Does Global-GAP policy reduce smallholder greenhouse gas emissions from French bean production in Central and Eastern regions of Kenya?

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Abstract

The need to minimize farm-level greenhouse gas (GHG) emissions from Kenya's smallholder French bean production is gaining increased attention. French beam production has over the years adopted private voluntary standards notably Global-GAP that regulates both environmental and food safety aspects among farmers. Despite increasing global warming concerns, the impact of Global-GAP policy on smallholder farmers' GHG emissions is unclear. This paper documents effects of Global-GAP policy on GHG emissions among French bean farmers in Central and Eastern regions of Kenya using household data collected between September and October 2013 from a random sample of 616 farmers. The study used a combined linear programming (LP) and life cycle assessment (LCA) models to examine the economic and environmental metrics and ordinary least squares (OLS) regression method to analyze factors affecting farm-level GHG emissions. Eco-efficiency, defined as net farm income divided by global warming potential, was used as an integrated indicator for assessing the economic and environmental feasibilities. There was a significant ($p > 0.05$) higher eco-efficiency in Kenya Shillings per ton of carbon dioxide equivalence (Kshs per tCO_2e) among Global-GAP policy complying farmers compared to non-complying farmers due to a reduced GWP (by 7 percent) and a higher net farm income given the optimum activity level used. The Global-GAP regulatory measures on the management practices seems to have caused economic advantage in exchange for environmental advantage (lower emissions in tCO_2e by 7 percent). The regression model results found that Global-GAP compliance negatively and significantly affect GHG emissions. It further found that region of the farmer, French bean yields, gasoline fuel use, DAP fertilizer application and French bean seed positively and significantly affected smallholder farmer' GHG emissions. More explicitly, the model using these explanatory variables indicates that smallholder farmers complying with Global-GAP policy are more likely to emit less GHG compared to non-complying farmers. The paper recommends inclusion of Global-GAP compliance and these other significant socio-economic factors in the smallholder French bean greenhouse gas emission reduction strategies by the government and industry stakeholders.

Key words: Global-GAP, Greenhouse gas emissions, Eco-efficiency, LCA model, LP model, smallholder, French beans, Central region, Eastern region, Kenya

1. Introduction

Agriculture is a significant contributor to global emissions of greenhouse gases (GHG), notably nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4). It contributes 10-12 percent of overall global emissions of which crop production is assumed to be responsible for about 20 percent of global agricultural GHG emissions (FAO, 2006). The reduction of food production's contribution to climate change is gaining increased attention among developed countries' consumers with potential implications on the livelihoods of smallholder producers in developing countries (Macgregor, 2010). These consumers form the bulk of the market for high value fruits and vegetables and are increasingly becoming concerned about environmental conservation and food safety (Diop and Jaffee, 2005; Jaffee *et al*., 2005; Muendo *et al*., 2004; Okello *et al.*, 2007). This has shifted the focus to how smallholder producers, as part of the supply chain, are aligning their production practices to these buyers' environmental and ethical objectives (Humphrey, 2008, Henson and Humphrey, 2009; Mithöfer *et al.*, 2007). In Kenya, this focus is more prominent on French bean which is one of the leading fresh export vegetables of increasing socio-economic systems and livelihoods importance, mostly grown by smallholder farmers as a source of income (Government of Kenya, 2010; HCDA, 2007; McCulloh and Ota, 2002; Mutuku *et al*., 2004; Minot and Ngigi, 2004; Odero *et al*., 2012; World Bank, 2010a; World Bank, 2010b).

Kenya's agriculture sector contributes 30 percent to the national emissions (Government of Kenya, 2010b). This equally means that the sector will need to adopt more effective and climate-friendly systems in its quest for continued provision of adequate food for a growing population and increased foreign exchange earnings from exported food produce and products (Government of Kenya, 2013). Among fresh export vegetables, French bean production accounts for 60% of all vegetable exports and 21% of horticultural exports (Okello *et al.,* 2007). Smallholder French bean production represent about 90 percent of Kenya's French bean total produce and has been assuming increased intensification in response to export market demands (HCDA, 2010; Lagerberg-Fogelberg and Carlsson- Kanyama, 2006; Blengini and

Busto, 2009; Neue, 1997). Despite the expectation for French bean industry to continue growing as a result of the increasing food demand, it is also very sensitive to climate change and in 2010 for instance had a 37 percent reduction in the area under production. Between 2008 and 2010, the production volume and value decreased by 39 and 45 percent respectively due to prolonged drought in 2008 – 2009. In addition, during the year 2010, out of 55,841 metric tons produced, only 34 percent were exported.

Globally, the current GHG emissions management policy for the agriculture sector has shifted from absolute emissions to production efficiency that leads to increased output per unit of emission in line with the Kyoto Protocol (UNFCCC, 1998). For instance, food and agriculture organizations (FAO)'s strategy focuses on supporting agriculture that sustainably increases productivity, adaptation to climate change, reduction in GHG and enhancing achievement of national food security and development goals (FAO, 2013). It aims to realize this through promotion of good agricultural practices (GAP) addressing environmental, economic and social sustainability for on-farm processes with results in safe and quality food and non-food agricultural products.

In response to the policy shift, most developed country governments who have ratified the Kyoto Protocol have gone ahead to revise their regulations pertaining to labeling of fruits and fresh vegetables with certain information in order to protect the environment and consumers (Legge *et al.*, 2006 Legge *et al.*, 2009; MacGregor and Vorley, 2006, Van Hauwermeiren *et al.*, 2007; Appleton, 2007). These policy considerations are based on evidence suggesting that environmental burdens can be reduced through technical options of the production activities (Nakashima, 2010). All these measures are instituted with the expectation of making agriculture sector part of the solution to emission reduction through taking appropriate measures.

These regulatory changes, together with perceived commercial risks, have in turn led private companies, especially major supermarket chains operating under private voluntary standards (PVS) to develop their own standards pertaining to environmental risks (Dolan and Humphrey, 2000). The most widely recognized assurance PVS scheme for good agricultural practice is Global-GAP (Okello *et al.*, 2007;

Global-GAP, 2009). In the past decade carbon has been introduced into Global-GAP for the food system as part of a process change in the supply chain. This has been done with a believe that if carbon is to be a persistent concern and private businesses are to be assessed according to their carbon emissions, then Global-GAP will likely help identify hotspots and, where possible, reduce emissions. To measure carbon footprint, the Carbon Trust with the British Standards Institute (BSI) has developed the carbon reduction Label that will inform consumers of the amount of carbon dioxide and other GHG produced during the full life-cycle analysis (LCA) of the product including use and disposal (Carbon Trust, 2008). The Carbon Trust defines a carbon footprint as the total set of GHG emission caused directly and indirectly by an individual, event, organization, and product, expressed as carbon dioxide equivalent (CO_2e) (Bingley, 2008). In effect, the Carbon Trust's general regulations have been benchmarked with Global-GAP since 2009. This has made the retailers to over the years add on more information to the label for the benefits of the environment and the consumers including traceability, recipes and different accreditations such as Fair Trade, Organic and Environmental Standards such as Linking Environment and Farming (LEAF) (Rigby and Brown, 2003). Farms that are LEAF standard accredited should already have achieved a certificate for Global-GAP or a benchmarked scheme approved by Global-GAP for each enterprise on the farm. The benchmarking of Global-GAP with LEAF makes it a viable environmental Policy that enables farmers commit to optimize usage of power, water and other consumables through adoption of integrated farm management (IFM). The IFM principles are expected to help a reduction of 'greenhouse gases' (GHG) through good resource management and covers a commitment to soil management and fertility, crop health and protection, pollution control and by-product management, landscape and nature conservation, energy efficiency and water management for both environmental and economic reasons and using water from sustainable sources.

Recent studies suggest that the upstream changes in Global-GAP, enforced through third party certification, have the potential of reducing environmental impact of farming among smallholder farmers (Macgregor, 2010). However once retailers insist on having only products that have a specific label then market access will continue becoming an issue for many smallholder fresh export vegetables

producers including French bean in Kenya. While a number of smallholder farmers have complied and are producing French bean under Global-GAP regulatory measures, a high proportion is still undertaking unregulated production. Unregulated production management practices like intensive fertilizer application and motorized irrigation on crop farms like French bean are thought to lead to increased direct and indirect N_2O, CO_2, and CH_4 emissions (Kramer *et al.*, 1999; Nakashima, 2010). The future challenge confronting smallholder French bean industry is therefore three-fold: to adapt to a changing and more variable climate, to increase production and to reduce GHG emissions (Kristensen *et al.*, 2011; Nakashima, 2010).

This paper addresses the second and last part in relation to smallholder French bean farming. A number of approaches including life cycle assessment (LCA) and optimization have been used to evaluate the economic and environmental impacts of agriculture (Halberg *et al.*, 2005; ISO, 2006a; Payraudeau and van der Werf, 2005; Thomassen and de Boer, 2005; Van der Werf *et al.*, 2007; Van der Werf and Petit, 2002). Researchers mostly in developed world have applied LCA to agricultural production systems in response to environmental impact concerns. This has been done both at single crop variety level like rice (Blengini and Busto, 2009), vegetables (Williams *et al.*, 2006), biomass production (Nguyen *et al.*, 2008) and at farm-scale level (Flessa *et al.*, 2002). These recent farm-scale LCA analyses have shown technological interactions between crops productions and the resulting GHG emissions, allowing for the design of more friendly farming systems from a technological point of view.

Kramer *et al.* (1999), in their study of GHG emission related to the Dutch crop production system showed that of 0.171 kg carbon dioxide equivalent (CO_2e) per kg of produce emitted 52 percent N_2O, 47 percent of CO_2 and 0.6 percent of NH_4 from French bean production. This study concluded that while emissions of CO_2 are caused by the use of fossil fuels as well as production of agricultural inputs, the N_2O emissions are mainly caused by the production and application of synthetic nitrogen fertilizer. It noted that for most crops the N_2O emissions have a major contribution to the total emissions of CO_2 eq. Similarly, Koga *et al.* (2006) studied GHG emissions from arable land farming systems in Japan and established that as much as 64 to 76 percent of the total GHG emissions well over

the sum of off-farm and fuel related on-farm emissions are soil derived. The study concluded that soil management practices that enhances carbon sequestration in soil may be an effective means to mitigate large GHG emissions from arable land cropping systems. In another incidence, de Figueiredo *et al.* (2010) analyzed GHG emissions associated with sugar production in Brazil and found that sugarcane burning system was responsible for 44 percent of total GHG emission. Oppong-Anene *et al.* (2011) also analyzed environmental system of tomato production in Ghana and found that fertilizer application ranks first among the activities that generate GHG with a share of 97 percent.

While most LCA studies reviewed point to some of the management practices and technologies associated with increased GHG emissions, implementing policy recommendations made still present a challenge (Nakashima, 2010). This is based on the fact that technological information needs economic ground and the tasks of policymakers is to create economic incentives for producers. Hence the major shortcoming of the LCA is that even though it provides the technical information, it lacks the capacity to analyze GHG emissions at optimum level of economic activity. It also does not have the capacity to evaluate effects of policy measures which are frequently adopted in the agricultural sector to economically motivate farmers and regulate their activities. This has led to the need for an integrated approach that measures both environmental impact and economic returns. Food and Agriculture Organization Sourcebook (2013) amplifies this by advocating for agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals.

To address the shortcomings of the LCA approach, agricultural sector optimization models have been integrated with LCA models to provide a quantified framework for organizing kinds of information about the structure and functions of an agricultural sector (Weber, 2003; Burell, 1995; Heckelei, 2005). This has allowed for the maximization of the producer surplus subject to production and resource constraints. They also allow for direct modeling of production technology, support systems, fixed production factors, resource constraints and capacity levels and can be run for different policy scenarios. One of the sector models that has been integrated with LCA is the linear programming (LP) model

(commonly referred to as an "activity analysis model") whereby all the individual sectors are exhaustively characterized as production units (Ssempirima, 2013). In an LP model, the individual agricultural production units, or farms, are realistically treated as producers of numerous output commodities. This applies in the case of Kenya whereby like in any other economy with quite heterogeneous regional characteristics, production planning and equipment like production costs, may vary considerably even on farms of the same size and type. Given the natural and economic conditions, individual farms may also specialize in production as allowed by their resource constraints and preferences. In such a situation, resources like some particular types of land owned by some groups of farmers, may not be made easily available to other farmers. LP hence supplements or substitute for budgeting and analyzed change using it is considered as the change in the decision variables (Howitt, 2005). Therefore, with LP model, it is possible to analyze the efficiency of different agricultural policy regimes, for instance the economic impact of Global-GAP policy on farm income and GHG emissions.

In Kenya's context, French bean is one product in a small sub-sector of the agricultural sector of the economy in terms of value added and its effect on another sub-sector may be very small. LP model integrated with LCA may therefore be able to give a succinct indication of the effect of the policy on the sub-sector or French bean commodity (Banse and Tangermann, 1996). This is because it can help examine in greater details the policies directed to specific commodities and inputs. Since more specifically it focuses on principal agents affected by policy in question, its use in the analysis of the impact of Global-GAP policy may help by comparing marginal cost of production with prevailing products revenue and environmental effects when integrated with LCA model. To understand a similar, though possibly relatively small effect of policy changes, LP models could be aggregated from farm-level models that represent representative farms specializing in production of certain commodities of interest. Such information is useful in policy-making and development strategies in any industry like French bean or in an economy (Ala-Mantila, 1998).

More recent studies that have applied combined optimization-LCA models at the farm scale to crop

farms, to determine the trade-off between the economic and environmental feasibilities of adopting environmental measures and/or evaluate the economic and environmental impacts of policy changes include Nakashima (2010) and Senthilkumar *et al.* (2011). Nakashima (2010), evaluated GHG emissions as an ecological indicator; however, their analyses did not include French bean fields, which are seen as an important source of N_2O emissions due to its economic importance. On the other hand, in Senthilkumar *et al*. (2011), only nitrogen was taken into account as a pollutant emitted from rice paddy fields. Consequently, these previous studies have not addressed the problems of adopting policy measures like Global-GAP to support mitigation of global warming in smallholder farms. More importantly in Kenya, no studies have set out to examine the economic and environmental effects of Global-GAP policy on GHG emissions based on empirical smallholder French bean farm-level data. The purpose of this study was therefore to assess the effect of Global-GAP policy on economic and GHG emissions at farm-gate and examine factors influencing smallholder GHG emissions at the farm-level.

2. Data and Methods

The data used in the analysis was collected on the last crop of French bean from a random sample of 616 smallholder farmers during a primary field survey conducted between September and October 2013 using a semi-structured questionnaire. This was done in major French bean growing areas of Central (Kirinyaga county) and Eastern (Makueni and Meru Counties) regions of Kenya. According to horticultural crops development authority (HCDA) 2010 report, these regions produced 90 percent of the total national French bean output mainly through smallholder farming. A higher proportion of smallholder producers in these regions have complied with Global-GAP policy making it an ideal area to study the economic impact of Global-GAP policy on greenhouse gas emissions. Many appropriate climate change adaptation agricultural practices adopted under Global-GAP policy that reduce climate vulnerability in these areas are also assumed to reduce emissions and improve agricultural production potential (Government of Kenya, 2010b). The socio-economic data was collected and production performance, economic turnover, GHG emissions and factors influencing GHG emissions were analyzed per season with the estimates data being stratified by Global-GAP policy (complying and non-complying)

in each region.

On production performance, farm-level resource availability data were estimated from actual observed smallholder producers' data which was used to estimate the enterprise budget data on yields and farm resource requirement per hectare of French bean production activity. Output, output price and the vector of variable physical inputs were predetermined since smallholder fresh export vegetables production is assumed to be resource constrained. These data were validated with records of production activities estimated by HCDA, other empirical studies and consultation with extension officers.

The economic and environmental performance was analyzed and expressed in net farm income, global warming potential, and eco-efficiency. Eco-efficiency, defined as net farm income divided by global warming potential, was used as an integrated indicator for assessing the economic and environmental feasibilities (Masuda, 2016). Eco-efficiency measurement from farm modeling based on farm management handbooks in this paper has the advantage of lower data requirements (Kuosmanen *et al.*, 2005; Vázquez-Rowe *et al.*, 2010). The study made an assumption that there was no difference in net revenue, GHG emissions and eco-efficiency among French bean farmers complying and non-complying with Global-GAP policy in the two study regions. The combined optimization and LCA models were used to analyze the net farm revenue and GHG at the optimum activity level (Masuda, 2016; Nakashima, 2010; Ssempirima, 2013).

2.1 Modelled farm

The smallholder farm-scale optimization model used in this paper had the form of a standard linear programming model (Ssempirima, 2013). Since the production of French bean is done by the smallholder farmers for the market, it was assumed that the objective of the farmer was to get maximum returns in terms of net farm income from the sales of the output. The farmer's optimization problem was therefore to choose the appropriate activity level (land under French bean production) and to maximize profits subject to inputs availability. Since the farmers' behavior in the two regions was assumed to be that of maximizing net farm income (an objective function, **cx)** under the constraints for land use activities and

labor inputs, the problem for the modeled farm was expressed as:

$\mathbf{CX} = \mathbf{X}_0$ (maximum)   (1)

Subject to:

$\mathrm{A}\mathbf{x} \leq \mathbf{b}$

$\mathbf{x} \geq \mathbf{0}$

Where, $\mathbf{x}$ is a vector of activity levels for the respective French bean production systems in the model; $\mathbf{x_0}$ is a scalar quantity indicating the maximum magnitude of the dependent variable of the objective function; $\mathbf{c}$ is a vector of activities gross margin for the respective French bean production systems in the model; $\mathbf{b}$ is a vector of bounds for the two regions and the respective French bean production systems in the model; A is a matrix constituted of the technology matrices for the respective French bean production systems in the model; $\mathbf{x} \geq \mathbf{0}$ satisfies the non-negativity assumption that no negative activity level is observed.

The general form of the empirical model of optimal French bean production at the farm-level was formulated for four-production systems two-regions as illustrated in table 1. In this case, smallholder French bean production economy was assumed to have two regions (A and B), and each of these regions was assumed to have smallholder farmers producing French bean under different production systems (Global-GAP policy complying and non-complying) i. A and B are the matrices of technical coefficients for the regions A and B respectively. For example, A_i is a matrix of technical coefficients for French bean production under production system iA in region A, B_i is a matrix of technical coefficients for French bean production under production system iB in region B. It was assumed here that every region had only two French bean production systems. K_{Ai} is a vector of bounds for production system iA in region A, and K_{Bi} is a vector of bounds for production system iB in region B. K_A is a vector of bounds for region A, and K_B is a vector of bounds for region B. K_C is a vector of bounds for the combined two regions C.

Table 1: The Matrix-Structure of the agricultural sector model with all farms in the regions selected

Restrictions	Variables, Activities				RHS
	Hectares for production under Global-GAP compliance A_1				$\leq KA_1$
		Hectares for production under non-Global-GAP non-compliance A_2			$\leq KA_2$
			Hectares for production under Global-GAP compliance B_1		$\leq KB_1$
				Hectares for production under non-Global-GAP non-compliance B_2	$\leq KB_2$
	Region A				$\leq KA$
			Region B		$\leq KB$
	Total sector aggregates				$\leq KC$
	Objective function				Min/Max

Source: Adapted from Ssempirima, 2013

The basic structure of the LP matrix, with the right hand side representing the constraints on the resources was presented as in table 2.

Table 2 Linear Programming Matrix

	GNCC (Ha)	GCC (Ha)	GNCE (Ha)	GCE (Ha)	RHS
	X1	X2	X3	X4	
Objective function (KES)	180254	387471	382977	329420	Maximize
Resource					Available
Land (Ha)	1	1	1	1	4
Labour (Man-hours Ha^{-1})	2538	2230	3681	3650	2280.16
Irrigation water (M^3 Ha^{-1})	16779.6	18487.9	41539.71	25651.16	18640.46
Seed (Kg Ha^{-1})	37.5	28.7	25.7	25.6	23.838
Insecticide (Kg)	4.6	9.6	1.5	2.1	3.975
Fungicide (Kg Ha^{-1})	19.2	17.1	3.9	8.5	10.703
CAN fertilizer (Kg Ha^{-1})	296	365.1	325.7	352.9	1339.7
DAP fertilizer (Kg Ha^{-1})	196	136	162	145	127.01
Manure fertilizer (tons Ha^{-1})	40400	15000	16900	19800	92100
Motor gasoline (litres Ha^{-1})	296	350	449	657	329.59
Capital (Kshs Ha^{-1})	196312.1	202233.9	237050.7	296404	931999.8

Source: Survey, 2013

NB: GNCC–Global-GAP policy non-complying households in Central region; GCC–Global-GAP policy complying households in Central region; GNCE–Global-GAP policy non-complying households in Eastern region; GCE–Global-GAP policy non-complying households in Eastern region;

1 US$ = Kenya Shillings (KES) 86.4 in 2013

2.2 Global warming potential

The LCA model was used to calculate the total global warming potential (GWP) in the modeled farm (ISO 2006; Oppong-Anene *et al.*, 2011). Because the optimized crop-planted areas were obtained by solving the optimization model, the GWP intensities for French bean crop production were referenced to an area-based functional unit (per ha). The average data on materials (inputs's active ingredients) per hectare of activity and yields were used to prepare life cycle inventory for all emissions sources under the various modeled production systems (de Figueiredo *et al.* 2010; IPCC, 2006; IPCC, 2007; Kramer *et al.*

1999; Koga *et al.* 2006; Nakashima, 2010). Furthermore, the GWP intensity from the fixed and common costs was calculated. The study only included the GHG emissions as a result of anthropogenic influences. The natural background emissions from processes like decomposition and respiration were outside the scope of the study. On- and off-farm emissions of three primary GHG (CO_2, CH_4 and N_2O) were taken into account. The types of GHG emission sources taken into consideration based on literature review included: (1) off-farm emissions from production of agricultural materials like fertilizers, (2) emissions from management of agricultural soils, and (3) emissions from fuel consuming operations like motorized irrigation. Both the direct and indirect emissions were considered. The direct emissions included production of pesticides, fungicides, calcium ammonium nitrate (CAN) fertilizer, di-ammonium phosphate (DAP) fertilizer; applied CAN, DAP, manure, crop residue nitrogen (N) returned to the soil; and motor gasoline used in farm operations like irrigation water pumping). The indirect emissions included volatilization of applied CAN Fertilizer N, volatilization of applied DAP fertilizer N, volatilization of Organic Manure N, leaching/runoff of applied CAN Fertilizer N, leaching/runoff of DAP fertilizer N, leaching/runoff of Organic Manure N and leaching/runoff of Crop residue N. The system boundary was the farm gate of the modeled farm. Capital goods were included only in the first order of the life cycle; hence GHG emissions of agricultural machines were included in the system. The capital goods related to the production of synthetic inputs like nitrogen fertilizer were placed outside the system boundaries. This was because the allocation of GHG emissions related to crop production is based on their economic values (van Zeijts et al., 1996). The study did not also allocate the intervention related to crop rotation, but only current crop benefits from use of applied inputs like fertilizers and pesticides.

However, since emission inventory data were not available for Kenya's French bean, all the emissions were estimated using the default emission factors developed by IPCC (1997; 2006). The net emissions of key GHG related to off-farm activities from manufacturing of agricultural materials like fertilizers, those from management of agricultural soils, and those from fuel consuming operations like motorized irrigation taken into account were CO_2, N_2O and CH_4. All values were converted to CO_2e following the

individual global warming potential for a period of 100 years for each gas, using 1 to CO_2, 21 to CH_4, and 310 to N_2O (IPCC, 1997). The total GWP was calculated as

$$TGWP = \sum_{i=1}^{4} GWP_i x_i'$$ (2)

where TGWP is the total GWP intensity (t CO_2e); GWP_i is the ith GWP coefficient for French bean production system (t CO_2e per ha); and x'$_i$ i is the ith model-optimized planted area (ha).

To estimate the potential aggregate GHG emissions at the regional level, regional French bean farm resource availability data for Central and Eastern regions was collected from the annual validated HCDA report for 2010. As per the report 2,384 hectares of land was put under French beans production in Central and 1,769 hectares in Eastern regions in 2010 (with a production of 16,526 Metric tons (MT) for Central and 33,596 MT for Eastern regions respectively). The proposition of the state department of agriculture through Agriculture, Fisheries, and Food Authority (AFFA) is to enhance compliance with Global-GAP policy to increase export market access for improved smallholder income and foreign exchange earnings. In addition, the Global-GAP policy has added additional and increasing stringent requirements to ensure compliance with environmental management and GHG emissions reduction. Assuming that the average farm size under French bean production in the two regions would remain the same as in 2010, the total land resource under French bean production was assumed to be 2,384 hectares in Central plus 1,769 hectares in Eastern region. Weighted average, based on the actual activity levels, was used to estimate the distribution of farm resource in each French bean production system in each region, and total for two regions (the farm production system was defined by Global-GAP compliance). Of the total French bean farm production system in Central, 1,192 hectares was under Global-GAP compliance production and 1,192 was under Global-GAP non-compliance production. Of the total French bean farm production systems in Eastern 799 hectares was under Global-GAP policy compliance, and 970 hectares was under Global-GAP policy non-compliance production. The above was used to estimate the GHG emissions by production system at the regional level, overall emissions by production system, and the overall emissions for the two regions by multiplying by the emissions per hectare normalized at the optimal production activity level.

2.3 Factors influencing smallholder GHG emissions

Since the findings from the integrated LP-LCA analysis may not indicate whether the results are sensitive to other factors, the study assumed that smallholder farmer's GHG emissions is influenced by a number of factors including Global-GAP policy (Kramer et al., 2009; Nakashima, 2010; Pant, 2009). Factors likely to influence the farmers' GHG emissions were assessed by estimation of a model that allowed the inclusion of respondents' socio-economic, technological and institutional factors as independent variables into the GHG emissions function. These were analyzed using the OLS regression model specified as follows:

$$P_i = \beta_0 + \beta_1 W_i + \beta_2 Y_i + \varepsilon_i \tag{3}$$

where P_{it} is Kg CO_2 equivalent of GHG emitted by smallholder French bean production for respondent i, Y_i is a dummy measures compliance equals 1 if the farmer is complying with Global-GAP and 0 otherwise, Wi is a vector of observed control variables, εi is an error term and $\beta_0 .....\beta_n$ are parameters to be estimated (Pant, 2009). The functional form, the linear equation used was based on the logic of linear effects at the mean level, strength of the equation being tested and the logical validity of the coefficients to be estimated.

3. Results and discussion

3.1 Global warming impact in the modeled farm

Table 3 shows the findings of the analysis of the GWP intensities of each production system in the modeled farm. A contribution analysis was undertaken to help identify the emission sources with greatest intensity and environmental hotspots. Since the LCA components such as system definition, GHG emissions coefficients, and CO_2 equivalence factors differs, it is difficult to compare these results with the GWP intensities in previous LCA studies.

Table 3: GHG emissions (CO$_2$e) at optimal farm-level activity level by production system as a percentage of the combined regions

Production system	Central Region-optimal level		Eastern region-optimal level		All production systems	Farm industry structure GHG emission by activity level	
						Central (% of total)	Eastern (% of total)
	Farm-level unit (ha)	GHG emission (tCO$_2$e)	Farm-level unit (ha)	GHG emission (tCO$_2$e)	Emission (tCO$_2$e)	(%)	(%)
Global-GAP Complying	**1.43**	**6.907**	**1.13**	**6.108**	**13.015**	**53.1**	**46.9**
CO$_2$ emission		1.185		1.352	2.537	46.7	53.3
N$_2$O emission		5.710		4.747	10.457	54.6	45.4
NH$_4$ emission		0.011		0.009	0.020	55	45
Global-GAP Non-complying	**0**	**0**	**1.132**	**6.558**	**6.558**	**0**	**100**
CO$_2$ emission		0		1.031	1.031	0	100
N$_2$O emission		0		5.514	5.514	0	100
NH$_4$ emission		0		0.013	0.013	0	100

Source: Survey data, 2013

The results show that optimum activity level were 0 and 1.43 ha and 1.32 and 1.13 ha respectively for Central (Global-GAP non-complying and complying) and Eastern (Global-GAP non-complying and complying) regions. The results indicated that at optimum level, the Global-GAP non-complying farmers in Central opt not to produce maybe due to increased capital requirement. GHG emissions among Global-GAP complying farmers in Central region (53 percent) were higher than those from Eastern region (47 percent). As noted in previous studies (Kramer et al., 1999), the major contribution to GHG emissions from French bean (83 percent) came from N$_2$O with 54 percent of the total emitted in Central region. At the same time, a higher amount of C0$_2$ emissions occurs in Eastern region (53 percent share of the total). Use of large quantities of fertilizers (DAP and CAN) in the farms and

motor gasoline for irrigation water pumping seems to be the primary contributor to higher levels of N_2O and CO_2 emissions among smallholder farmers in Central and Eastern regions respectively. Because of large quantity of fertilizers for high production, chemical fertilizer production and field emissions from fertilizer application seems to be the environmental hot spots in French bean production (pelletier *et al.*, 2008). The present LCA also confirmed fuel combustion as another likely major source of global warming impacts as reported by some studies (Kramer *et al.*, 1999). While the Global-GAP non-complying farmers opt not to produce at optimum activity level, the present study found that Global-GAP policy complying farmers in Eastern region emitted lower GHG by 7 percent compared to non-complying farmers. Table 4 present the GWP intensities from optimal smallholder French bean farm-level production activity aggregated at the regional level for each production system in the modeled farm.

Table 4: Base year regional smallholder French bean GHG emissions at optimal activity level by production system as a percentage of the combined regions

Production system	Central Region activity level				Eastern region activity level				All regions	Farm industry structure GHGE by activity level	
										Central (% of total)	Eastern (% of total)
	Production system (ha)	Farm-level unit (ha)	Emission at Farm-level unit tCO$_2$e	GHG emission farm type (tcO$_2$e)	Farm type (ha)	Farm-level unit (ha)	Emission at Farm-level unit tC0$_2$e	GHG emission farm type (tCO$_2$e)	GHG emission	(%)	(%)
Complying	**1,192**	**1.43**	**6.907**	**5757.4**	**799**	**1.13**	**6.108**	**4,318.8**	**10076.2**	**57.1**	**42.9**
C0$_2$ emission			1.185	988.2			1.352	956	1944.2	50.8	49.2
N$_2$0 emission			5.710	4759.7			4.747	3,356.5	8116.2	58.6	41.4
NH$_4$ emission			0.011	9.5			0.009	6.4	15.9	59.7	40.3
Non-complying	**1,192**	**0**	**0**	**0**	**970**	**1.132**	**6.558**	**5,619.5**	**5,619.5**	**0**	**100**

CO_2 emission	0	0	1.031	883.5	883.5	0	100
N_2O emission	0	0	5.514	4,724.9	4,724.9	0	100
NH_4 emission	0	0	0.013	11.14	11.14	0	100

Source: Survey data, 2013; HCDA, 2010

A contribution analysis at optimum activity level still shows that at regional aggregate level, a higher level of GHG (57 percent of the total) was emitted in Central region by smallholder farmers complying with Global-GAP policy compared to Eastern region. The major contributor to GHG among smallholder producers in the two regions still remains N_2O (81 percent of the total). Emissions of CO_2 and N_2O were higher compared to Eastern region. This could be attributed to the fact that there are more smallholder Global-GAP complying farmers in Central compared to Eastern region. While the Global-GAP non-complying farmers opted not to produce at optimum activity level, the present study still found that at the aggregate regional level Global-GAP policy complying farmers in Eastern region emitted lower GHG by 23 percent compared to Global-GAP non-complying farmers.

3.2 Model-Optimized Results

The model-optimized results of land and other input use were similar between Global-GAP complying and non-complying farms (Table 5).

Table 5: Model-Optimized results for Eastern region

	Central region		Eastern region	
	Non-complying	Complying	Non-complying	Complying
Land (Ha)	0	1.43	1.132	1.13
Labour (Manhours)	0	4447.00	3520.27	3514.06
Irrigation water (M^3)	0	39684.58	31414.65	31359.14
Seed (Kg)	0	38.37	30.38	30.32
Insecticide (Kg)	0	6.69	5.46	5.45
Fungicide (Kg)	0	14.90	11.80	11.77
CAN fertilizer (Kg)	0	518.90	410.76	410.04
DAP fertilizer (Kg)	0	209.84	166.11	165.81
Manure fertilizer (Kg)	0	24.39	19.30	19.27
Motor gasoline (litres)	0	678.32	536.96	536.02
Capital (Kshs)	0	360985.83	285759.41	285254.54

Gross margins (Kshs)	0	526752.29	416981.53	416244.81
GWP (tCO$_2$e)	0	6.907	6.558	6.108
Eco-efficiency (Kshs per tCO$_2$e)	0	76,263.5	63,583.6	68,147.5

Source: Survey data, 2013

The results show that the net farm income at optimum activity level for Global-GAP complying farms were higher in Central compared to Eastern region. the GWP intensities were also lower in Central for complying farms compared to Eastern region given that the farms had increased activity level to 1.43 ha at optimum level compared to Eastern region (1.13 ha). Global-GAP complying farms in Central region therefore had a higher eco-efficiency (kshs 76,263 per tCO$_2$e) compared to Eastern region.

The results further show that at optimum activity level Global-GAP complying farms in Eastern region had higher eco-efficiency (by 7 percent) compared to non-complying farms as a result of lower GWP intensities (by 7 percent) and a higher net farm income compared to non-complying farms. These results were significant at 5 percent. The findings suggest that global-GAP complying farms produce lower GHG and are more eco-efficient compared to non-complying farms.

3.3 Factors influencing smallholder farmers' GHG emissions at the farm level

Table 6 shows the factors influencing smallholder farmers' GHG emissions from French bean production in the study area.

Table 6: OLS regression model results for factors influencing smallholder farmers' GHG emissions

Dependent Variable: Amount of farm-level greenhouse gas emissions				
Variable	**Coefficient**	**Standard Error**	**t**	**p>t**
Region	0.104*	0.061	1.705	0.088
Global-GAP Compliance	-0.154**	0.070	2.183	0.029
Amount of harvest	0.00003*	0.00002	1.922	0.055
Amount of gasoline fuel	0.0001**	0.00004	2.259	0.024
Irrigation	0.002	0.003	0.414	0.679
Amount of manure fertilizer	0.00001	0.00001	0.716	0.474
Amount of DAP fertilizer	0.003***	0.0006	4.076	0.000
Amount of CAN fertilizer	-0.0003	0.0003	-0.774	0.439

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Amount of biocide	0.766	0.523	1.465	0.143
Amount of seed	0.109***	0.006	19.290	0.000
Household size	0.016	0.015	1.084	0.278
Intercept	0.138	0.110	1.256	.209
Number of observations	616			
F (11, 604)	70.46			
p>F	0.000			
R^2	0.562			
Adj. R-Squared	0.554			
Standard error of the estimate	0.686			

Note: *, ** and *** implies statistically significant at 10%, 5% and 1% respectively

Source: Survey data, 2013

The results of the regression model show that Global-GAP compliance affected smallholder GHG emissions negatively and significantly. It further indicates that region where the farmer is located, quantity of French bean harvest, quantity of gasoline fuel used, quantity of DAP fertilizer applied, and amount of planting seed used positively and significantly affected smallholder farmers' GHG emissions. More explicitly, the model using these explanatory variables indicates that smallholder farmers complying with Global-GAP policy are more likely to emit less GHG compared to non-complying farmers (table 5). It shows that farmers complying with global-GAP policy are likely to have reduced GHG emissions by 0.154 units, holding region of the farmer, amount of harvest, amount of gasoline fuel, amount of DAP fertilizer, and amount of seed used constant. The results also show important regional variation. Farmers in Eastern region are likely to emit more GHG compared with farmers in the Central region. Indeed, according to HCDA report (2010), farmers in Eastern region produced 33,596 metric tons of French beans compared to 16,526 metric tons in Central region. This high production is also linked to higher levels of usage of gasoline fuel in motorized irrigation, higher levels of DAP fertilizer and seed which are all positive and significant in the model. Farmers in Eastern region are more likely to emit higher GHG by 0.104 units. The equation estimated is statistically significant and explains 56 percent of the variations on the smallholder GHG emissions.

The indirect GHG emission coefficients were converted in terms of CO_2 equivalence using the default IPCC (2007; 2006), characterization factors, 1 of CO_2, 21 of CH_4, and 310 of N_2O on a 100-year time horizon selected for GWP assessment in this paper. In the sensitivity analysis,

the GWP results that were recalculated using the new CO_2 equivalence factors, CO_2 1, CH_4 28, and N_2O 265 on a 100-year time horizon (Stocker *et al.*, 2013; Masuda, 2016), were compared with those shown in Table 3. When the new CO_2 equivalence factors were used, the GWP results for GNCC, GCC, GNCE, and GCE were 4.497, 4.029, 4.254, and 4.810 t CO_2e per ha, respectively. The recalculated GWP intensities were lower than the GWP results calculated for the modeled farm which were 5.148, 4.830, 4.586, and 5.408 tCO_2e for GNCC, GCC, GNCE, and GCE respectively. This may have been because a lower CO_2 equivalence factor for N_2O contributed to a reduction in the GWP intensities for French bean production in all production systems. Given the model-optimized results of land use (Table 5), the GWP intensities of the Global-GAP non-complying and complying farms were 4.815 and 5.423 tCO_2 e respectively in Eastern region. As with the results of eco-efficiency shown in Table 5, the eco-efficiency value (Kshs 86,600 per t CO_2e) of the Global-GAP non-complying farm in the recalculation was greater than that (Kshs 76,755 per t CO_2e) of the complying farm. Thus, even with the use of the new CO_2 equivalence factors, the fact remains that Global-GAP compliance is important for improving eco-efficiency in the farm.

4. Conclusions

Based on the study findings, there is an indication that smallholder French bean producers complying with global-GAP get higher returns and emits lower levels of GHG compared to non-complying farmers. There is need to integrate Global-GAP compliance into extension services outreach to reach a large number of farmers since the results shows that farmers complying with Global-GAP are more likely to emit reduced levels of greenhouse gases. Other GHG emission hotspots identified from the study include high production, increased use of gasoline fuel in motorized irrigation, increased application of DAP, region of the farmer and seed. The results support need for strengthening production management among smallholder farmers to conform to Global-GAP environmental policy if the industry is to continue accessing developed county markets for incomes and foreign exchange earnings. This will also contribute to Kenya's goal of reducing GHG emissions from agriculture sector by the year 2030 (Government of

Kenya, 2010b). The paper recommends the inclusion of these factors by policy makers and industry stakeholders in the smallholder GHG emissions reduction strategies.

Acknowledgement

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