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Techno-economic analysis (TEA) and life cycle assessment (LCA) of maize storage in developing countries

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Abstract

Techno-Economic Analysis (TEA) plays an important role in assessing economic performance and potential market acceptance for new technologies. Previous work has shown that the construction and operation of a cellulosic bioethanol plant can be very expensive. One of the largest cost categories is pretreatment processing. The purpose of this study was to conduct a detailed cost analysis to assess low moisture anhydrous ammonia (LMAA) pretreatment process at the commercial-scale, and to estimate the breakeven point in large-scale production. In this study, capital expenses, including annualized purchase and installation fees, and annual operating costs associated with each unit operation were determined. This research compared the unit cost per year between different scales of the LMAA process, and focused on exploring the optimal cost-effective point for this pretreatment method for bioethanol production.

Keywords

Techno-Economic Analysis, LMAA, Commercial-scale

Disciplines

Agriculture | Bioresource and Agricultural Engineering

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TECHNO-ECONOMIC ANALYSIS (TEA) AND LIFE CYCLE ASSESSMENT (LCA) OF MAIZE STORAGE IN DEVELOVING COUNTRIES

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Abstract.

Maize is the most widely cultivated cereal crop worldwide, currently ranked the third most important crop globally after wheat and rice. It is a key staple food in many developing countries. However, maize is produced on a seasonal basis, usually harvest once per year. To maintain a constant supply throughout the year, maize should be properly stored. But this entails high cost and high-energy consumption, which can contribute significant amounts of greenhouse gas emissions. In this study, three storage capacities (2,500 kg/y, 25,000 kg/y, and 250,000 kg/y) were evaluated for economic analysis and environmental impact. The results show that the larger the storage capacity, the more economical, and the total annualized storage cost per kg decreased as storage capacity increased (61.83 $/kg/y, 14.05 $/kg/y, and 5.91 $/kg/y). Likewise, as storage capacity increased, more energy was required to operate the equipment. Consequently, more greenhouse gas emissions (CO_2, CH_4, and NO_X) were emitted to the environments. Thus, to obtain an optimal balance between economics and the environment, it is important for the farmers in developing countries to understand the concepts of techno-economic analysis (TEA) and life cycle assessment (LCA).

Keywords: Maize storage; techno-economic analysis; life cycle analysis; capital cost; fixed cost; variable cost.

Introduction

The agricultural sector contributes significant amounts of greenhouse gas emission (GHS's) (methane, carbon dioxide, and nitrous oxide), the latest data show roughly one-fifth of the total GHS's come from agriculture (Smith et al., 2008; Li et al., 2010; Duxbury, 1994), although at the same time plays an important role in the global flux (sources and sinks) of GHS's emissions (Andersson et al., 1994). According to Food and Agricultural Organization of the United Nation (FAO) agriculture emits about 10% to 12% of the total GHG emissions equivalent to 5.1 Gt CO_2 equivalents per year to 6.1 Gt CO_2 equivalents per year (Niggli et al., 2009). Generally, agricultural activities are the largest producer of methane (CH_4) and nitrous oxide (N_2O) contributes around 45% to 50%, and 20% to 70% of the total GHS's emission, respectively (Verge et al., 2007).

Likewise, Bouwman (1996) estimated that every year agriculture production contributes around 20% of CO_2 and over 70% of N_2O in the atmosphere. Revealed by Intergovernmental Panel on Climate Change (IPCC), GHS's emissions from agriculture sectors accounted for 14% of non-CO_2 of total emissions, 80% of total N_2O and over 40% of total CH_4 emissions (Li et al., 2010). US agricultural production is a relatively minor source (Figure 1) and contributes about 7% of the total GHS's (Johnson et al., 2005). In typical agricultural operations, post-production processes such as transportation, drying, and storage of grain contributes a large proportion of GHS's emissions (Gregorich et al., 2005). There is increased awareness that the environmentally conscious farmer of the future will consider ecological and ethical criteria in selecting agricultural practices as a way of mitigating GHS's emission (Andersson et al., 1994). Many publications show that agricultural production is the focus point of GHS's emissions and with application of life cycle assessment (LCA) can help identify more sustainable solutions (Roy et al., 2009).

Maize is considered the largest and fastest cultivated cereal crop worldwide, currently ranked third most important cereal crop globally after wheat and rice (Suleiman et al., 2013). Over 800 million metric tons were produced in 2011/12; the production is expected to double by 2025 and to be the number one cereal crop by 2050 (M'mboyi et al., 2010). It is a staple food in developing countries. However, they are produced on a seasonal basis, usually harvest once per year. To maintain a constant supply throughout the year, maize should be properly stored. The key economic benefit of grain storage are to even out seasonal fluctuations in the market supply, ensuring domestic food supply, reducing the loss of maize during and after harvest, and providing food security for times of scarcity (Tefera et al., 201;

Proctor, 1994).

Conversely, maize storage is associated with cost and high-energy consumption, which contributes a significant amount of greenhouse gas emission. Consequently, grain producers are facing economic and environmental challenges, to obtain optimal levels of economic and environmental, farmer should understand concepts of techno-economic analysis (TEA) and life cycle assessment (LCA). In this paper, three different storage capacities (2,500 kg, 25,000 kg, and 250,000 kg) kg were used to develop techno-economic analysis and evaluate the environmental impact (life cycle assessment) for maize storage in developing countries.

Methodology

Maize is the key staple food in many developing countries; subsistence farms with small part of land and often far from markets mainly produce it. Moreover, they are produced on a seasonal basis; usually harvest once per year (Proctor, 1994), but consumption is evenly spaced throughout the year (Benirschka and Binkley, 1995). Thus, storage plays a significant role in ensuring constant supply, and in stabilizing the food supply at the household level by smoothing seasonal food production (Tefera et al., 2011). The main function of maize storage in the economy is evened out fluctuations and reduces bottlenecks in the distribution channel (Proctor, 1994). Stable price benefits both producers and consumers because it reduces the uncertainties associated with planning farm investment and household expenditure (Proctor, 1994).

For subsistence farms, the main roles of maize storage are to ensure household food supplies, reducing the loss of maize during and after harvest, for seed, providing food security in times of scarcity, guarantor as inflation proof savings banks, as well as improve agricultural income (Tefera et al., 2011). From a government point of view, maize (grain) is stored for several purposes such as, a food security reserve, a price stabilization stock, a national storage reserves or strategic reserves, buffer stocks, and production controls (Proctor, 1994). Maize storage costs include both fixed and variable components. Fixed costs are incurred regardless of whether the grain is actually stored in the storage facilities or not, whereas variable costs are incurred only when maize is stored. General assumptions and storage scenarios are shown in Table 1 and 2 respectively.

Life cycle assessment (LCA) is a new approach to grain supply chains and slowly is integrated in the farming practices as more farmers become aware of GHS's emissions since affecting their productivity. LCA is defined as a tool for evaluating environmental effects of a product, process, or identifying and quantifying energy, materials used, and wastes released into the environment which, is known as a 'from cradle to grave analysis' (Roy et al., 2009; Walker et al., 2011; Hospido et al., 2003). It is a recognized procedure for assessing GHG emissions of different products from ethanol production to food production to grain storage (Feng et al., 2008). In recent day, LCA has become a key element in agricultural production and environmental policy all over the world from US to India to South Africa (Guinee et al., 2010). The main purposes of LCA as outlined by ISO 14040 standard are process improvement, production, assess environmental performance indicators, decision-making and market claims (Tillman, 2000). There are two main types of LCA, retrospective (accounting perspective) and prospective (modeling the effects of changes) (Tillman, 2000). In this study, prospective LCA was used. According to ISO 14040, LCA framework comprised four main phases (Figure 2); goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation of the results.

The Life Cycle Assessment (LCA) methodology has been used to evaluate the environmental profile of maize storage in developing countries.

Goal and scoping

Goal and scoping is the most essential component of an LCA, since the analysis is carried out according to the statements made in this phase, which defines the purpose of the study (Roy et al., 2009). This establishes the functional unit, system boundaries, and quality criteria for inventory data. The goal of this study was to estimate the life cycle assessment of maize storage.

Functional unit

The functional unit (FU) is described as the functional outputs of the product system. It is important for the result of an LCA and depends on the environmental impact category and the aims of the investigation (Schau and Fet, 2008). The purpose of FU is to provide a reference unit to which the inputs and outputs can be related. According to Cederberg and Mattsson, (2000), the functional unit is often based on the mass of the product under study. In this study, the focus was on the storage of maize grain, so the functional unit was defined as maize grain and the reference flow was 1 kg of maize grain.

System boundary

The definition of system boundaries could determine the outcome of an LCA and often illustrated by a general input and output flow diagram (Schau and Fet, 2008), it includes all operations that contribute to the life cycle of the product, process, or activity fall within the system boundaries (Roy et al., 2009). This includes all input processes to the maize grain storage system, as shown in Figure 3. In this study, farm infrastructure and agricultural input such as fertilizers are not included in the system boundary.

Inventory analysis

The inventory analysis includes a detailed description of the functions and boundaries of the system, data collection, calculation and assessment of sensitivities and uncertainties.

Investment costs

The investment costs of grain storage can be divided into two main categories: first the cost due to equipment, this was the largest cost of storage facilities it includes the costs of storage bins, dryers, conveyance equipment, grain carts, and truck (Table 3), second was the cost due to building, it comprised costs of space, concrete floor, and bin erection. Equipment cost data was collected from several manufacturers and vary by size. For instance, in the first scenario 9,000 kg bin will cost $ 8,475 per kg or $ 1.07 per kg. The cost of a concrete floor and erection was estimated according to Dhuyvetter et al., (2007). Investment cost has a significant effect on the storage capacity. In general, the larger the storage facility the lower the investment cost per unit ($/kg/y) as shown in Table 3.

Fixed costs

The fixed costs are costs related to storage facilities and equipment ownership. Typical fixed costs in grain storage facilities are depreciations, interest, overhead, taxes, handling, repairs and insurance cost.

Variable costs

Variables costs is a main cost category in grain storage, it includes the costs that are only incurred if grain is stored (Brennan and Lindner, 1991). It is a parameter that changes and depends on the amount of grain stored and the length of the storage period (Dhuyvetter et al., 2007). It includes costs such as labor, management, trucking in and out of storage, insecticides, interest for the grain, and cost of energy (e.g. liquid propane and electricity) for grain drying (Reff, 1983).

Results and Discussion

Three main storage scenarios were evaluated in this study. An outline of the farm structure and material flows are shown in Figure 3 and 4. Both scenarios were typical storage capacity for a farm in developing countries, scenario 1 was baseline and assumed 5 kg of maize will be stored per day, for 6 months (1/2 year) and 1000 operational hours, the total of 2,500 kg will be stored per year (i.e. 5*0.5*1000 = 2,500 kg/y). The second and third scenarios were estimated to be 25,000 kg/ y and 250,000 kg/ y respectively.

Fixed costs

The fixed costs of grain storage are those costs that are incurred whether grain was stored in the facilities or not (Reff, 1983). Total annual fixed costs depend on the length of storage and capacity of the storage facilities (Dhuyvetter et al., 2007). It includes parameters such as depreciation, insurance, interest, overhead cost and taxes; it also comprised handling and maintenance costs (Rosentrater, 2013). The interest fixed cost was a major part of total storage cost and it was the combination of the interest due to investment (equipment and building) as well as interest due to maize being stored. According to Reff (1983) interest on grain is the largest cost because it includes rate of existing loan and rate of return from investment.

Furthermore, revealed by Kenkel, (2008) that fixed costs contribute large component of the total costs in commercial grain operation. Schnake and Stevens (19983) estimate that fixed costs comprised 64% of the total operation costs in grain storage facility. For this study, investment interest was calculated as 1% of the total equipment and building cost. For simplicity straight-line depreciation (i.e. purchase price minus salvage value divided by its estimated useful life) was used in this paper. As shown in Figure 5, annualized fixed cost increased as storage capacity increased. Likewise, the annualized fixed cost per kg decreased as the storage capacity increased. Similarly, survey conducted by Baumel (1997) in Iowa between two crop years (1993 to 1995) show that as crop production increasing handling and storage costs decreasing from $0.152 per bushels for 2.6M bushels to $0.103 for 4.4M bushels.

Variable costs

The variable costs include the operating cost such as utilities (electricity) for drying, aeration, and conveyance; it also contains labor and management costs as well as the cost of insecticides, turning and aeration, shrinkage, and liquid propane (Kenkel, 2008). The cost for electricity and liquid propane will depend on the initial and final moisture contents of maize, airflow rate, and time of drying. Moreover, the cost of electricity for aeration, augers and conveyance; differs from one place to another and mainly depend on the cost of electricity per kilowatt-hour (kWh), motor size, and time of aeration. For instance cost of electricity was 0.07$/ kWh, motor size was 60 HP with 75% efficiency, and 100 operating hours, the total cost of electricity for 6 months (1/2 year) will be = 0.07* 60*0.75*100*0.5 = 157.5$/ kWh /y.

Since the maize will be stored for 6 months, another important parameter to look at and incorporated in our variable cost calculation was shrinkage, maize like other grain, it loses moisture during storage, so it loses weight as well, the weight loss is what we called shrinkage, hence maize is sold based on weight shrinkage should be considered (Alexander and Kenkel, 2012). Moisture shrinkage was calculated by using equation 1.

$$\text{Moisture shrinkage}(\%) = \frac{\mathrm{M_i}\% - \mathrm{M_f}\%}{100 - \mathrm{M_f}\%} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where M_i and M_f = initial and final moisture content respectively, for our case initial moisture content was assumed to be 20% and final moisture content to be 14%, hence the moisture shrinkage = 6.97%.

$$\mathrm{M.S}(\%) = \frac{20 - 14}{100 - 14} \times 100 = 6.97\%$$

Table 1 shows the estimated variable costs of three storage capacities. It was noticed that the annualized variable cost per kg decreased as the amount of grain stored increased (i.e. 0.80$/kg/y, 0.14$/kg/y, and 0.06$/kg/y), this contributed by many things like the cost of electricity and will decrease when exceeding certain amount of kilowatt-hour per month.

Total storage costs

Total storage cost was the sum of the operational and fixed cost. In this analysis, the total annual storage cost per kg decreased as storage capacity increased, as shown in Figure 6, and followed an exponential trend, the estimated annual storage costs per kg were 61.83 $/kg/y, 14.05 $/kg/y, and 5.91 $/kg/y for scenario I, II, and III respectively. This concurred with Valente et al., 2011, who reported that higher reduction storage costs and economic viability occurred when the amount of stored product increased.

The results of the LCA are summarized in Table 4. The results from LCA indicate the environmental impact generated from maize storage increased as storage capacity increased.

Energy use

Energy usage was divided into electricity and fossil fuel (diesel and liquid propane). The total energy used in maize storage ranges from 244 kWh to 22,313 kWh. Comparing the two sources of energy, electricity was primary energy used in almost all activities except on trucks and in addition to electricity; liquid propane was also used in the dryer. The emission was calculated based on assumption made earlier. The result shows energy usage was proportional to storage capacity and emission production increased and this agreed by many authors (Searchinger et al., 2008; Norman et al., 2006; Kim and Dale, 2005)

CO_2 emissions

Many studies agreed that GHG's emission, especially CO_2 emissions as leading causes of climate change or global warming (Soytas et al., 2007; Zhang and Cheng, 2009; Halicioglu, 2009). It was once reported by The World Bank that CO_2 is held responsible for over 50% of the total global GHG emissions (The World Bank, 2007). According to IPCC guidelines, CO_2 emissions data are based on estimates, as emissions from very few sources such as agricultural production and grain storage can be measured directly or continuously depend on applications (Bastianoni et al., 2004). In maize storage study, CO_2 emissions was calculated by adding together all main sources of CO_2, the results found CO_2 emissions were the highest contributor of GHS's emissions. The system boundary in this study started at harvest, hence CO_2 emissions from the field was not included in this calculation, and CO_2 emissions due to human respiration was considered negligible compared to other source like CO_2 emissions from trucks. The emission varied from the scenario I to scenario III. Higher CO_2 emissions were observed in scenario III. Additionally, the results indicated that the CO_2 emissions have a significant impact on maize storage and it was directly proportional to energy consumption (Figure 7). This result supported by other authors. For instance, Zhang and Cheng, (2009) found strong tie between carbon emissions, energy consumption, and economic growth in China.

CH_4 and NO_x emissions

Many governments around the world have implement strong policies to reduce GHG emissions from agriculture especially CH_4 and NO_x (Boadi, 2004). Research conducted by Beauchemin et al., (2010) revealed that collectively CH_4 and NO_x accounting for over 30% of the total global GHG emissions. Methane is generated to the atmosphere through anaerobic activities of microorganism like *Methanobacterium omelianskii* bacteria, the many sources of CH_4 to the atmosphere from agriculture activities are paddy rice production fertilized with urea, animal wastes, biomass burning, and enteric fermentation in ruminant animals (Duxbury, 1994). In this study, no CH_4 gas was emitted to the environment because we only focused on storage of maize. Moreover, N_2O emissions from agriculture are mostly comes from nitrogen fertilizers and manure application (Popp et al., 2010; Kim and Dale, 2005). On top of this, another major sources of NO_x identified by many scientists several decade ago is fossil fuel combustion (Delmas et al., 1997). For the case of NO_x in this study all comes from fossil fuel. The result of NO_x emissions show direct relationship between storage capacity and NO_x production. As expected, the highest NO_x emissions were observed at scenario III (Figure 8).

CO_2 equivalent emissions

All emissions were converted to CO_2 equivalents, this was done by adding CO_2, NO_x and H_2O vapor, as predicted, highest CO_2 equivalent was observed at scenario III, followed by scenario II and scenario I (Figure 9). As shown on Figure 10 CO_2 equivalent per kg increased as storage capacity increased.

Conclusions

In this paper, techno-economic analysis (TEA) and LCA for maize storage in developing was calculated, some similarity between these two aspects was observed as the storage capacity increased the cost of storage per bushels also increased, the same trends were spotted in LCA, as storage increased more energy was needed to operate the equipment. Consequently, more GHS's emissions were emitted.

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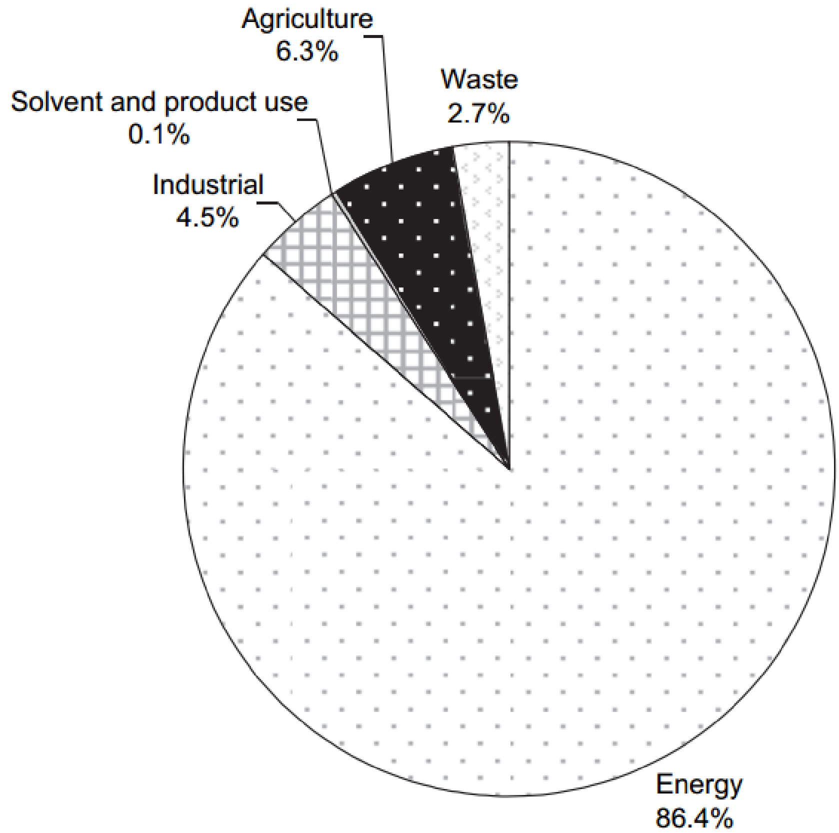

Figure 1. Relative contribution of agriculture to greenhouse gas emission (Adopted from Johnson et al 2007).

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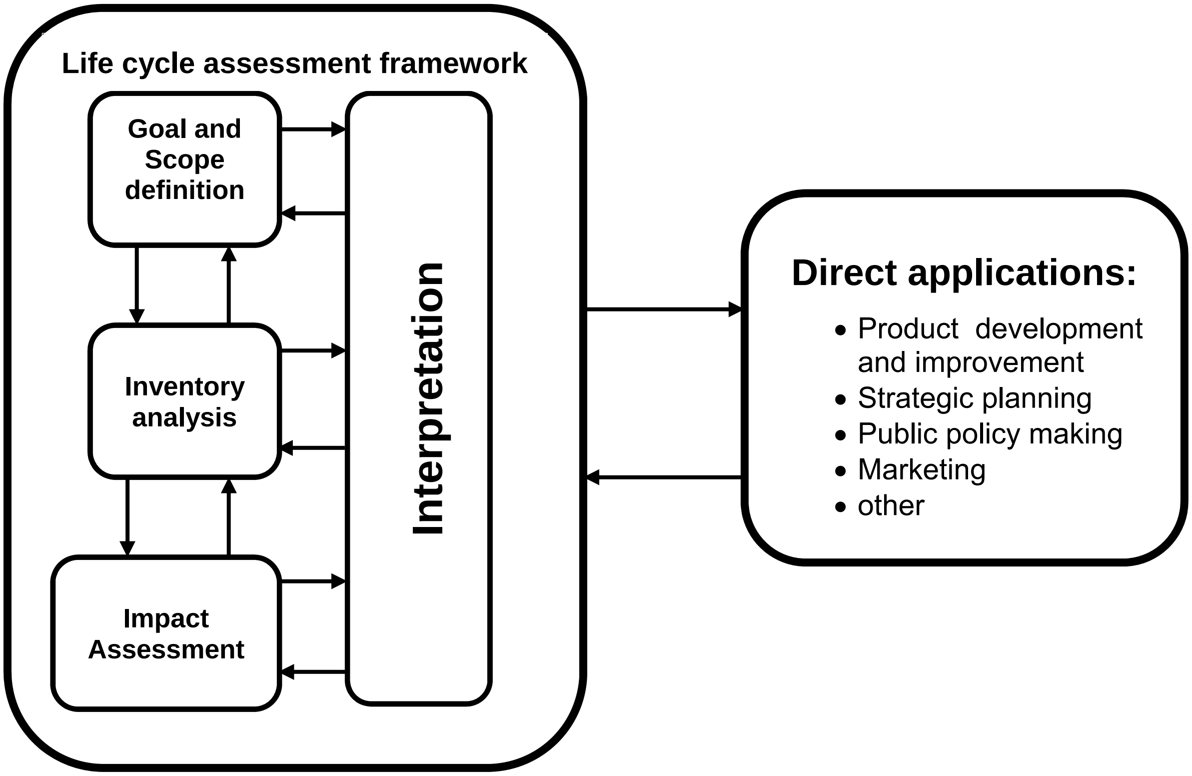

Figure 2. Stages of life cycle assessment (Adopted from ISO, 2006).

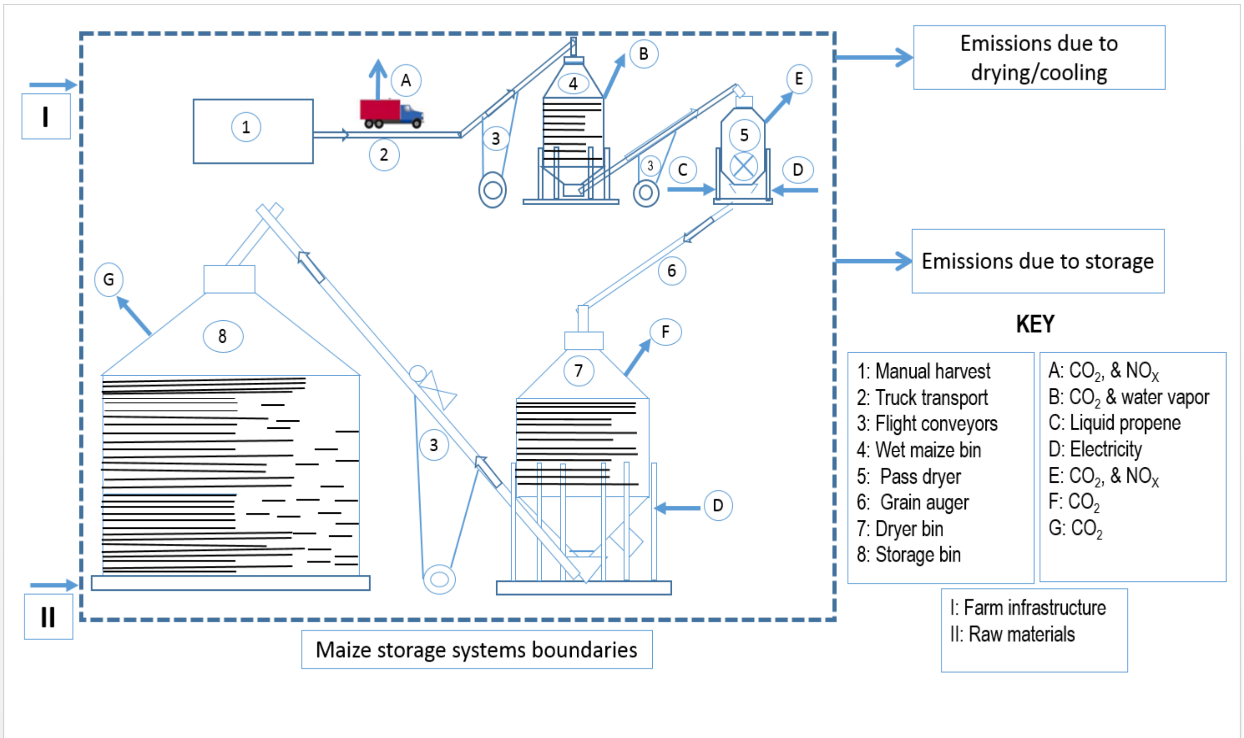

Figure 3. Process flow diagram for farm scale maize storage.

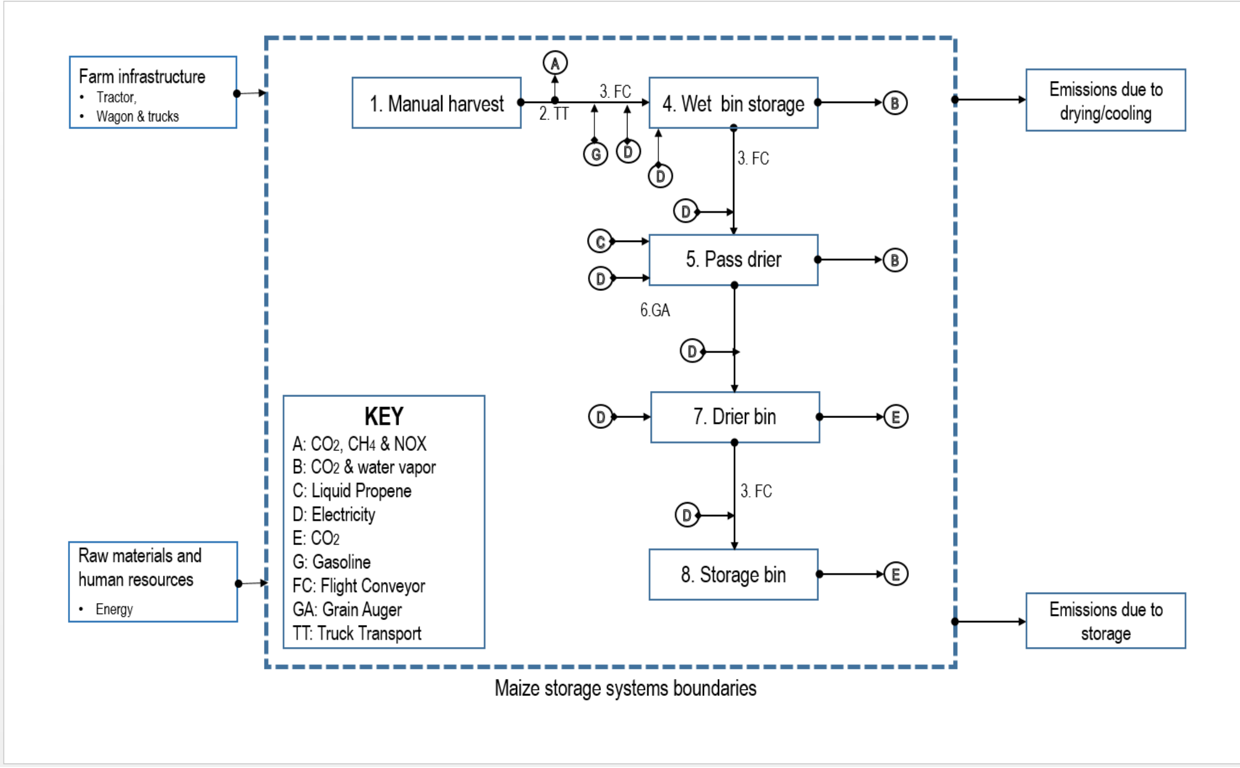

Figure 4. Process flow and systems boundaries for farm scale maize storage.

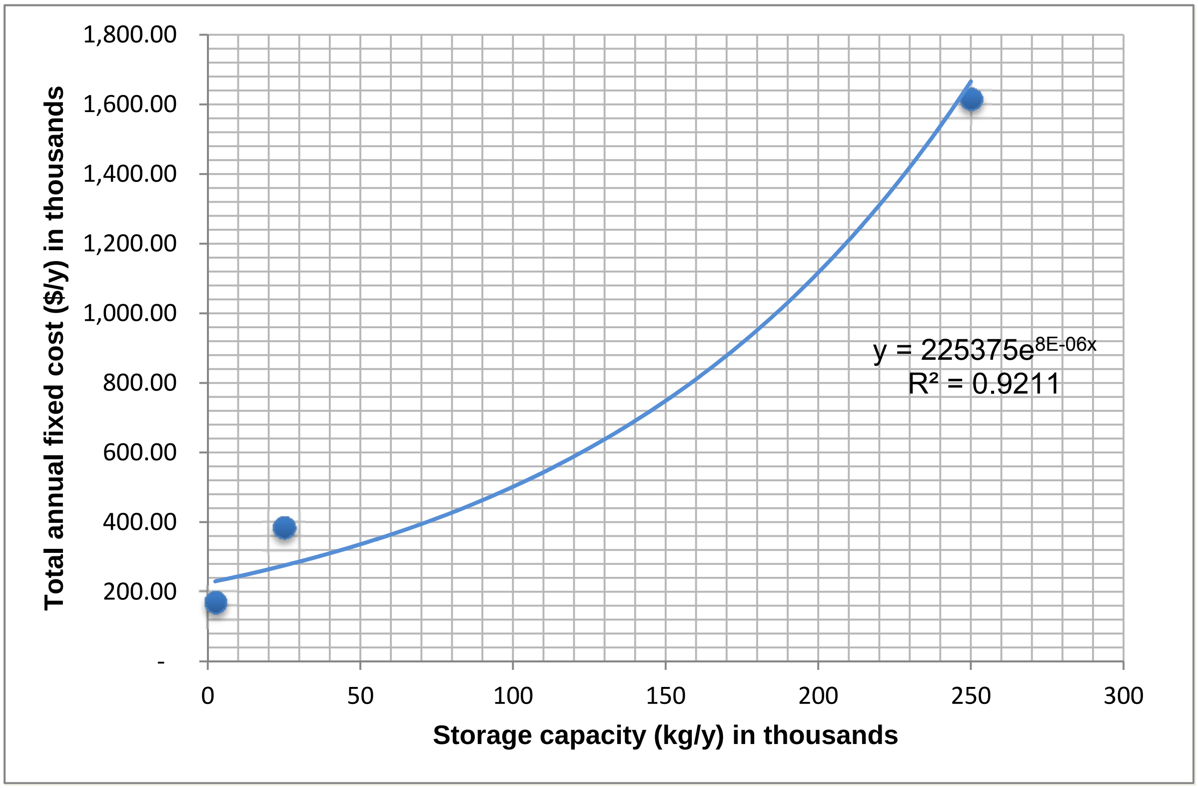

Figure 5. Annual fixed cost for farm scale maize storage.

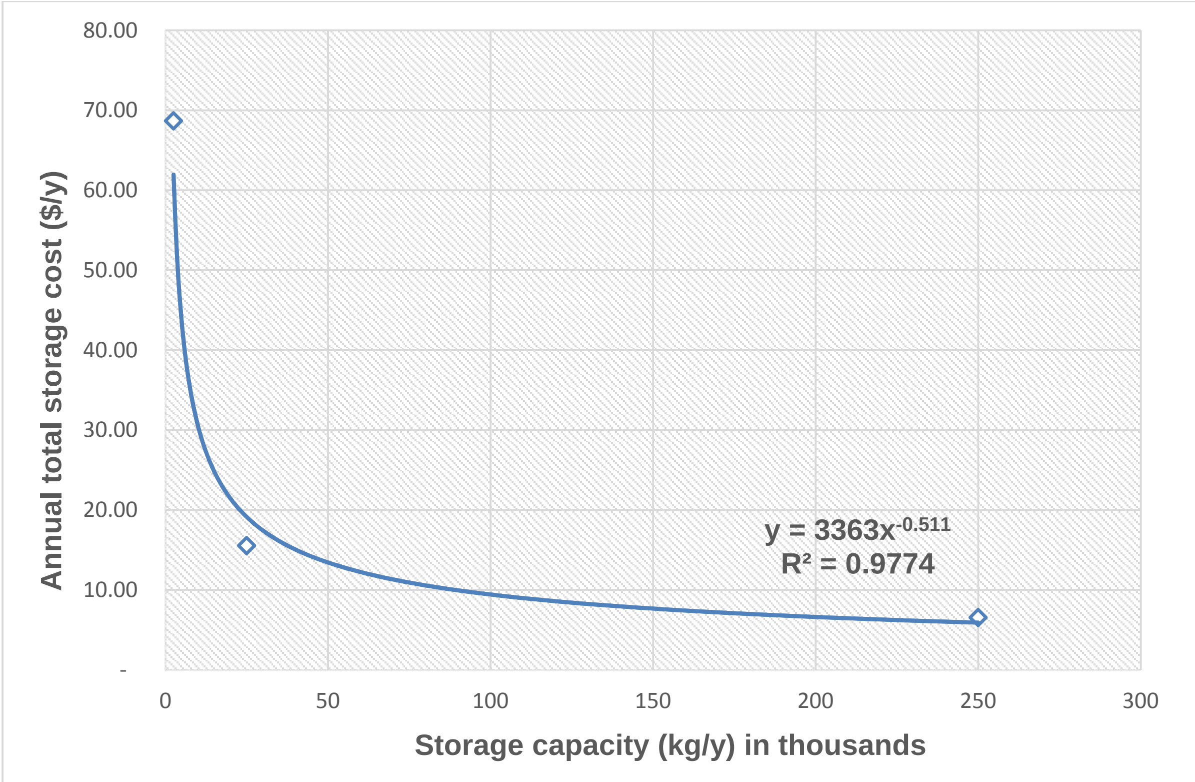

Figure 6. Annual total maize storage cost per $ per kg/y for farm scale maize storage.

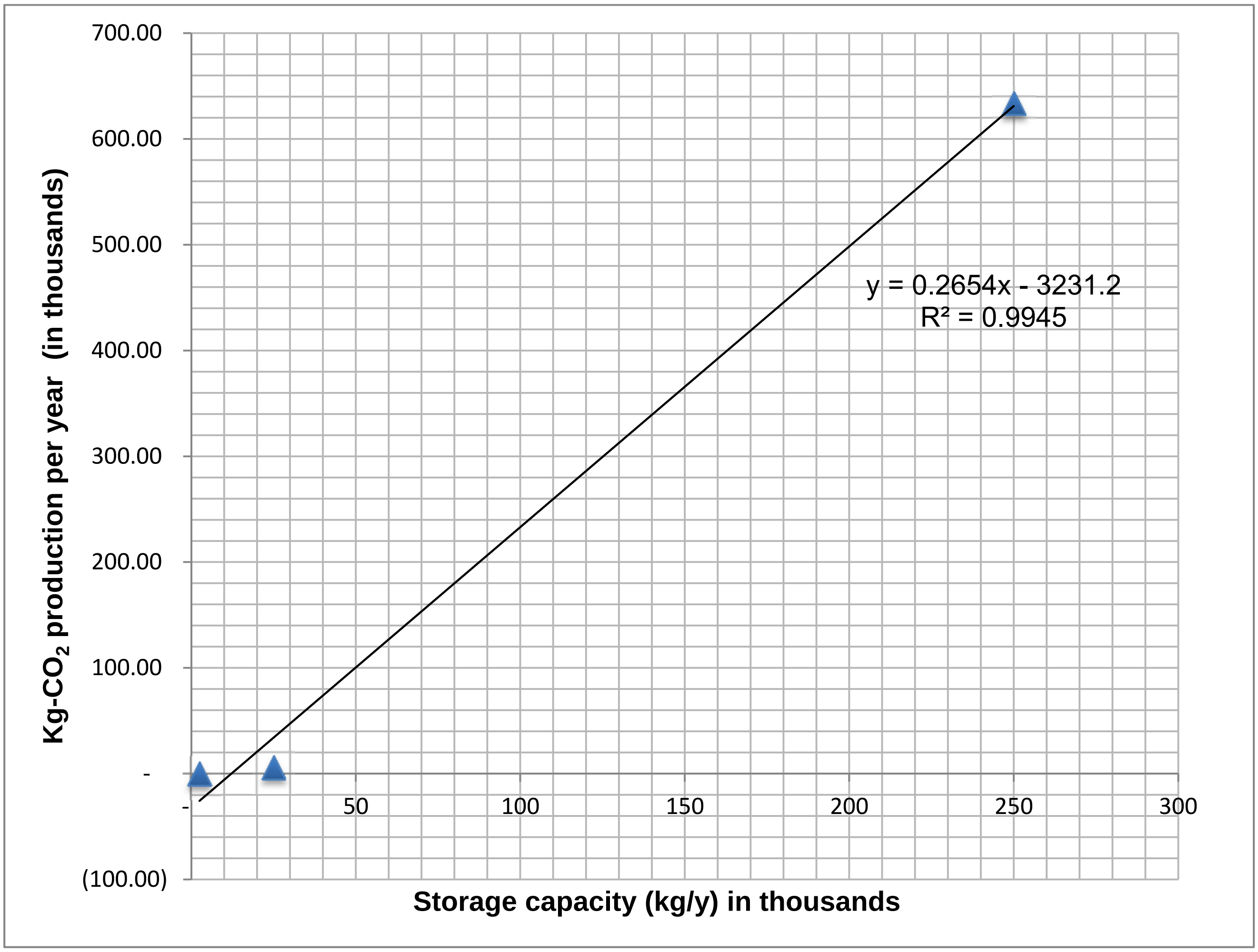

Figure 7. CO_2 emissions for farm scale maize storage.

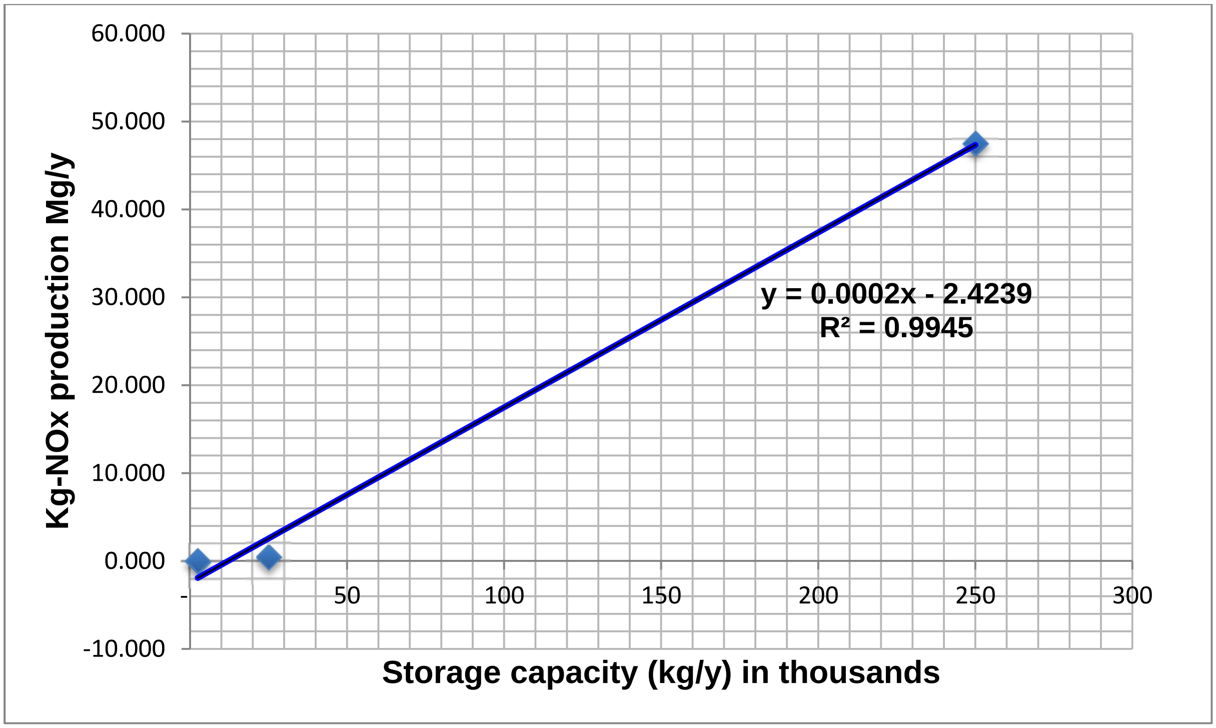

Figure 8. NOx emissions for farm scale maize storage.

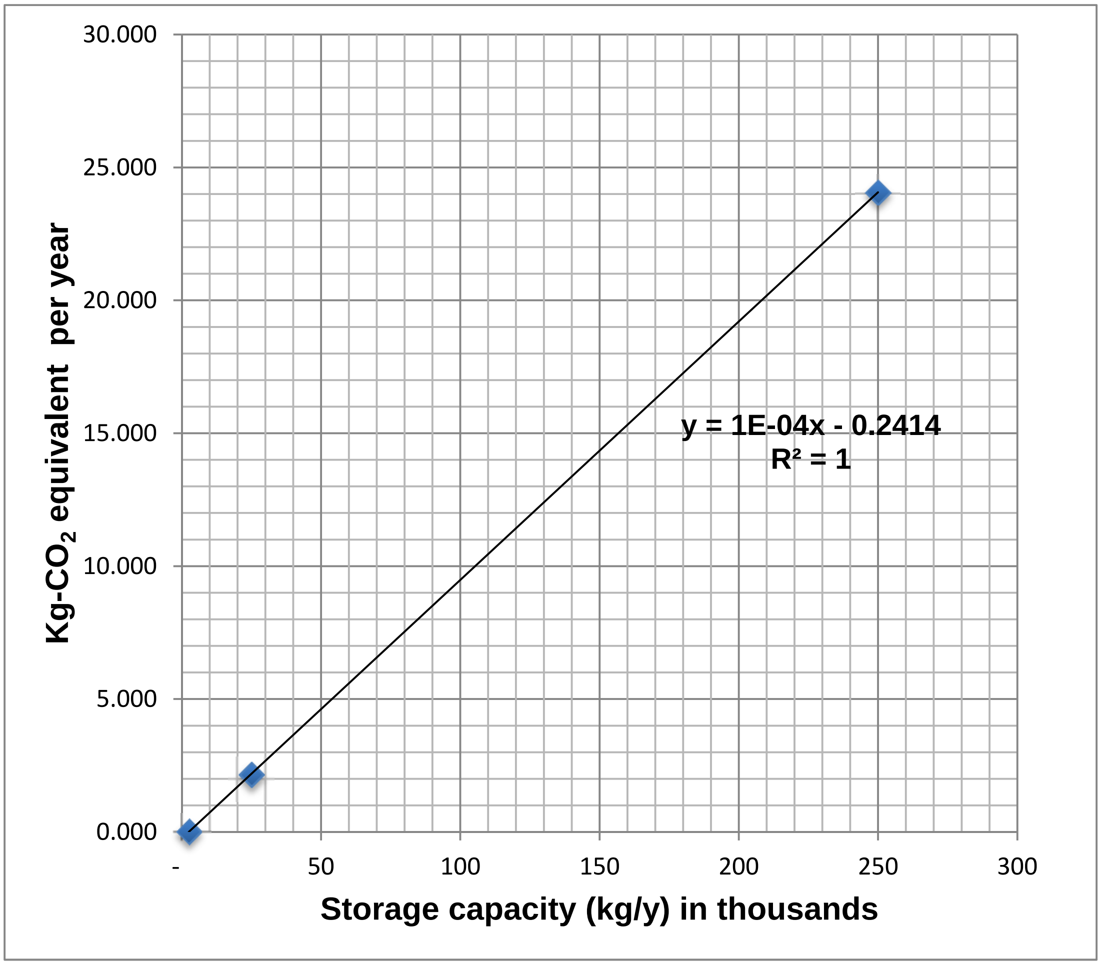

Figure 9. CO_2 equivalent for farm scale maize storage.

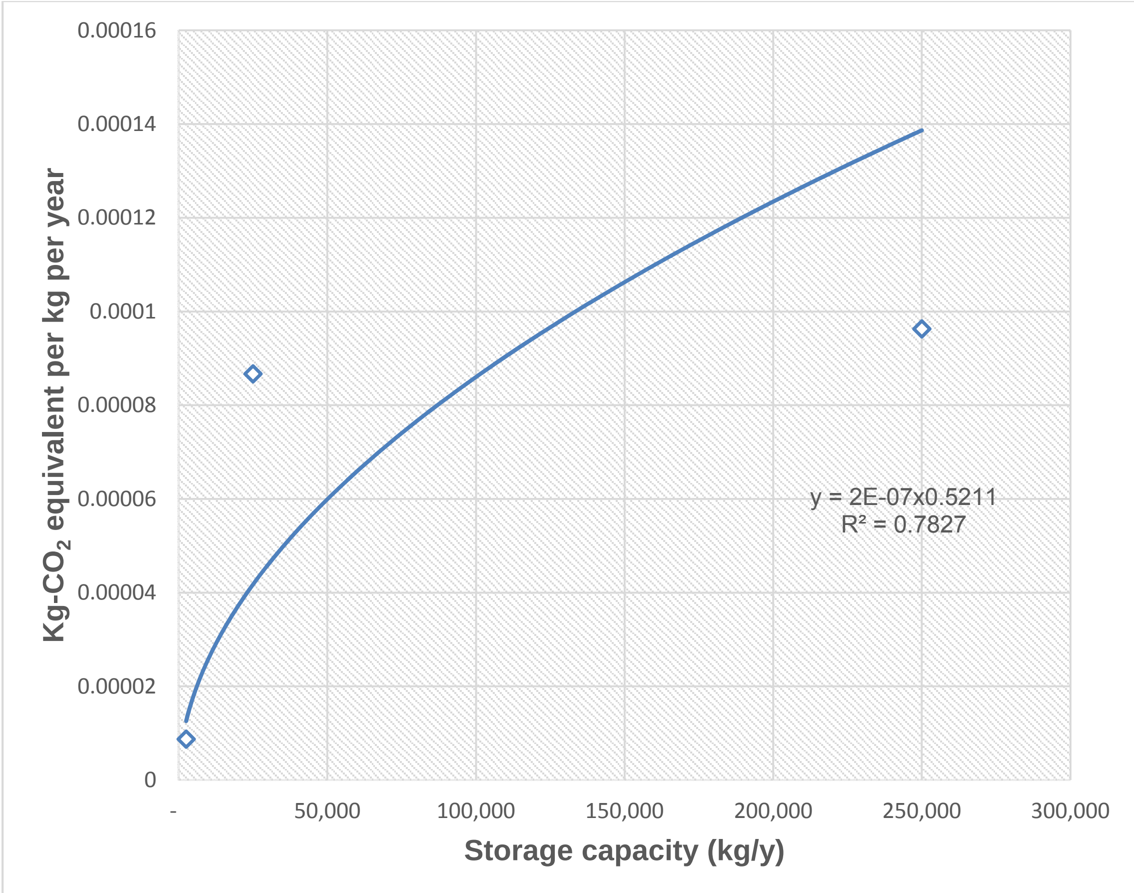

Figure10. Carbon dioxide (CO_2) equivalent/ kg for farm scale maize production.

Table 1. General Assumptions used for TEA and LCA.

General Assumptions		
Corn harvested, dried and stored on farm		
All storage bins are new		
Corn harvested	20	% (w.b)
Bin service life	25	y
Yearly operation	1000	h
Corn yield	1000	tone/ha
Corn storage time	6	m
Farm storage size	50* 100	ft^2
Capacity of flight conveyor	80	m^3/h
Total length of conveyor	10	m
Energy used = 0.75kWh/kg	0.75	kWh/kg
Corn will stay in wet bin	2	w

Table 2. Production scenarios used for TEA.

	Scenarios		
	I	II	III
Daily storage capacity (kg/d)	5	50	500
Yearly storage rate (G) – kg/y	2,500	25,000	250,000
Interest rate (I)	8.0%	8.0%	8.0%
Life expectancy (L), y	25	25	25
Operation hours (OH), h/y	1000	1000	1000

Table 3: Estimated costs for maize storage.

Scenario	Storage capacity (kg)	Capital cost ($/kg/y)	Fixed cost ($/kg/y)	Variable cost ($/kg/y)	Storage cost ($/kg/y)
I	2,500	61.83	67.75	0.80	68.55
II	25,000	14.05	15.38	0.14	15.52
III	250,000	5.91	6.46	0.06	6.52

Table 4. Emissions due to maize storage.

Emissions due to maize storage								
Scenario	Capacity (kg)	Energy used (kWh)	Kg-CO_2 (Mg/y)	Kg- CH_4 (Mg/y)	Kg- NOx (Mg/y)	Kg-H_20 vapor (Mg/y)	Kg-CO_2 eq (Mg/y)	Kg-CO_2 eq (Mg/y/kg)
I	2,500	245	7	0	0.005	4	0.022	8.73E^{-06}
II	25,000	2,008	571	0	0.428	383	2.167	8.86E^{-05}
III	250,000	22,314	63,366	0	47.532	38281	24.066	9.63E^{-05}

Abbreviations

Term	Description
CH_4	Methane
CO_2	Carbon dioxide
Eq	Equation
FAO	Food and Agriculture Organization
FU	Functional Unit
GHS's	Greenhouse gases emissions
H_2O	Water vapor
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard Organization
Kwh	Kilowatt-hour
LCA	Life Cycle Assessment
NO_x	Nitrous oxide
TEA	Techno-economic analysis
US	United States of America