among this is the effect of institutional fabric on risk [34]. Market prices (risks) are among the most critical determinants in climate compatible technologies uptake [58–60]. Risk be critical in livestock production on the account that they are major drivers of environmental footprints [61].

Risk describes economic, legislative, climatic, and social dynamics that lower profits or increase expenses [62,63]. Accordingly, exploring the linkage between institutions, risk and GHG emissions is critical in search for alternative carbon transitions. In agriculture, the interaction between market risks and environmental spillovers is more often framed in terms of income and consumption smoothening strategies [64]. In livestock production for instance, resource poor farmers tend to stock hardy breeds that dependent on locally available forages other than marketed concentrates [65]. Evidently, resource constraints have the potential to limit farmer adaptive capacity to adopt alternative technologies that mitigate pool problem, such as CH₄. In ruminant livestock, the relationship is evidenced by low uptake of technologies that reduce emissions [66].

2.3. Agricultural Emissions: The Case of the Livestock Subsector

Food systems are the largest drivers of global environmental change [7]. In particular, the role of livestock in livelihoods, income and nutrition objectives [67], as well as its centrality in adaptation for communities under changing climate [68] increase its relevance in food transformation. As a key driver of environmental footprints [69], livestock produce most of the GHG emissions in AFOLU [68,69]. Ruminant livestock in particular account for about 44% of human activity related GHG emissions [70,71]. Most of the GHG emissions from livestock come as methane (CH₄), a highly potent global warming GHG [72]. Accordingly, ruminant livestock provide opportunities for rapid reduction in CH4 emissions [20,72]. They are also critical analytical lens for innovative scaling of local contexts into adaptation and mitigation planning [73]. Ruminant cattle in general, and the dairy sector value chain lends itself to scaling, replication, analytical and conceptual innovation.

2.4. The Case of Resource-Constrained Farmers, Western Kenya

AFOLU related sectors are associated with about 70% of GHG emissions in Kenya. About 90% of these emissions is attributed to livestock [74]. The GHG emissions are expected to rise from 73 million tons of carbon dioxide equivalent (Mt CO₂-eq) in 2010 to 143 MtCO₂-eq in 2030. At less than 0.01% of global emissions, Kenya's share in global emission generations is negligible [75]. Nonetheless, Kenya intends to increase the share of emissions from agriculture by about 5% by 2030. About 1.3 Mt CO₂-eq of the 100 Mt CO₂-eq is projected to be generated from the agricultural sector.

The significance of the livestock subsector in Kenya is underscored by the dominance of small-scale farmers, who account for about 73% of all marketed milk [76]. Agricultural systems and the livestock subsector are thus critical in the pursuit of Kenya's NDC ambitions [75]. Kenya's NDCs largely focus on low-carbon policies to pursue national and agricultural development objectives [77]. Though such policies are consistent with external coherence and integration principles, they lack a comprehensive cross-sectoral strategy and overarching goal in managing environmental externalities. This is compounded by a lack of expertise for planning specific risk assessment at a local level [74].

Implicitly, most policies are characterised by inadequate understanding of the interplay between risk lenses in land use and the potential outcomes at local and extra-local levels [78]. For example, though innovative instruments, i.e., PES, have the potential to reduce GHG emissions [59], most of such projects and programs on climate change adaptation and mitigation are donor-driven with a tendency for duplication [79]. Duplication tends to undermine coherence and effectiveness [80].

The dairy subsector in Kenya is inefficient and characterised by high production and price risks. Such risks are amplified by climate change risks [81], as well as institutional constraints. For instance, the official milk marketing value chain is controlled by five of the 23 milk processors. The five processors represent about 80% of the milk value chain [82]. The oligopolistic market structure tends to compound market and price risks as evidenced through collusion tendencies (farmgate prices do not shift upwards during drought cycles, while during the rainfall season the prices often fall), which is in juxtaposition with the law of supply and demand. Apparently, extreme climatic events significantly increase price risks, hence the vulnerability of the poor smallholder farmers to financial risks [81]. The institutional reach in the smallholder dairy sector in Western Kenya is particularly low. For instance, none of the 23 processors and only a few of the 47 cooling plants are found in the Western Kenya counties of Kakamega and Bungoma [82].

Though vertical integration could address credit, input, and processing capacity constraints [65], policy interventions in the dairy subsector have been biased towards physical infrastructural development [83], i.e., construction of small scale milk collection and cooling plants. To a large extent, such interventions have failed to address price risks in the long run. The evident lack of policy coherence drives methane emission risks [81]. It also amplifies ecological threats to land, soil, water, and biodiversity [83].

2.5. Effectiveness Lens in Adaptation and Mitigation

Globally, policy response to climate change crisis has mainly been through adaptation and mitigation strategies [45]. Accordingly, effectiveness has emerged as critical to adaptation and mitigation planning [84]. Though effectiveness could be qualified on the basis of spatial and temporal metrics, externalities, as well the extent of synergy achieved between individual and collective action, it generally refers to the ability to achieve expressed objectives [85]. In policy analysis, effectiveness invariably connote the extent to which any given policy instrument and availed resources contribute to attainment of a specific policy goal [86].

The analytical lens on the effectiveness of policy effort focuses both on intended and unintended effects or implementation deficit as well as policy coherence or the extent to which vertical and horizontal integration is attained [87]. Intuitively, effectiveness examines the extent of interplay between local interests and institutions in resolving the fundamental drivers of the problem [5,30]. The definition of adaptation and mitigation implicitly provides the metrics for assessing the effectiveness of respective climate policy objectives. While mitigation focuses on technological, institutional, and behavioural actions that curtail the magnitude of GHG emissions, adaptation refers to preparedness and responses to consequences of climate change that take advantage of opportunities therein [88].

Externalities such as GHGs represent social costs that are allocated across time and geographical boundaries, hence shared responsibility for their mitigation [89]. This underscores the common but differentiated principles in global climate policy [13]. Implicitly, spillover systems and GHG emissions provide lenses for the assessment of effectiveness in socio-ecological system interplays at local scale and the implementation of development initiatives that do not compromise the needs of future generations [1-3,7].

2.6. Towards an Innovative Analytical Framework for Effective Local–Global Climate Action

Individual action provides the impetus for effective collective action and efficient steering of global commons, such as GHG mitigation [90]. Motivating individual action on mitigation and adaptation could thus be challenging for several reasons. First, mitigation qualifies as a public good, an attribute that undermines voluntary action among individuals [91]. The challenge is prevalent where weak incentives, price risks, and poor markets prevail [92]. The challenges seem to be anchored on game theory. According to game theory [93], the choices of a rational utility maximising individual conflict with collective-level objectives. Apparently, individuals tend to prioritise short-term objectives such as profit over long-term public good objectives, such as the internalisation of GHGs [2].

Fit is reflected in the extent to which policy captures and addresses scope issues, such as externalities, as well as time-related preferred discount rates [94]. Incentivising individual action is thus significant in climate action and green growth initiatives [8]. Incentives are particularly critical in the pursuit of development trajectories that curtail environmental footprints and the decarbonisation of economies [3,9].

A value chain comprises a full set of activities, value links, and feedbacks required to bring a service or a product, such as milk, from the production point as well as associated activities such as aggregation, processing, and distribution to the final consumer [33,95]. Such value chain feedbacks are visualised from the perspective of actors' input–output and institutional interdependencies [15,33,96]. Notably, horizontal and vertical linkages in a value chain influence information flow, standards, and market power [33], with a potential negative impact on voluntary action that internalises GHG emissions. In an oligopolistic market structure, for instance, price fixing, and collusion feedbacks could adversely impact sustainability objectives.

Literature suggest that the value chain development principles can be applied to identify social, economic and sustainability implementation gaps in CSA approaches [36]. To increase the probability of successful implementation and optimise integration of environmental, social and sustainability policy goals, Sustainable Food Value Chain (SFVC) suggest a focus on the most constraining factors such as price risks [33]. SFVC lends itself as

tool for identifying the root causes of performance gaps, as well as envisioning how value chain actors at scale can synergistically address the binding constraint [33]. The framework can be adapted to wide socio economic and sustainability challenges. Herein effective policy is presented as a framework that integrates the interplay between individual action, production, and market constraints, as well as potential outcomes at scale (Figure 1) Local and extra local actors are critical drivers in climate action planning [18,97]. In synthesis of existing literature (Figure 1), risk is framed as an integral attribute indecision making. Risk influences adoption of CSA technologies and/or maladaptation. In this way, risk disposition of an individual farmer is critical to effective climate action as it impacts the magnitude of GHG emissions and their diffusion across geographical, political, and economic spheres, as well as the adverse impact on ecosystems and third parties. Institutional lock-ins are also critical drivers in the choice of management choices and carbon transitions. This is in turn influenced by policy, legal and institutional frameworks. Effectiveness is thus framed as the extent to which institutional frameworks, local and extra local actors' impact collective action and drive synergies between adaptation and mitigation. The influence is seen from the extent to which the local and extra local actors, as well the institutional framework (legal, policy) is transformative in addressing adaptation-mitigation dualism.



Figure 1. A conceptual framework on role of risk on environmental externalities.

3. Methodology

3.1. Study Area

This study was conducted in Bungoma and Kakamega counties. These two counties in western Kenya are located between longitude 34°35′ E and latitude 0° and 0°15′ N [98]. Table 1 provides the socio-economic background relevant to this study. Crop agriculture and livestock are the main livelihood activities among small-scale farmers who dominate the area [76,98]. Kakamega county covers an area of 3051 km² with a population of 1,660,651. This translates to a population density of 544.3/km². Bungoma county covers an area of 3024 Sq. km with a population of 1,670,570, translating to 552 persons/Sq·km.

	Kakamega	Bungoma
Social Economic characteristic		
Total Population	1,867,579	1,670,570
Households (HH)	433,207	358,796
Area (Size) in Sq. km	3020	3023.9
Pop density (No. of persons)/km ²	618	552
HH size (persons per Household	4.3	4.6
% Poverty	50	52
% Ms use	95	72

Table 1. Social-economic characteristics for Kakamega and Bungoma Counties, Western Kenya.

Source: KNBS Census and Housing Report, 2019.

Rainfall levels, agricultural potential, and productivity in terms of livestock type, crop varieties, and actual/potential yield levels vary across administrative jurisdictions of the counties [98]. Generally, the two counties have experienced warming and intensive dry spells. Agriculture employs 80% of the population and is critical to livelihoods in the two counties. This is significant because poverty levels in the two countries are above 50% [76]. Poverty is one of the critical drivers of vulnerability to climate change risks and maladaptive practices in the dairy subsector.

3.2. Field Data and Literature Review

Mixed methods approach consisting of agent survey and methane emission simulation from various dairy cattle feeding strategies was employed in the study. A cross sectional survey design was used to collect information through a multistage sampling technique (Table 2). The sampling frame consisted of a list of farmers from target sub counties provided by personnel in the department of Agriculture. In Stage 1, Agroecological Zonation (AEZ) was used as proxy for rainfall amount and dairy feeding strategy adoption. During the second stage, population density was taken as proxy for land size and adoption of integrated production systems. Participating farmer households were then selected through lottery system. The semi structured questionnaire was administered between March and May 2019. The questionnaire focused on dairy feeding options and institutional factors influencing dairy feeding strategies.

Sampling **Data Collection Study Population Unit** Size (N) Method Instrument 400 Household Heads Multistage Questionnaire Feed producers Purposive 6 Interview schedule 13 Interview schedule Agro-vet shops Purposive FDG members 12 Interview schedule Purposive Farmer cooperative 7 Interview schedule Purposive managers Advisory organisation 5 Purposive/census Interview schedule Managers

Table 2. Summary of Study Population Units, Sampling Method, and Data Collection Instruments.

The information from household surveys was triangulated through Key Informant Interviews (KIs) and Focus Group Discussions (FDGs). Extensive literature on climate policy was undertaken from grey literature, i.e., books, as well as peer-reviewed publications. Focus Group Discussions (FGDs) were also undertaken to elicit information on factors influencing the choice of dairy feeding strategies.

3.3. *Empirical Models*

3.3.1. Gross Margin Analysis

Gross margins of various adaptation measures in terms of dairy cattle feeding strategies were calculated according to Equation (1). Input costs and output prices were obtained from farmers, feed stockists, and milk marketers.

$$\prod = R. Q - VC = R. Q - E_1 X_1 - E_2 S_2 - \dots E_n S_n$$
(1)

where:

$$\begin{split} &\prod = \text{Gross revenue;} \\ &R = \text{Price of the raw milk at farmgate;} \\ &Q = \text{Quantity of raw milk sold in Litres (L);} \\ &VC = \text{Total Variable cost of inputs in milk production;} \\ &S_i = \text{Amount of concentrate (legume fodder) in the feed ration;} \\ &E_i = \text{cost of ith concentrate (legume fodder) in the feed ration.} \end{split}$$

3.3.2. Methane Emission Simulation

Equation (2) provides the adopted simulation model. The model follows methanogenesis process described by [99]). Simulation was preferred because it is timeous, saves resources and allows for integration and utilisation of already existing literature data base [100,101]. Comparisons of various Ms and supplementation regimes were made against conventional strategies, namely Napier (*Pennisetum* species) and Boma rhodes (*Chloris gayana*).

Simulated models give a range of scenarios that can be tracked in both directions to visualise scenarios and project impacts in any socio-ecological system setting [102]. The non-linear monomolecular models were preferred apriori due to their flexibility across ration types and feeding levels. According to [99], non-linear monomolecular models are robust enough to accommodate data sets that do not provide detailed feed values. Furthermore, non-linear models account better for observations at the extreme CH_4 output and feed intake ratios. Feed value data in the simulation was obtained from [99,103–105].

Methane
$$(Mj/day) = 1.06 (S.E 2.41) + 10.27 (S.E 3.59)$$
 dietary forage
proportion + 0.87 (S.E 0.074) DMI (2)

where:

DMI = Dry matter intake. S.E = Standard error.

Assumptions in the Simulation

The complex nutritional interactions and enteric fermentation processes and physiological variations with age, environment, and lactation performance of dairy cattle called for several assumptions and simplifications. The main assumptions and methodological choices made in the simulation are:

- i. Animal breed/type does not significantly influence methane emission levels.
- ii. Optimum PH value of 6.3–7.4 is assumed due to its effects on absorptive processes, fibre degradation, and microbial recycling within the rumen.
- iii. Fermentation within the rumen and hind gut are similar.
- iv. No errors in analysis of feed stuffs whose values were used in methane simulation.
- v. No inherent variation in nutrient composition between samples of the same feed stuff (i.e., composition does not vary with soil types and weather and the time of cutting).
- vi. No substitution effect of legumes for stover in maize stover–legume-based rations.

3.3.3. Estimation of Ecoefficiency

In agriculture, GHG mitigation policy has shifted from absolute emissions to emissions per unit of product [72]. The policy is reflected through eco-certification initiatives in carbon markets that provide incentives and influence farmer decision making on their uptake [106]. The ecoefficiency approach biases innovation towards GHG emission mitigation to impact sustainability objectives [32]. Ecoefficiency is an integrated index for assessing the economic and environmental feasibilities [106]. Equation (3) is used to calculate ecoefficiencies according to Masuda [107]. The ecoefficiencies were based on Intergovernmental Panel on climate change (IPCC) default emission factors for livestock management [108]. The default global warming potential of 1 for CO_2 and 34 for CH_4 [88] were assumed.

$$Eco - efficiency = \frac{Net \ Farm \ Income}{Global \ Warming \ Potential}$$
(3)

The decision to supplement and the levels of supplementation thereof reflect the interaction between institutions, management options and risk attitude. The break-even price for dairy farmers during the survey was Kes 25 (100 Kes = 1\$). The break-even price provided guidance on the evaluation of market risk on ecoefficiency. The mean price for the lower band (Kes 20 and 15) and the upper band (Kes 30 and 45) provided the baseline scenarios. In fitting the data, 18 L/cow was adjudged as carbon neutral point. Three level of dairy productivity viz; the lower production point as 0–9 L; medium level of 9–18 L and the upper point of 18–27 L and 27–36 L.

4. Results

4.1. Dairy Feeding Adaptation Strategies

FGDs and key informant and farmer interviews revealed that Ms and deferred harvesting of Napier grass (*Pennisetum pauperum*) are the most preferred dairy cattle feeding risk management strategies. The risk management strategy was practiced by about 70% of the respondents (Table 3). Less than 15% and 3% of the farmers used hay and silage, respectively. Further, silage making as an adaptation opportunity, especially during peak and above normal rainfall periods, is poorly adopted. About 85% of the sampled households attributed this to a lack of technical knowhow and information. As a result, surplus fodder available during above normal/peak rainfall periods is wasted. The use of hay legumes was practiced by less than 1% of the farmers, who cited limited land sizes and a lack of technical information.

Table 3. Nutritional interventions practiced by farmers, Kakamega and Bungoma Counties, Kenya.

	% Aw	areness	% Ad	opted		
Nutritional intervention	KAK	BGM	KAK	BGM	OAW (%)	OA (%)
Molasses	25	21	15	12	23	13.5
Minerals	48	45	27.5	16.3	46.5	16.3
Legume fodder	5	7	1	1	6	1
Potato vines	25	42	13.5	33.5	33.5	24.4
Grain residues	40	23	25	3	31.5	14
Silage	30	28	3	2	29	2.5
Hay	76	42	13	9	59	11
Ms	95	90	87	83	92.5	85
Napier (Deferred)	85	75	75	65	80	70

Source: Authors field data analysis. OAW; Overall awareness, OA; Overall adopted, KAK, Kakamega; BGM, Bungoma.

Low milk producing dairy cattle breeds were evident in 65% of households in the Kakamega and 75% in the Bungoma respectively. The observation explains the low uptake of feed conservation strategies among farmers. The results from methane simulation suggest that delayed harvesting and utilisation of napier increases methane emission risk

by up to 30% (Table 3). Agroforestry encompasses the joint production of trees and/or legumes with livestock in the same agricultural production unit [109]. Though fodder legumes and agro-forestry systems have potential to mitigate CH_4 emissions, about 5% of the sampled households had adopted the system. Further, at least 85% of the respondents used Ms feeding strategies without any form of supplementation. As a result, most of the sampled households using Ms reported about 30% of the milk production potential from their dairy herds during droughts.

Table 4 provides the simulated CH₄ emission levels from different dairy feeding strategies in the study area. Ms had a mean of 0. 813 CO2-eq against 0. 608 CO₂-eq for Napier and 0.611 CO₂-eq for legume fodder and grain supplemented strategies. Though the highest CH₄ mitigation effect in the dairy feeding strategies from external inputs such as CSC are evident, the effect on CH₄ is not significantly different ($p \le 0.05$) from farm grown legume fodder such as *Luceana* and *Sesbania*. In effect, farm produced legume fodder including dairy-agroforestry integrated systems could be as effective in the mitigation of CH₄ emissions from ruminants. However, the adoption of legume fodders is extremely low at about 1% of the surveyed households (Table 3). About 84% of the farmers attributed the low uptake of agroforestry to competition between food crops and fodder production objectives, as well as the high market risks. Vertically integrated cooperatives could provide a window of opportunity to address the market risks.

Table 4. Simulated methane emission levels	(upper and lower limit) in CO ₂ -ec	ן 10 ⁻³	³ from maize-based rations.
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Ratio of Stover to Supplement/Feed DM (g kg^{-1}) Level							
Ration type DM (g kg $^{-1}$)	1.0	0.9	0.8	0.7	0.6	0.5	Mean
887. ¹	887.7	857.8	827.9	798.3	768.4	738.5	813.1
whole Slover (950)	432.8	407.7	382.5	357.3	332.2	307.0	369.9
Star (1 900) 8	874.8	846.3	817.7	789.1	760.6	732.0	803.4
Slover (top 890)	422.3	397.8	374	349.9	325.3	301.6	361.8
Napier cilego (168)	617.2	617	615.1	613.7	612.3	611	614.4
Naplei Shage (408)	207.1	206.0	203.0	202.0	200.6	199.6	189.7
	615.9	615.4	613.4	611.0	608.6	606.2	608.3
Naplei fiesti (175)	201.7	201.3	201.3	199.6	197.5	196.2	199.6
Desmodium (210)	No	615.4	612	610.0	608.6	605.2	610.2
Desmodium (210)	INd	203.3	200.6	199.9	197.2	196.2	188.7
L	Na	615.4	613.7	611.7	608.6	607.2	611.3
Leucaena (240)	INd	203.3	201.6	199.9	198.2	196.5	199.9
Sesbania (230)	No	615.4	613.4	611.3	608.9	607.2	611.2
	INd	203.3	201.6	199.9	198.2	196.5	199.9
Calliandra (220)	Na	615.7	613.4	610.0	609.3	606.9	611
Camaricita (220)	INA	203.7	201.6	198.3	198.2	196.2	199.6
Potato vines (100)	616.42	615.4	612.7	610.3	607.6	605.2	611.3
Totato villes (100)	208.4	203.3	200.9	198.9	196.9	194.5	200.5
Mean (MBSWM)	Na	615.7	608.8	606.3	604.9	601.8	607.5
	INA	203.7	197.5	195.8	194.5	191.8	196.7
Mean for grain residue	616.8	613.0	612.0	611.3	609.3	612.5	
mixture (MBSWG)	INA	204.3	201.3	201.0	199.6	198.2	200.9
Mean MBSM with	Na	615.4	613.0	611.0	608.6	606.6	610.9
molasses (20% DM)	INA	203.3	201.6	199.6	197.9	195.8	199.6
Mean MBSMC	Na	616.1	613.0	611.7	610.0	607.9	611.7
wiean widdwig	ING	203.7	201.3	199.9	198.9	197.2	200.2

Source: Author's calculation based on literature data and field validation, 2019. Na—ration not nutritionally feasible based on various considerations such as antinutritive factors (i.e., tannin) content that renders the ration nutritionally impractical. SEM—Standard Error of Means, MBSWM—overall for Ms, legumes, and Napier, MBSM—MS with molasses, MBSWG—MS with maize grain (Simulated methane emissions in the numerator and denominator of each ration represent Upper and lower emissions respectively.

4.2. Weather Variability and Price Risks in Dairy Feeding Strategies

Table 5 provides variance of prices for various feeding strategies. The price variance for locally available dairy feed resources is significantly lower relative to external resources, such as cotton seed cake ($p \le 0.05$). The highest price variance was observed in dairy feeding strategies that have highest positive impact on CH₄ mitigation while the lowest variance is in the local resource such as Ms (which also have the highest methane emission potential). This could explain popularity of Ms as a risk management strategy among the sampled households. It can be inferred that price risks play a significant role in maladaptive practices and predictors of shifting vulnerabilities. The effect of output price on gross margins(profit) at different supplementation levels is provided in Supplementary File S1 (SP1). Increased supplementation using external inputs increases leads to negative gross margins in most of the informal marketing channels. This is an indicator of financial risks.

Feeding Strategies	Sum	Mean	Variance
Ms	25.43	3.18	7.51
Ms + L	57.92	7.24	34.55
Ms + Cs + M	61.87	7.73	40.51
NaP	103.96	12.99	129.36
Nap + L	43.53	5.44	16.56
Nap + csc + M	85.59	10.70	84.93
Ms + Nap	43.13	5.39	16.15
Ms + Nap + csc	126.19	15.77	194.71
Ms + Nap + Csc + M	143.54	17.94	254.54

Table 5. Interplay of weather variability and price risks in dairy feeding strategies.

Source: Author's calculation based on field survey data among resource constrained farmers, 2019. Nap = Napier.

Weather variability and supplementation are thus intertwined and impact market risks in dairy farming. The mean production price for Ms is Kes 3.2 against 17.9 for external input supplemented strategy. The variance in price is significant across all the feeding strategies. The highest variance is noted in external input supplemented strategies. This contrasts with very low variance hence low market and price risks in the locally available feed resources.

4.3. Ecoefficiency

Externalities provide a case study where scope mismatches, sustainability, coherence, integration, and sectoral focus in climate adaptation policy could converge. Table 6 provides the effect of various dairy feeding strategies on ecoefficiency. Coping strategies represented by maize stover (Ms) at 113.43 ± 6.79 give the lowest ecoefficiency, while feeding strategies that utilise external resources, but which are highly vulnerable to price shocks at 693.37 \pm 276.78, produce the highest ecoefficiencies. Similarly, resource integration, i.e., dairy–legume fodder, has a significant effect on ecoefficiencies (p = 0.05) for the analysed feeding strategies. From the findings, external inputs, such as cotton seed cake (Csc), play a significant role in dairy productivity and the management of GHG emission footprints, yet are less adopted among farmers. The low adoption of external inputs is attributed to high financial risks. Implicitly, price risks should be the focus, especially in the design of market instruments and adaptation financing targeting agricultural production systems.

Feeding Strategies	Mean Eco. Eff.
Ms	113.4 ± 6.8
Ms + L	277.4 ± 37.8
Ms + Cs + M	296.7 ± 44.3
NaP	501.5 ± 140.9
Nap + L	206.7 ± 18.1
Nap + csc + M	412.2 ± 92.6
Ms + Nap	204.7 ± 17.7
Ms + Nap + csc	609.6 ± 211.8
Ms + Nap + Csc + Nap	693.4 ± 276.8

 Table 6. Comparison of ecoefficiency between various dairy feeding strategies.

Source: Authors' calculation from field data, 2019; Significant at $p \le 0.05$.

5. Discussion

There is overwhelming evidence that GHG emissions are responsible for global warming risks; hence, they are a driver of the increased vulnerability of humanity and ecosystems to suffer harm [28,88]. The mainstreaming of agricultural emissions into the global climate agenda has thus emerged as one of the alternative carbon transition pathways [7,26]. Equally, there is an increasing need to address the dualistic framing of adaptation and mitigation [8]. Approaches such as CSA are significant in this direction, as well as enhancing adaptation–mitigation synergies and mitigation co-benefits [28,35]. CSA operationalises the triple bottom line objectives on adaptation, mitigation, and sustainability. In essence, CSA frameworks could decrease vulnerability to climate-related risks, improve capacity to respond to shocks, as well as lower emission intensities [98]. Agriculture is one of the sectors with potential for an immediate and large-scale reduction in emissions [23]. Since emission intensities are indicators of mitigation in agriculture [90], they are adopted as a strategic vision in the mainstreaming of agricultural emissions into the climate action agenda [81]. Agriculture has thus emerged as one of the sectors with potential for an immediate and large-scale reduction in emissions [23].

CSA presupposes the integration of climate change into sustainable agriculture planning and implementation at a local scale [110]. Though consensus on the need for sustainable practices and technologies, such as agroforestry and crop livestock integration, abounds as CSA approaches [81,111], several limitations remain unresolved. CSA, as well as existing analytical lenses such as telecoupling, tends to discount the importance of GHG spillover systems [1]. For instance, under CSA approaches, investment in adaptation is generally not linked to concomitant resilience goals, such as the mitigation of GHG emissions [81]. Further, a focus on specific elements, such as productivity, may fail to capture critical socio-economic and ecological linkages and feedbacks therein [15]. In turn, this could undermine policy effort, as well as meaningful transformation in a food system [112].

Though the Paris Agreement climate targets assume a strong implementation mechanism and the revitalisation of global partnership advocated for under the Sustainable Development Goals [13], to cascade GHG emission reduction targets regionally, nationally, and eventually locally, such a vision could be undermined by free riding and weak incentives for individual action [92]. A focus on the interplay between local interests, institutional frameworks, and fundamental drivers of the problem is thus fundamental [5,30]. Institutional lock-ins are particularly significant as they tend to undermine inclusive and effective carbon transition pathways. The failure to focus on the underlying cause of vulnerabilities further undermines resilience building [40]. For instance, though most developing nations, such as Kenya, have increased the contribution of agriculture emissions in their NDC ambitions, the proportion of agricultural emissions in the submitted ambitions fails to reflect the magnitude of agriculture sectors' role in GHG emissions and mitigation.

Trajectories of vulnerability over time reflect an interplay of institutional context and individual decision making, as well as risk perception [113]. Implicitly there is need to focus on policy and market conditions that (dis)incentivise and influence the choices made by economic agents and how this impact the flow of GHGs in a spillover system [2]. In turn,

it impacts cost-effectiveness in planning [45]. The findings underscore the need for holistic frameworks. Integration is especially critical in the maximisation of GHG mitigation benefits from AFOLU sectors [88,114]. This study thus contributes on filling knowledge gaps, notably the role of small-scale farmer practices in environmental governance [34].

Though, evaluation of risk in agricultural production is widespread, there is paucity of published literature on its role in GHG emissions. Attempts to use resilience lens to mediate convergence between adaptation and mitigation, however, fail to address underlying root causes of vulnerability [8,40]. Resilience approaches fail to account for resource constraint- risk nexus in vulnerability dynamics [8,47]. The linkage of resource constraints, maladaptation and increased methane emissions in the study area underscores the centrality of market risks. The findings underscore [46], observation that adaptation action could potentially to spill beyond geographical and economic boundaries.

Crop-livestock integration is one of the strategies for internalizing environmental externalities. For instance, some studies suggest agroforestry could provide several environmental co-benefits [67]. Integrated livestock-agroforestry management practices which encompass the combination of trees and/or legumes with livestock have the potential to mitigate GHG, capture and store carbon from the atmosphere. However, uptake of integrated systems is dependent on the ability of institutions to meaningful tackle existing bottlenecks (or institution fit), such as market access and price risk [65]. In the study, market risks tend to undermine supplementation as well the uptake of legume fodders. The negligible supplementation interventions in Ms dairy cattle feeding among poor farmers suggest that market risks and financing interventions are critical in agriculturally based carbon transitions.

Though Western Kenya is an idiosyncratic typology in global climate policy agenda, it provides invaluable insights on common environmental and sustainability challenges across scale and how they impact effectiveness of GHG mitigation initiatives. Further it illustrates the linkages of market risks on GHG emissions and/or aggravation of shifting vulnerabilities among resource constrained farmers. In essence the institutional-GHG-market risk nexus suggested herein demonstrates the multifaceted challenges in adaptation and mitigation discourses. It further underscores the centrality of contextual factors as suggested by [19], the indivisibility, as well as the need for concurrent use of socio-economic and environmental triple bottom line principles in carbon transitions.

The strength of this study lies in the integration of the triple sustainability bottom-line and market risks to visualise GHG emission levels that informs transformative discourses on climate change. use of literature data to estimate emission risks, may result into biased emission extremes (either low or high). Quantification of real-world emission levels would go a long way in overcoming the limitation. Agent-based scenario modelling holds considerable promise towards quantification of actual methane emission risks.

6. Conclusions

Effective tackling of global climate crisis largely depends on positioning agriculture and food systems as alternative carbon transition patways, climate financing, as well as enhancing adaptation-mitigation synergies. Concomittant to food system transformation is the need for integration of GHG emissions into climate action agenda. The article has framed the increasing GHG effect, as a collective challenge. Small-scale farming production systems are expected to provide urgently needed solution space for transition to alternative carbon transitions and the transformation process. Implicitly, adoption of CSA technologies by a critical mass of small-scale farmers could significantly reduce GHG emission gaps herein framed as effectiveness. Livestock subsector is considered as priority agricultural subsector due to its significant role in adaptation, livelihoods and GHG emissions. The first objective in the study thus investigated whether local decision making on dairy feeding strategies has effect on GHG emissions at scale. Uptake of dairy feeding technologies is visaualised through adoption theory [115]. In tandem with Koundouri et al. [63], risk including market risks were posited to and were found to play a critical role in the adoption of the dairy feeding technologies. According to simulation results on emethane emissions, dairy-agroforestry integration staretegies were as effective as externally sourced inputs in reducing GHG emissions by upto 30%. However, uptake of agroforestry/legume foddder alternatives among scale farmers in the study area is extremely low. The high market risks accounted for low adoption of agroforestry/fodder legume technologies. Evidently adoption of CSA technologies as a decision making process impact GHG emission levels and effectiveness of local-global initiatives. The use of Ms without and/or suboptimal supplementation, used herein further illustrates the risk of maladaptation. Maladaptation, as well as low adoption of alternative carbon pathways not only undermine local-global initiatives on GHG mitigation, but also deepens GHG emissions and future global warming risks. An association between adoption of CSA (i.e., dairy feed supplementation and dairy-agroforestry integration) and market risks thus established reveal the association between micro-level decision making, risk, GHG emission, as well as suggest global interconnectivity. Maladaptive responses in the case study further highlight the growing need to debunk framing of adaptation as a local issue [19,46], as well the urgency to address maladaptive practices in small-holder farmer production systems [116].

Some studies [117] suggest the need to deliberately direct adaptation finance towards resource constrained farm households. The study has highlighted the effect of resource constraints on uptake of CSA technologies. In particular, it underscores market risks as binding constraints in the supplementation of dairy cattle feeding strategies. The study recommends use of SFVC as an analytical lens to visualise the institutional gaps in carbon transitions, facilitate institutional coherence and re-engineer institutions towards innovation, specifically the inclusion and integration of small-scale farmers into climate finance initiatives. Together the suggested framework addresses transformation gaps in resilience building as suggested by [8,40]. This could foster adoption of CSA technologies by a critical mass of small-scale farmers and positively impact effectiveness of carbon neutral transitions. The finding provides an innovative analytical lens for effective adaptation planning and the positioning of food systems as alternative carbon transition pathways. In conclusion, cogent climate action policies at scale need to focus on decision making-price risk- resource constraint nexus and feedbacks.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10 .3390/atmos12111507/s1. File S1: Effect of output price variations on risk management at different levels of basal diets on Gross Margin.

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