

LIFE CYCLE ASSESSMENT OF WHEAT PRODUCTION AND PROCESSING SYSTEM

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ABSTRACT

Wheat being the leading source of vegetable protein in the human diets has higher protein content than other major staple grains or cereals like rice or maize; therefore it was necessary to study the environmental impacts associated with its field production and industrial processing using the life cycle assessment tool. The functional unit selected for the study was 1kg of wheat, and emission from various inputs into the system was aggregated into a large inventory table. Four environmental impacts were considered namely; global warming, acidification, eutrophication and ozone layer depletion. It was discovered that global warming has the highest impact score which is closely followed by eutrophication; 4.7153E – 02 kg CO₂ equivalent and 3.5907E – 04kg NO₃⁻ equivalent respectively, while ozone layer depletion has the lowest environmental impact score of 1.1889E – 07 kg R11 equivalent. High emission of CO₂ gas from fossil fuel during field operations and processing of wheat was observed as the reason for the high impact score of global warming.

Keywords: Wheat; Functional unit; Inventory; Life cycle assessment; Environmental impact.

1. INTRODUCTION

Previous studies and researches had shown the importance of Life Cycle Assessment (LCA) tool, in that it has been able to effectively determine the potential environmental impacts associated with a product throughout its life cycle, from the raw material acquisition through the production, use, end of life treatment, recycling and to final disposal (that is cradle to grave assessment) (Roy *et al.*, 2009). LCA major function is for the identification of the parts of life cycle where the greatest improvement can be made. Due to great energy used by food industries, which is one of the world's largest industrial sectors, it is important to take into consideration the effect of food production and processing such as green house gas emission, which has increased remarkably due to tremendous energy use and has resulted in global warming, which seems to be the most serious problem the humankind faces today (Roy *et al.*, 2007). Food production, preservation and distribution consume a considerable amount of energy, which contribute to total CO₂ emission, thus, it is essential to evaluate the environmental impacts and utilization of resources in food production and distribution systems for sustainable consumption and this can be accomplished by the Life Cycle Assessment tool.

For an appropriate life cycle assessment to be conducted there is a need for critical and optimal

analysis of energy input into production and processing systems. Data collected include all energy requirements and emissions attributed to the acquisition, transportation and processing of fuels." The objectives of life cycle assessment were to identify and quantify the potential environmental impacts associated with some agricultural production and processing, so as to identify the activities that are not performing sustainably" (Ntiamoah and Afrane 2007). So in order to analyse critically, the sources, causes and effects of the environmental impacts of wheat production and processing system, a critical study, using the life cycle assessment approach was carried out and this is aimed at investigating the possibility of reducing these environmental impacts

Wheat (*Triticum spp*) is a grass which originated from the Fertile Crescent region of Near East, but is now cultivated worldwide (NAERLS, 2004). Globally, wheat is the leading source of vegetable protein in human food, having higher protein content than either maize or rice which is the other major cereals. In terms of total production tonnages used for food, it is currently second to rice as the main human food crop and ahead of maize. In the light of this, Life Cycle Assessment of the wheat

production and its' processing into flour was considered.

2. MATERIALS AND METHOD

2.1 Materials: One of the instruments used to obtain data from wheat processing industry was a mercury thermometer (110°C) which was used to measure the ambient temperature of the environment, inlet and outlet temperature of mass flow in and out of the system. Other parameter taken such as fuel consumption rate, mass flow quantities and electric motor power ratings were all obtained from installations in the plant and inquiry from the plant operators.

The data on the wheat production and processing systems were collected using the various methods of data collection which are personal contacts, sites visitation, as well as personal observation on the selected site and main basic energetic parameters measured include; electrical, manual, and thermal energy.

2.2 Life Cycle Assessment Model: Life cycle assessment (LCA) has several standard steps, methods and procedures which had been specified for its application. A life-cycle assessment includes four phases according to the International Standard Organisations (ISO, 1997a), as outlined by Finnveden (1999):

a. Goal and scope definition: As stated in the aim of the study, the various contributions and impacts of emissions from the production and processing of wheat in four major environmental impacts were assessed. The environmental impact includes; global warming, acidification, eutrophication and ozone layer depletion. The functional unit for this study is one kilogram 1(kg). While the transportation of wheat was not included in the study because of the limitation of obtaining relevant data, the production stages of wheat which includes the bed preparation, planting, maintenance, harvesting, threshing and cleaning were considered alongside with its processing into flour and bran.

b. Inventory analysis: This phase deals with the data collection and data analysis of the inputs, outputs and emissions of wheat production and processing throughout its life cycle. The inventory analysis resulted in a large table of all inputs to the system (resources, etc.) and all outputs from the system (emissions such as CO₂, SO₂, NO₂, CO etc.).

c. Life cycle impacts assessment: This phase aims at understanding and evaluating environmental impacts based on inventory analysis, within the framework of the goal and scope of the study. Likely human and ecological effect of material consumption and environmental releases identified during inventory analysis were calculated. According to Ntiamoah and Afrane (2007),

classification and characterisation following the ISO14042 (2000) guidelines were applied to the inventory data in order to assess the potential environmental impacts.

d. Interpretation of results: This was a systematic technique used to identify and quantify, check and evaluate information from the results of the inventory analysis and the impact assessment, in line with the defined goal and scope.

2.3 Method of Data Analysis: The quantities of fuel used for each of the operations in litres per hectare and the quantities in kilogram were found from the density of diesel which was taken as 860kg/m³ as given by Canavate and Hernanz (1997) The output - input ratio, output productivity and net energy gain of the wheat production system were also calculated using the equation given by Garavand *et al.* (2010) as stated below;

$$\text{Output - Input Ratio} = \frac{\text{Output Energy (MJ/ha)}}{\text{Input Energy (MJ/ha)}} \quad (1)$$

$$\text{Energy Productivity} = \frac{\text{Wheat Output (kg/ha)}}{\text{Input Energy (MJ/ha)}} \quad (2)$$

$$\text{Net Energy Gain} = \text{Output Energy (MJ/ha)} - \text{Input Energy (MJ/ha)} \quad (3)$$

As specified in literature, Life Cycle Inventory Assessment was carried out using the emission estimation method. Also from literature the characterization factors used to convert the values related to the functional unit into modelled environmental inputs and output data, aggregated to the inventory table for the Life Cycle Assessment were obtained.

CO₂ emission from mobile and stationary engines

$$\text{CO}_2 \text{ emission (kg)} = \text{Fuel combusted} \times \text{HHV} \times \text{EF}_{\text{CO}_2} \quad (4)$$

N₂O and CH₄ emission from Mobile engines

$$\text{N}_2\text{O and CH}_4 \text{ emission (kg)} = A_s \times \text{EF}_{\text{p,s}} \quad (5)$$

N₂O and CH₄ emission from Stationary engines

$$\text{N}_2\text{O and CH}_4 \text{ emission (kg)} = \text{Fuel} \times \text{HHV} \times \text{EF} \quad (6)$$

NO_x, SO₂ and CO emission from mobile engines (fuel use basis)

$$\text{Emission} = \text{Fuel} \times \text{LF} \times \text{EF}_i \quad (7)$$

NO_x, SO₂ and CO emission from stationary engines

$$\text{Emission} = P_{\text{kw}} \times \text{OP (hrs)} \times \text{EF}_i \times (1 - \text{ER}/100) \quad (8)$$

Fuel combusted = mass or volume of fuel used in kg or litres

HHV = Default high heat value supplied = 45 MJ/kg for Diesel fuel

EF_{CO₂} = Emission factor for CO₂ in fuel = 10.15 kg/gal for diesel = 2.91 kg/kg (density used = 860 kg / m³).

A_s = Activity level (miles²)

EF = Emission factor (kg/kg) = 8×10⁻⁶, 4.5×10⁻⁴, 9.84×10⁻³, 1.05 ×10⁻² and 1.14×10⁻³ for N₂O, CH₄, CO, NO_x and SO₂ respectively.

LF = Load factor = 0.55 for wheeled tractor

P_{kw} = engine power in kW

OP = operating time of the engine (hours)

ER = emission reduction technology (wt %)
 $(1 - ER/100) = 1.0, 0.8 \text{ and } 1.0$ for CO, NO_x and SO₂ respectively.

Source: California air resource board institutional guidance for mandatory greenhouse gas Emission Reporting (2008), Emission estimation techniques manual for combustion engines (2002) and direct emission from mobile combustion sources (2008).

The emission of N₂O from Nitrogen use in wheat cultivation was calculated as specified by

Bouwan (1996) and quoted by Delucchi and Lipman (2003) and this is given as;

$$\text{Loss} = 1.00 + (0.0125 \times \text{kg Nitrogen application}) \quad (9)$$

NO_x and CH₄ emissions were computed by assuming 20% of applied Nitrogen and 10g /kg Nitrogen according to Holland et al. (1999) quoted by Delucchi and Lipman (2003).

Table 1: Energy values for various fuel types

Energy Source	Energy content	Production	Total energy costs
Gasoline	38.2 MJ/L	8.1 MJ/L	46.3 MJ/L
Diesel	38.7 MJ/L	9.1 MJ/L	47.8 MJ/L
Fuel oil	38.7 MJ/L	9.1 MJ/L	47.8 MJ/L
LPG	6.1 MJ/L	6.2 MJ/L	32.3 MJ/L
Natural gas	41.4 MJ/m ³	8.1 MJ/m ³	49.5 MJ/m ³
Coal	30.2 MJ/kg	2.4 MJ/kg	32.6 MJ/kg
Electricity	3.6MJ per kWh	8.4MJ per kWh	12.0 MJ/kWh

Source: Canavate and Hernanz (1997)

3. RESULTS AND DISCUSSION

Results of the energy analysis for wheat production system is based on calculations from about four (4) basic operations which are; land preparation (ploughing, harrowing and planting),

maintenance (fertilizer, pesticide and herbicide application), harvesting (drying, cleaning and threshing) and storage. Table 2 shows the detailed total energy use in the production of wheat based on the direct and indirect energy use.

Table 2: Energy consumption in wheat production

Input	Quantity	Energy Intensity	Energy Value of Input	
			MJ/ha	%
Direct energy use				
Diesel	62.00 L/ha	47.80 MJ/L	2,963.60	15.87
Indirect Energy use				
Machinery	3.54 kg/ha	877 MJ/kg	3,104.58	16.63
Fertilizers Nitrogen (N)	100.00 kg/ha	78.10 MJ/kg	7,810.00	41.83
Phosphorus (P ₂ O ₅)	50.00 kg/ha	17.40 MJ/kg	870.00	4.66
Potassium (K ₂ O)	30.00 kg/ha	13.70 MJ/kg	411.00	2.20
Herbicides (Chlorotoluron)	2.00 kg/ha	365.00 MJ/kg	730.00	3.91
Fungicide (Benlate)	0.64 kg/ha	397 MJ/kg	254.08	1.36
Fungicides (Captan)	6.33 kg/ha	115 MJ/kg	727.95	3.90
Seeds	130.00 kg/ha	13.00 MJ/kg	1,690.00	9.05
Labour	66.50 h/ha	21 men/ha	110.16	0.59
Total	-	-	18, 671.37	100.00
Output	3,800.00 kg/ha	13.00 MJ/kg		49,400.00

The highest energy consumption from Table 2 was observed from the energy sequestered in nitrogen (41.83%) and this is due to the fact that wheat production is associated with the use of large nitrogen fertilizer (100 kg Nitrogen needed). The energy use in machineries in the course of production contributes about 16.63% of the total energy in the system, the fuel quantities needed associated with machinery operations is also quite large (15.87%). The use of manual labour for

harvesting, drying of the pods after harvesting and operation of machineries has the lowest energy use (0.59%). Potassium and fungicide due to their low energy content are also characterized by low energy consumption, 2.20% and 1.36% respectively. The calculated output input energy ratio, energy productivity in (kg/MJ) and net energy gain in (MJ/ha) were obtained as 2.65, 0.20 kg/MJ and 30,728.63 MJ/ha respectively.

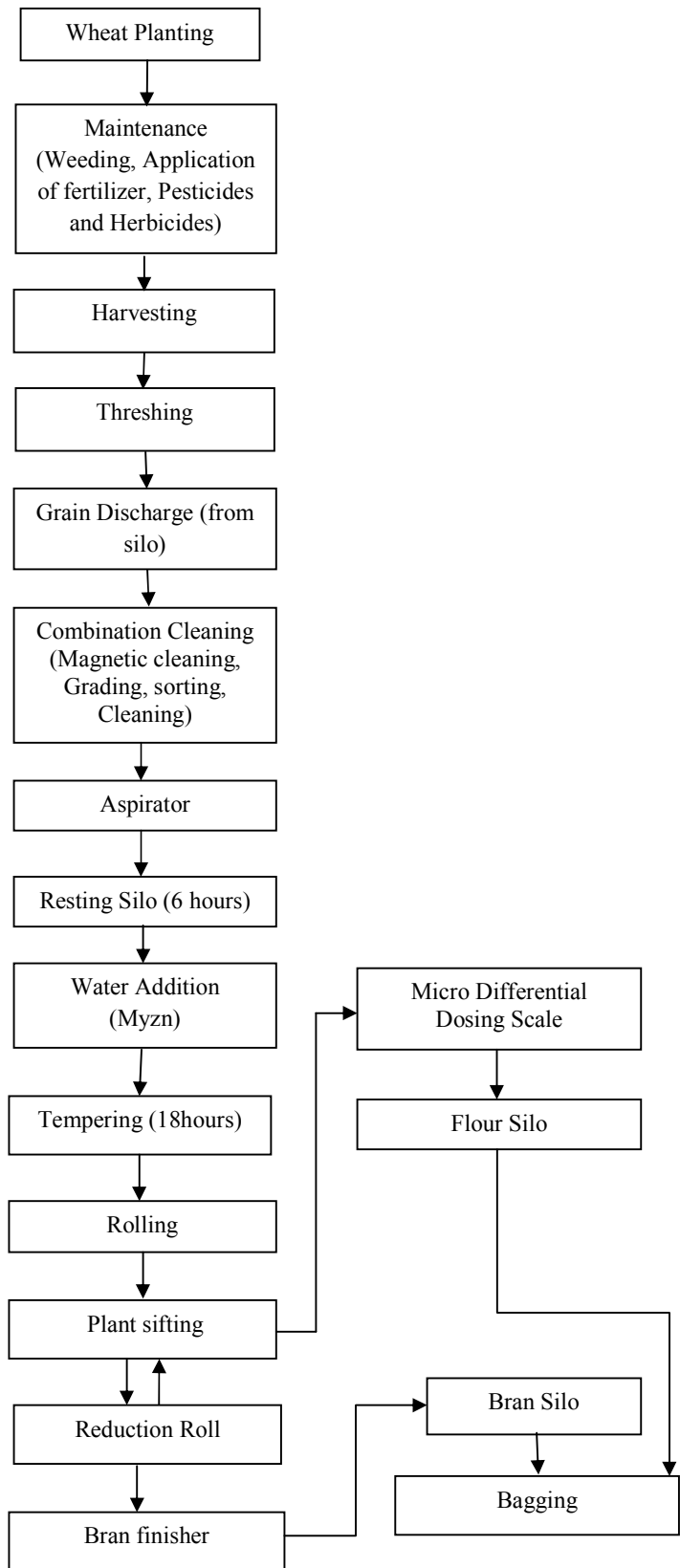


Figure 1: Flow chart of wheat flour production and processing systems.

The life cycle assessment of wheat production and processing of one (1) kg wheat seed was performed to include the four phases of life cycle assessment as spelt out by the International Standard Organizations (ISO, 1997a), outlined by Finnveden (1999). The inventory table was formulated by using emission estimation methods for the emission of green house gases. The green house gas emissions from the production and transportation of 100kg SSP, 250kg CAN and 200kg NPK (15:15:15) fertilizers which are needed for fertilizing wheat were calculated from the emission estimation records of Wood and Cowie (2004), while the emission from the fertilizer use were calculated from the estimation methods and assumptions reviewed by Delucchi and Lipman (2003). Similarly, the emissions from insecticide and herbicide use were calculated from the methods specified by Rafaschieri *et al.* (1999). The Table 3 below shows the detailed Life Cycle inventory (LCI) of wheat production and processing system.

As indicated in Table 4, the impact category assessed by this study is limited to Global warming, Eutrophication, Acidification and Ozone

layer depletion. Table 5 on the other hand indicates the characterization factors and units used for the characterization of the emissions as classified on Table 6

The result of the characterization for production and processing of 1kg wheat as shown on the Table 5 indicated that Global warming has the highest impacts score (4.7153E – 02 kg CO₂ equivalent) and this is due to high combustion of diesel in the production and processing of wheat. Diesel is used as fuel or source of energy in the production of fertilizers, mobile field operations and stationary engines such as generators and threshers for the processing of the grains. Carbon dioxide (CO₂) contributes majorly to the high impact score of global warming and this is due to the incomplete combustion of the high carbon fuel. The impact score of eutrophication closely followed the high impact score of global warming, while ozone layer depletion has the least impact score. Figure 2 compares the impact scores of the four impact categories assessed in this study which shows the very minimal effect of ozone layer depletion and its relationship to other impact categories.

Table 3: Summary of inputs, outputs and emissions for the production and Processing of 1kg of wheat

Inputs/Outputs	Amount	Unit
<i>Energy Inputs</i>		
Electricity	8.3945E – 02	MJ
Diesel	5.5967E – 02	kg
<i>Materials inputs</i>		
Fertilizer (NPK 15:15:15), SSP(SUPA) and CAN	1.4474E – 01	kg
Fungicide (Benlate)	1.6842E – 04	kg
Herbicides (Chlorotoluron)	5.2632E – 04	kg
<i>Products / by products</i>		
Wheat Flour	6.9444E – 01	kg
Bran	2.4802E – 01	kg
<i>Some Emissions from diesel fuel</i>		
Nitrogen dioxide N ₂ O	1.6548E – 05	kg
Sulphur dioxide SO ₂	2.9930E – 04	kg
Nitrogen oxides NO _x	2.7567E – 03	kg
Carbon dioxide CO ₂	7.3289E + 00	kg
Carbon monoxide CO	2.5292E – 03	kg
Methane CH ₄	9.3083E – 04	kg
<i>Some Emissions from fertilizers production, transportation and use</i>		
NO _x	5.2632E – 03	kg
N ₂ O	1.2421E – 01	kg
CH ₄	6.5001E – 03	kg
CO ₂	9.9251E – 02	kg
<i>Some Emissions from Insecticides use</i>		
Fungicides to air	8.4211E – 06	kg
Fungicides to water	1.8947E – 05	kg
Fungicides to soil	7.5789E – 05	kg
<i>Some Emissions from Herbicides use</i>		
Herbicides to air	2.6316E – 05	kg
Herbicides to water	1.2632E – 06	kg
Herbicides to sil	9.4737E – 06	kg

Table 4: Classification Results for the production and Processing of 1kg of wheat

Environmental Impact Category	Emissions	Amount (kg)
Global Warming	CO ₂	7.4282E + 00
	CH ₄	7.4309E - 03
	N ₂ O	1.2423E - 01
	CO	2.5292E - 03
Acidification	SO ₂	2.9930E - 04
	NO _x	8.0199E - 03
Eutrophication	NO _x	8.0199E - 03
	N ₂ O	1.2423E - 01
	Fungicide to water	1.8947E - 05
Ozone Layer Depletion	Herbicide to water	1.2632E - 06
	Fungicide to air	8.4211E - 06
	Herbicide to air	2.6316E - 06
	Fungicide to soil	9.4737E - 06
	Herbicide to Soil	7.5789E - 05

Table 5: Characterization results for the production and Processing of 1kg of wheat

Environmental Impact Category	Total Impact Score	Units ^b
Global Warming	4.7206E - 02	kg CO ₂ equivalent
Acidification	5.6139E - 06	kgSO ₂ equivalent
Eutrophication	3.5907E - 04	kg NO ₃ ⁻ equivalent
Ozone Layer Depletion	1.1889E - 07	kg R11 equivalent

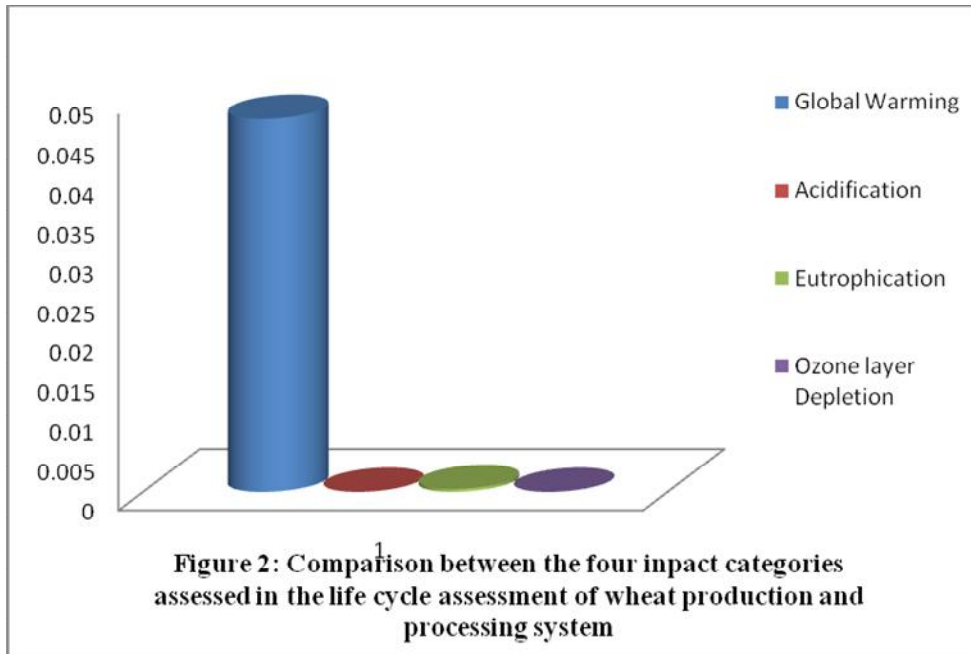
Table 6: Characterization Factors for the production and Processing of 1kg of wheat

Environmental Impact Category	Emissions	Amount (kg)	Characterization factor ^a	Units ^b
Global Warming	CO ₂	7.4282E + 00	0.0010	kg CO ₂ equivalent
	CH ₄	7.4309E - 03	0.0025	
	N ₂ O	1.2423E - 01	0.3200	
	CO	2.5292E - 03	0.0020	
Acidification	SO ₂	2.9930E - 04	0.0010	kg SO ₂ equivalent
	NO _x	8.0199E - 03	0.0007	
Eutrophication	NO _x	8.0199E - 03	0.0014	kg NO ₃ ⁻ equivalent
	N ₂ O	1.2423E - 01	0.0028	
	Fungicide to water	1.8947E - 05	0.0015	
Ozone Layer Depletion Potential	Herbicide to water	1.2632E - 06	0.0015	kg R11c equivalents
	Fungicide to air	8.4211E - 06	0.0015	
	Herbicide to air	2.6316E - 06	0.0015	
	Fungicide to soil	9.4737E - 06	0.0012	
	Herbicide to Soil	7.5789E - 05	0.0012	

a: Characterization factors are obtained from Kasmaprapruet *et al.* (2009) and Frischknecht *et al.* (2004).

b: The units are obtained from Kasmaprapruet *et al.* (2009) and Ntiamoah (2007).

c: R11: trichlorofluoromethane.



CONCLUSION

The life cycle assessment of wheat production and processing system investigated the various potential environmental impacts associated with the system as a result of the inputs, outputs, emissions, total energy use and losses from the system. The system considered was as a result of the great importance of wheat in the diet and nutrition of man. The assessment showed that global warming has the highest impact score and this is due to the high combustion of diesel in the production and processing of wheat as shown by the carbon dioxide emissions due to the incomplete combustion of diesel. The high impact score of global warming potential of wheat production and processing system can be checked by encouraging the use of fuel derived from biological sources such as biodiesel in combustion engines instead of fossil fuels uses. This will in turn reduce the emission associated with fertilizer production and transportation. Also, the use of organic fertilizer or manure can be encouraged in order to reduce the large use of inorganic fertilizer which causes high pollution to the environment.

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