Techno-economic analysis (TEA) and life cycle assessment (LCA) of maize storage for small and middle sized farmers

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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 may entail high cost and high-energy consumption, which can contribute significant amounts of greenhouse gas emissions. In this study, three storage capacities (25,000 bu, 250,000 bu and 2,500,000 bu) of maize were evaluated for economic analysis and environmental impact. The results showed that the total storage cost per bushel decreased as storage capacity increased (3.68 \$ bu^{-1}, 1.89 \$ bu^{-1}, and 0.40\$ bu^{-1}). Likewise, energy consumption (electricity, diesel and liquid propane) increased as storage capacity increased. Consequently, more greenhouse gas emissions (CO_2, CH_4, and NO_X) were emitted to the environment as storage scale increased. Thus, to obtain an optimal balance between economics and the environment, it is important for small and middle-sized farms to understand the concepts of techno-economic analysis (TEA) and life cycle assessment (LCA).

Keywords: maize storage, techno-economic analysis, life cycle analysis, greenhouse gas emissions, engineering economic analysis

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1 Introduction

The maize crop is the mostly widely cultivated cereal crop worldwide, together with wheat and rice are the three most important cereal crop in the world. Over 800 million metric tons were produced in 2012/13. Maize production is expected to double by 2025 (M'mboyi et al., 2010). Maize is produced on a seasonal basis; usually once per year (FAO/GIEWS, 2014), but consumption is evenly spaced throughout the year (Benirschka and Binkley, 1995). Thus, to maintain a constant supply throughout the year, maize should be properly stored. Grain storage plays a significant role to ensure a constant supply, and in stabilizing the food supply at the household level by smoothing seasonal food production (Tefera et al., 2011).

In addition, proper storage helps to minimize post-harvest losses of maize, acts as guarantor for inflation-proof saving banks, and improves agricultural income (Tefera et al., 2011). For the government, maize grain is stored as a food security reserve, a price stabilization stock, a national storage reserve or strategic reserve, buffer stocks, and production controls (Proctor, 1994). There are two main costs associated with maize storage: fixed and variable costs. Fixed costs are incurred regardless of whether grain is actually stored in the storage facilities or not, whereas variable costs are those that increase or decrease, and are incurred only when maize is stored (Edwards and Johanns, 2015).

2 Methodology

Life cycle assessment (LCA) is a tool that is common used to evaluate the environmental impact or effect of a product, process or systems throughout its life cycle (Roy et al., 2005). In this study, LCA has been used to evaluate

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the environmental profile of maize storage. The input data were obtained from different sources. Moreover, techno-economic analysis (TEA) is as a systematic analysis used to evaluate the economic feasibility aimed to recognize opportunities and threats of projects or product taking into account the capital, variable (operational), and fixed costs (Simba et al., 2012). Microsoft Excel was used to model LCA and TEA of maize storage for small and middle- sized family farmers. Table 1 and 2 showed general assumptions and storage scenarios used to build the LCA and TEA models for maize storage. The information from Table 1 was produced using multiple data sources (Electricity Local, 2019; Johanns, 2016; Uhrig and Maier, 1992; Water + Energy Progress, 2019). The length of the harvest period depends on the main factors such as the size of the operation, combined speed and capacity, and weather (McNeill and Montross, 2003). In this study, combining ground speed was assumed to be 2.5 miles per hour and combine operate for 12 hours. The total operational time (harvesting, transporting, drying and storage) varies from one scenario to another. The total operation time were assumed to be 300, 600, and 1000 hours for scenario I, II, and III respectively.

Table 1 General assumptions used for TEA and LCA

Property	Quantity	Unit
Maize are harvested, dried and stored on farm		
Brand new facility, include combine and transport truck		
Corn (yield)	1 acre	164 bushels
Corn harvested	21	% M.C (wet basis)
Target moisture content	16	%
Bins & dryer service life	25	years
Combine, track service life	15	years
Corn storage time	6	months
Capacity of flight conveyor	80	$m^3 h^{-1}$
Total length of conveyor	10	m
Interest rate (I)	8	%
Electricity cost (1 kWh) *	8.01	cents kW h^{-1}
All vehicles use gasoline (1 gallon) *	1.99	$
Liquid propane (1 gallon)	0.995	$
Truck travel distance	6.21	miles (10 km)
Fuel consumption for combine	2.24	gallons $acre^{-1}$
Fuel consumption for truck	4.25	mpg
Liquid propane consumption	0.02	gallons/bu/per % MC
Flight conveyor size	12×34	ft
Dryer size	42” diameter (9 rings)	
Facility (bins & dryer) installation: completed at beginning of year 0		
Capital, fixed and variable costs were only for the first year after installation		

Note: * Price in State of Iowa, USA.

Table 2 Production scenarios used for TEA.

	Scenario		
	I	II	III
Daily storage input (bu d^{-1})	50	500	5,000
Total storage capacity (bu)	25,000	250,000	2,500,000

2.1 LCA

An LCA comprises four main stages, including (Figure 1): goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation of the results (ISO 14040, 2006; Blengini and Busto, 2009). The goal and scope are an 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 is to estimate LCA of maize storage for small and middle-sized family farmers. Middle-sized family farms are defined as those farmers with 50 to 100 ha of land, or annual sales between $100,000 and $250,000 (USDA, 1997).

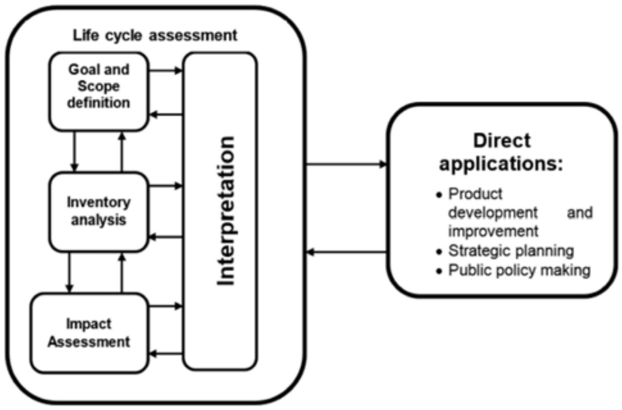

Figure 1 Stages of life cycle assessment (ISO 14040, 2006).

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 FU is often based on the mass of the product under study. In this study, FU is defined as 1 kilogram of maize grain stored. Moreover, the definition of system boundaries affects the outcome of an LCA. The system boundary includes all operations that contribute to the life cycle of the product or process and any activities that fall within the system boundaries (Roy et al., 2009). The system boundaries can be illustrated by a general input and output flow diagram (Schau and Fet, 2008). This includes all input processes to the maize grain storage system, as shown in Figure 2. In this study, farm infrastructure and agricultural input such as fertilizers were not included in the system boundary. The inventory analysis includes a detailed description of the functions and boundaries of the system, data collection, calculation and assessment of sensitivities and uncertainties.

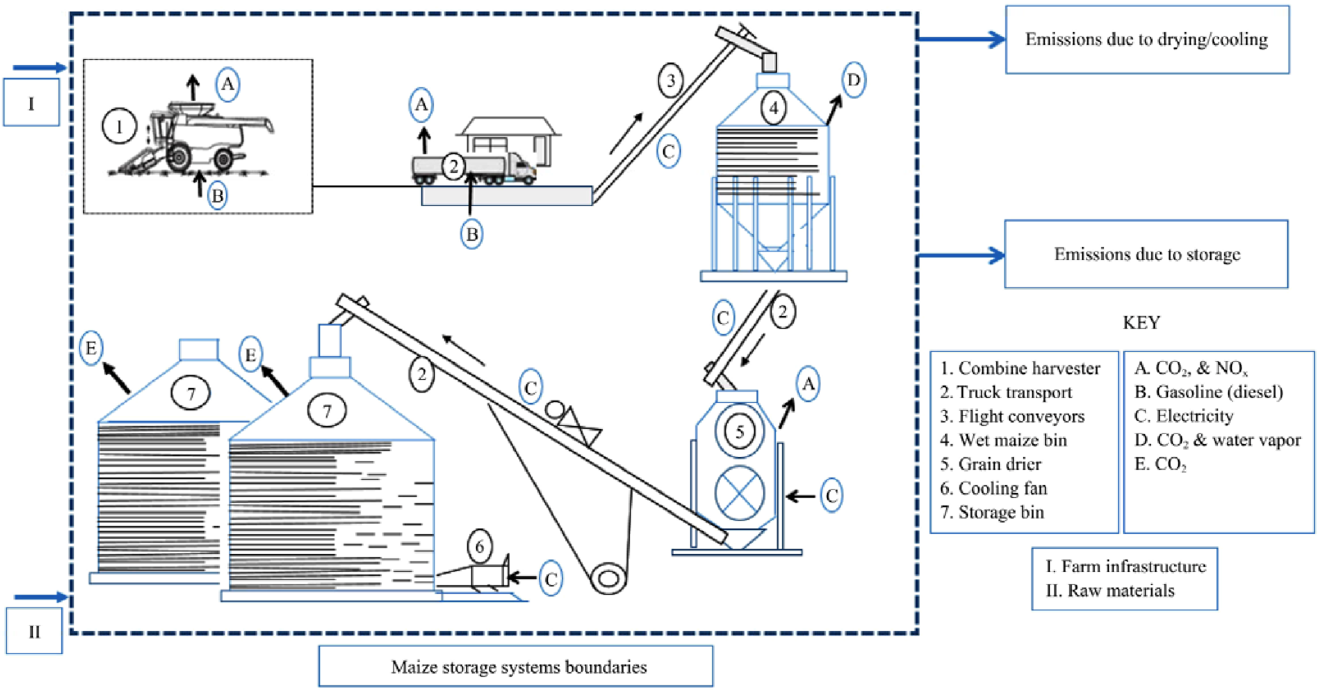

Figure 2 Process flow diagram for farm scale maize storage.

2.2 TEA

The investment costs of grain storage can be divided into two main categories. The first category includes the cost due to the equipment, this is the largest cost of storage facilities; it combines the costs of storage bins, dryers, conveyance equipment, grain carts/wagons, and trucks. The second category is the cost due to the storage facilities: these included the costs of space, concrete floor, and bin erection. The equipment cost data was collected from several manufacturers and varied by size. The cost of a concrete floor and erection was estimated according to Dhuyvetter et al. (2007). Storage capacity has a significant effect on investment cost. In general, the larger the storage facility, the lower the investment cost per unit ($ bu^{-1} y^{-1}).

In addition, the fixed costs are costs related to storage facilities and equipment ownership. Typical fixed costs in grain storage facilities include depreciation, interest, overhead, taxes, handling, repairs and insurance cost. Conversely, variable costs are the main cost for grain storage, and includes the costs that are only incurred if grain is stored (Brennan and Lindner, 1991). Variable costs change and depend on the amount of grain stored as well as the length of the storage period (Pardey et al., 2001; Dhuyvetter et al., 2007). These can include costs such as labor, management, trucking into and out of storage, insecticides, the cost of energy (e.g. liquid propane and electricity) for grain drying, etc. (Reff, 1983).

Because most countries have various currency and exchange rate fluctuates, all costs were calculated by using US dollars.

3 Results and discussion

3.1 TEA

In this study, three main storage scenarios were evaluated. An outline of the farm structure and material flows are shown in Figure 2 and 3. Scenario one was the baseline and assumed 25,000 bu of maize. The second and third scenarios were 250,000 bu and 2,500,000 bu respectively. The maximum storage time of maize was six months.

Another important cost associated with grain storage is the interest cost. The interest fixed cost is the major part of total storage cost and it is the combination of the interest due to the investment (equipment and building) and interest due to maize being stored. The interest cost of grain is the largest cost because it includes the rate of existing loans and the rate of return on investment (Reff, 1983). According to Wright (2011), when the interest rate is falling or if it remains low, it will encourage greater storage or higher stocks and subsequently stabilize and lower the grain prices. Moreover, supply and demand also have significant influences on prices of corn. The prices of wheat and corn are typically determined by the interaction of supply and demand functions.

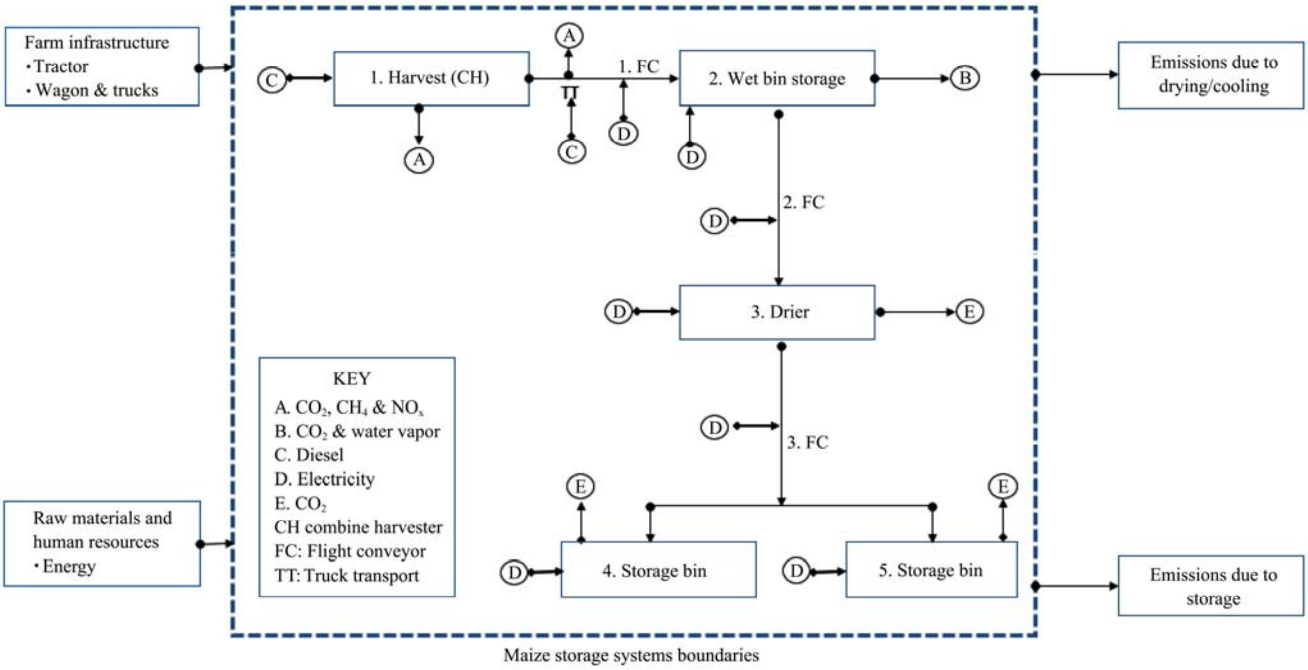

Figure 3 Process flow and system boundaries for farm scale maize storage.

Furthermore, the fixed costs contribute a large component of the total costs in commercial grain operation (Kenkel, 2008). In general, the fixed costs comprised about 64% of the total operation costs in grain storage facilities (Schnake and Stevens, 1983). In this study, investment interest rate was calculated as 8% 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. As shown in Figure 4, the fixed cost per kg decreased as the storage capacity increased. This concurred with the surveys conducted by Baumel (1997) in Iowa between two crop years (1993 to 1995) showing that as crop production increasing handling and storage costs, decreasing from $0.152 per bushel for 2 million bushel to $0.103 for 4.4 million bushel.

The variable costs included the operating cost such as utilities (electricity) for drying, lighting, and conveyance; it also contains labor and management costs as well as the cost of insecticides, turning and aeration, liquid propane and others related costs of operations (Kenkel, 2008; Pardey et al., 2001). The cost for electricity and liquid propane depends on the initial and final moisture contents of maize, airflow rate, and time of drying. In addition, the cost of electricity for aeration, augers, and conveyance, differs from one place to another and mainly depends on the cost of electricity per kilowatt-hour (kWh), motor size, and time of aeration. Another important parameter to incorporate in variable costs were shrinkage and handling losses. Maize like other grain, loses moisture during storage, so it loses weight as well. This weight loss is called 'shrinkage', and maize is sold based on moisture shrinkage (Alexander and Kenkel, 2012). Moisture shrinkage is calculated by using Equation (1). Likewise, the handling losses or 'invisible shrink' is the weight loss due to dry mater. It includes mechanical losses from broken kernels and foreign material, and loss of volatile compounds (oil). The handling loss of grain or corn depends on several factors such as method of drying, the handling processes during drying, physical quality of the corn, and how long the corn is dried (SDSU, 2014). According to Iowa State University research the handling loss for on-farm can range from 0.22% to 1.71%. In that study, the handling loss was assumed to be 0.5%.

Percentage moisture shrinkage (%) =

$$\frac{M_i\% - M_f\%}{100 - M_f\%} \times 100 \quad (1)$$

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%.

Percentage moisture shrinkage (%) =

$$\frac{20 - 14}{100 - 14} \times 100 = 6.97\% \quad (2)$$

The variable cost per bushel decreased as the amount of grain stored increased (i.e. 0.16 \$ bu^{-1}, 0.07 \$ bu^{-1}, and 0.04 \$ bu^{-1}), this contributed by many parameters like decrease in cost of electricity. Normally, the overall cost of electricity decrease when exceeding a certain amount of kilowatt-hour per month. Furthermore, the total storage cost was by adding up the operational and fixed cost. In this study, the total storage cost per kg decreased as storage capacity increased. The estimated total storage costs per bu were 3.68 \$ bu^{-1}, 1.89 \$ bu^{-1}, and 0.42 \$ bu^{-1} for the scenario I, II, and III respectively (Figure 5). The result concurred with those reported by Valente et al. (2011), that higher reduction storage costs and economic viability occurred when the amount of stored product increased. However, the values were for scenario I and II seem higher than those estimated by Edwards (2015) who reported cumulative storage costs for corn to be around 0.45 cents and 0.70 cents per bushel for on-farm storage and commercial rental storage respectively.

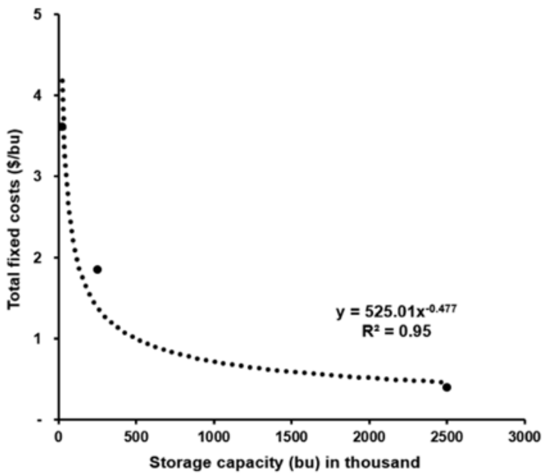

Figure 4 Total fixed costs (\$ bu^{-1}) of maize storage for small and middle-sized farmers

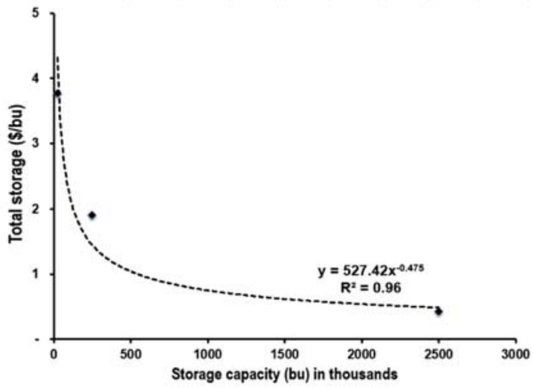

Figure 5 Annual total maize storage cost (\$ bu^{-1}) for small and middle-sized farmers

3.2 LCA

The results of LCA are summarized in Table 3. The results indicated the environmental impact generated from maize storage increased as storage capacity increased. Energy was main parameter determined in an LCA of maize storage. In this study, the energy usage was divided into two main parts: electricity and fossil fuel (diesel and liquid propane). The electricity used for drying, lighting and other operations in maize storage ranged from 0.33 kW h bu^{-1} to 0.78 kW h bu^{-1} (Figure 6). Electricity was primary energy used in almost all activities except on trucks. The total fuel consumption (diesel) used for combine and transport trucks increased as storage capacity increased from around 605 gallons for scenario one to 34,410 gallons for scenario three.

Table 3 Distribution of the emissions of three maize storage scenarios for small and middle-sized farmers.

Scenario	Capacity (bu)	Energy (kW h bu^{-1})	CO_2 Emissions (Mg y^{-1})	NOx Emissions (Mg y^{-1})	CO_{2eq} Emissions (Mg y^{-1})	CO_{2eq} Emissions (Mg y^{-1} bu^{-1})
I	25,000	0.33	231.33	0.02	8.85E^{-7}	3.54E^{-11}
II	250,000	0.51	357.10	2.72	13.66	5.46E^{-05}
III	2,500,000	0.78	546.01	4.15	208.84	8.35E^{-05}

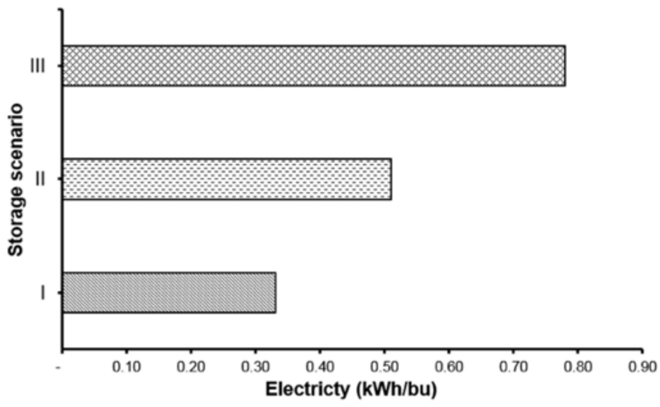

Figure 6 Electricity usage (kW h bu^{-1}) three different scenario for small and middle-sized farmers

In addition, liquid propane was also used in the dryer. The emission was calculated based on assumption made earlier. The result showed 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).

3.3 Greenhouse gasses emissions

Many studies agreed that greenhouse gas (GHG) emission, especially CO_2 emissions as leading causes of climate change or global warming (Soytas et al., 2007; Zhang and Cheng, 2009; Halicioglu, 2009). According to the World Bank reports, CO_2 is held responsible for over 50% of the total global GHG emissions (World Bank, 2007). Outlined in the Intergovernmental Panel on Climate Change (IPCC) guidelines that CO_2 emissions data are based on estimates. Emissions from different sources such as agricultural production and grain storage can be measured directly or continuously depending on applications (Bastianoni et al., 2004). In the maize storage study, CO_2 emissions were calculated by adding together all main sources of CO_2. The results showed CO_2 emissions were the highest contributor of GHS's emissions. Similar results have been reported by Roy et al. (2005) in the production and post-harvest of rice in Japan, and Carlsson-Kanyama (1998) in the storage and transportation of tomato, imported from Israel. The system boundary in this study started at harvest, hence, CO_2 emissions from the field were not included in the calculation, and CO_2 emissions due to human respiration were considered negligible compared to another source of CO_2 emissions such as trucks. The emission varied from the scenario I to scenario III. Higher CO_2 emissions were observed in scenario III (Table 3). Additionally, the results indicated that the CO_2 emissions have a significant impact on maize storage and it is directly proportional to energy consumption. This result supported by other authors. For instance, Zhang and Cheng (2009) found a strong tie between carbon emissions, energy consumption, and economic growth in China. According to Roy et al. (2009), greenhouse gas emission increased remarkably due to the increase in energy use. Likewise, Acaravci and Ozturk (2010) showed a positive relationship between energy usage, CO_2 production and economic growth in several European countries. In addition, the study conducted by Soytas et al. (2007) in the US found in the long run the main causes of carbon dioxide emissions was energy consumption.

3.4 CH_4, NO_x and CO_2 equivalent emissions

Many governments around the world have implemented strong policies to reduce GHG emissions from agriculture, especially CH_4 and NO_x (Boadi et al., 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 in 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). However, in this study, no CH_4 gas was emitted to the environment because we only focused on storage of maize. In addition, N_2O emissions from agriculture, mostly came from nitrogen fertilizers and manure application (Popp et al., 2010; Kim and Dale, 2005). Likewise, another major source of NO_x identified by many scientists is fossil fuel combustion (Delmas et al., 1997). In the case of NO_x in this study, all comes from fossil fuel. The results of NO_x emissions showed a direct relationship between storage capacity and NO_x production. As expected, the highest NOx emissions were observed at scenario III. Furthermore, to determine GHGs emissions, all emissions were converted to CO_2 equivalents, this was done by adding CO_2 and NO_x. The highest CO_2 equivalent was observed at scenario III, followed by scenario II and scenario I. The results showed CO_2 equivalent emissions increased as storage capacity increased (Table 3).

4 Conclusions

In this study, techno-economic analysis and life cycle assessment of maize storage were evaluated with three different storage scenarios. The results showed that as storage capacity increased, the total storage cost per bushel decreased. Similar results were obtained for fixed costs. Conversely, for the LCA, the study found a direct relationship between energy usage and storage capacity. As storage capacity increased more energy was required to operate the equipment. Likewise, higher carbon dioxide emissions were found for the largest storage scale. Therefore, the higher storage capacity, the lower the total storage cost per kilogram, the higher energy consumption, the more CO_2 produced. Consequently, more GHG were emitted.

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