Life Cycle Assessment of Rice Production at Farm Level Using ISO 14040/44

The Case Study of Kilombero Plantations Limited (KPL)

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ABSTRACT

This study focused on assessment of environmental impacts associated with rice production using Life Cycle Assessment (ISO 14040/44) as a tool. The need for carrying out this LCA was due to the fact that rice farming in Tanzania is practiced on a large scale and yet the assessment of the potential environmental impacts caused by the release of emissions into the environment from rice production processes have not been established. The research was conducted at Kilombero Plantations Limited (KPL). The assessment was conducted following the guidelines identified in ISO 14040/44 including inventory analysis that is establishment of system boundaries and process flow charts, and identification of input and outputs in each stage or process involved in rice plantation; calculation of impact scores and themes based on the inventory outputs. The study found that rice production at farm level at KPL passes through four main stages; land preparation, planting, crop maintenance and upkeep and harvesting before its transportation to the processing unit. The process which was observed to cause the most environmental impact was land preparation, followed by crop maintenance and upkeep, planting, harvesting and lastly transportation.

The study concluded that out of the eight impact categories assessed (climate change, acidification, photochemical oxidation, eutrophication freshwater ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity and human toxicity) three were identified to be the potential environmental impacts: climate change (139.70808 kg CO2 – eq.), freshwater ecotoxicity (84.49062 kg 1, 4-dichlorobenzene eq.) and eutrophication (34.13508 kg PO4--- eq). Release of 116.60% CO2 from combustion of diesel (a fossil fuel) in farm machinery was the main flow contribution to climate change. The major flow contribution to freshwater ecotoxicity was carbendazim emissions (50.16434 kg) into soil. Others were 2, 4-D (31.85496 kg), glyphosate (1.49307 kg) and zinc (0.95490kg) emissions into soil; copper (0.00096 kg), nickel (0.0001 kg) and zinc (4.53483E-5 kg) into air. The major flow contributions to eutrophication were 18.51% Nitrogen and 80.91% Phosphorous emissions from NPK fertilizer used to increase soil fertility. Based on the findings, the study recommended the application of one of the climate change proposed mitigation measures out of three; carbon sequestration, use of biogas as fuel for tractors and trucks and use of a whale filter to reduce diesel engine exhaust emissions. Climate change was the most significant potential environmental impact assessed in the study and its main flow contribution was CO2 produced from burning of fossil fuel in tractor and truck.

Keywords: Impact categories, ISO 14040/44, KPL, Life Cycle Assessment, Rice

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1 INTRODUCTION

1.1 BACKGROUND

Environmental performance refers to the environmental results that are achieved whenever the environmental aspects of activities, processes, products, services, systems, and organizations are managed and controlled [1]. Life Cycle Assessment (LCA) is a tool that can be used to assess potential environmental impacts of a product system and provide mitigation measures ultimately improving a product's environmental performance.

Uses of LCA in agricultural activities

Life cycle thinking and related tools like LCA have become a critical component of effective environmental management. They also provide an increasingly prevalent and recognized vehicle for product differentiation. A plethora of standardized methods, decision-support tools, and certification/labeling schemes that are now available or under development for agricultural and food sector applications

This phenomenon points towards the emergence of new norms and requirements that agricultural producers will face in order to maintain social license to operate as well as ensure access to current and emerging green markets [2].

Rice Production

Rice is the seed of the grass species Oryza sativa (Asian rice) or Oryza glaberrima (African rice). It is the agricultural commodity with the third-highest worldwide production, after sugarcane and maize. The world dedicated 162.3 million hectares in 2012 for rice cultivation and the total production was about 738.1 million tonnes. The average world farm yield for rice was 4.5 tonnes per hectare, in 201 [3]. In Africa, the African rice species (Oryza glaberrima) has been cultivated for 3500 years between 1500 and 800 BC. It propagated from its original center, the Niger River delta, and extended to Senegal. However, it never developed far from its original region and its cultivation declined in favor of the Asian species, which was introduced to East Africa early in the common era and spread westward [4].

In Tanzania rice is grown in three major ecosystems, rain fed lowland, upland, and irrigated systems. The area under rice increased from about 0.39 million ha in 1995 to about 0.72 million ha in 2010. Production increased from about 0.62 million tonnes in 1995 to about 1.33 million tonnes of paddy rice in 2009 but dropped to 1.10 million t in 2010 [5].

Environmental impacts associated with rice production and processing

There are several environmental impacts which are associated with rice production and processing. They include; deforestation, defoliation, biodegradable waste, land degradation and damage to ecosystem e.g. soil erosion from agro-chemicals, water pollution, water logging, poisoning, siltation, eutrophication & groundwater pollution, wetland rice system generates methane, grit and paddy husks create waste management problems [6].

Essence of the study

Rice is a major staple food and a mainstay for the rural population and their food security. It is central to the food security of over half the world population. Developing countries account for 95% of the total production and are the main players in the world rice trade, accounting for 83% of exports and 85% of imports (FAO, 2004). Carrying out LCA of rice production and processing will provide for quantification of the environmental impact categories including climate change, photochemical oxidant creation, acidification, human toxicity, ecotoxicity and eutrophication. Through this, feasible mitigation measures from the Life Cycle Impact Assessment can be drawn for this study and used by rice farmers locally, regionally and globally to improve the environmental performance of rice.

1.2 Problem Statement

Production of rice contributes to several environmental impacts which are: prevalence of diseases associated with swampy conditions like guinea worm and filariasis, rice production uses almost a third of earth's fresh water, increased land conservation, deforestation and biodiversity loss, salinization and soil nutrient degradation [6], 11% of the anthropogenic methane emissions are from wetland rice fields, contributing to 1.5% of anthropogenic greenhouse gases (GHG). Methane is twenty times more potent a greenhouse gas than carbon dioxide and increase in GHG in the atmosphere has led to rising temperatures thus global warming and eventually climate change [7]. Tanzania practices rice farming on a large scale about 0.72 million ha in 2010 (ricepedia.org) but LCA on rice has never been done before in the country. Assessment of the potential environmental impacts associated with rice production and processing have not been established. This study will assess all the environmental impacts associated with each process involved in rice production, identify which impacts are potential and suggest mitigation measures for the potential environmental impacts.

1.3 Objectives

Main objective

To establish environmental impacts of rice production at KPL and suggest mitigation measures through life cycle assessment.

Specific objectives

- To identify rice production processes at KPL
- To conduct inventory analysis of input and outputs in each process of rice production at KPL
- To assess the potential environmental impacts associated with rice production at KPL
- To establish mitigation measures for the potential environmental impacts assessed in rice production at KPL

2 METHODOLOGY

2.1 Goal and Scope Definition

The goal of the study is to establish the environmental impacts of rice production through its life cycle by identifying rice production processes; conducting an inventory analysis of inputs and outputs in each process; assessing the potential human and ecological impacts of the environmental emissions and establishing mitigation measures.

The rice produced at KPL is milled rice which is locally grown and processed for the local and foreign market. The main target group of this study is KPL which produces rice on a large scale and its consumers. Though the information obtained can be used by other groups which are: Tanzania's rice producers from small to large scale, government institutions like The Tanzania Rice Council and rice consumers

The functional unit has been defined as 6 tonnes of milled rice grown in one hectare of land at KPL. The study will cover the five main processes involved in rice production which are presented in figure 1: Land preparation, planting, maintenance and upkeep, harvesting and transportation.

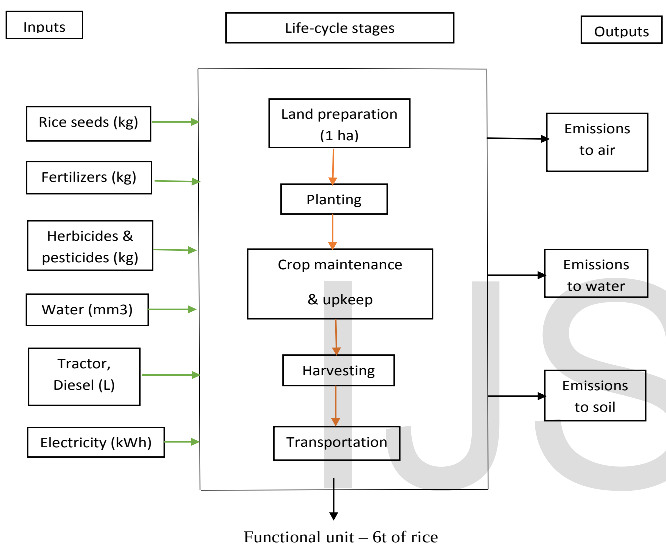

Fig. 1. System boundary of rice production at KPL

2.2 Life Cycle Inventory Analysis

The openLCA software was used to perform the inventory analysis. Raw data was first converted into an input and output format that could be used by the software.

Primary and secondary data were both used in the study. The primary data was collected using two tools; a guiding questionnaire and checklist. Secondary data was used to calculate the emission rates for transportation and during literature review of LCA related studies.

The calculation of environmental impacts was done with the use of openLCA software which is a powerful open source software for Life Cycle Assessment (LCA) and sustainability assessment developed by GreenDelta since 2006 [8].

2.3 Life Cycle Impact Assessment

Eight impact categories were assessed using CML baseline, CML non baseline and IPCC 2013 impact assessment methods, namely; climate change/global warming for 100 year time horizon, acidification, photochemical oxidant creation, eutrophication, marine eco toxicity, freshwater ecotoxicity, terrestrial ecotoxicity and human toxicity. For each impact category, respective characterization factors were used. Table 1 below shows the characterization factors used in the study for climate change, acidification and photochemical oxidation.

Table 1: Characterization factors for climate change, acidification and photochemical oxidation

Flow	Category	Unit	Factor
Carbon monoxide, fossil	air	kg CO2-Eq/kg	1.9
Dinitrogen monoxide	air	kg CO2-Eq/kg	298
Nitrogen oxides	air	kg CO2-Eq/kg	-10.8
Sulfur dioxide	air	kg CO2-Eq/kg	-38.4
Nitrogen oxides	Air	kg SO2 eq./kg	0.7
Sulfur dioxide	Air	kg SO2 eq./kg	1
Carbon monoxide, fossil	air	kg ethylene eq./kg	0.027
Sulfur dioxide	air	kg ethylene eq./kg	0.048

2.4 Interpretation and Reporting of Results

3 RESULTS AND DISCUSSION

Identification, quantification, checking and evaluation of results of LCI and LCIA was done after which the results, data, methods, assumptions, and limitations were assembled in sufficient detail in a comprehensive report.

3.1 Life Cycle Inventory Analysis Results

Inventory analysis for air and soil pollutants was done for fuel, herbicides, pesticides and fertilizers used in the different stages of rice production at KPL. Table 2 shows the LCI results for the rice production stages at KPL.

Table 2: Inventory results for air and soil pollutants

Flow	Category	Unit	Amount
Ammonia	air	kg	0.001051
Benzene	air	kg	0.0003811
Benzo(a)pyrene	air	kg	1.5775E-06
Cadmium	air	kg	5.261E-07
Carbon dioxide, fossil	air	kg	163.9716
Carbon monoxide, fossil	air	kg	0.30027
Chromium	air	kg	2.631E-06
Copper	air	kg	8.924E-05
Dinitrogen monoxide	air	kg	0.0063
Heat, waste	air	kg	2385.497
Methane	air	kg	0.00678
Nickel	air	kg	3.682E-06
Nitrogen oxides	air	kg	2.14732
NMVOC, non-methane volatile organic compounds	air	kg	0.13927
Particulates, diesel soot	air	kg	2.78374
Particulates, < 2.5 um	air	kg	0.22705
Sulphur dioxide	air	kg	0.05308
Zinc	air	kg	5.261E-05
Hydrocarbons	air	kg	0.00286
VOC, volatile organic compounds	air	kg	0.00283
Zinc	soil	kg	1.44668
Nitrogen	soil	kg	6.3000
Phosphorous	soil	kg	27.5400
2, 4-D	soil	kg	84.448
Carbendazim	soil	kg	55.68922
Glyphosate	soil	kg	1.64914

3.2 Life Cycle Impact Assessment Results

Six environmental themes and a total of eight impact categories were assessed in this study, namely; climate change/global warming for 100 year time horizon, acidification, photochemical oxidant creation, eutrophication, eco-toxicity (terrestrial, freshwater and marine ecotoxicity) and human toxicity. The assessment of the impact categories was done first for each rice production stage and later on a comparison of the total impact categories was done. Figure 2 presents the overall results of impact categories calculated.

The impact category with the most impact was marine ecotoxicity with a total of 242.89384 kg 1, 4-dichlorobenzene eq., followed by climate change with a total impact of 139.70808 kg CO2 - Eq., freshwater ecotoxicity follows with a total of 84.49062 kg 1,4-dichlorobenzene eq., human toxicity with a total of 59.57224 kg 1,4-dichlorobenzene eq., eutrophication with a total of 34.13508 kg PO4--- eq., terrestrial ecotoxicity with a total of 3.59687 kg 1,4-dichlorobenzene eq., acidification with a total of 1.63279 kg 1,4-dichlorobenzene eq. and the least impact was from photochemical oxidation with a total impact of 0.01078 kg ethylene eq

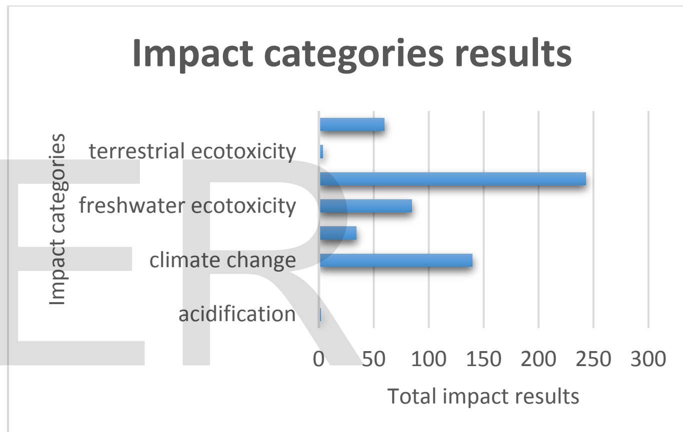

Fig. 2. Overall results of impact categories calculated for rice production at KPL

Marine ecotoxicity

It was the impact category with the highest impact, the flow contributions were zinc, copper, and nickel which are known toxic heavy metals and were emitted into air from diesel combustion in tractor during operation. Once these substances dissolve in marine waters, they contribute to marine ecotoxicity. Other substances are zinc emissions from fertilizer application, carbendazim emissions from use of carbendazim fungicide in seed treatment and 2, 4-D emissions from spraying of 2.4 D a post emergent herbicide all released into soil. These substances can remain in soil after the harvest and may dissolve into surface water flowing on the rice fields when it rains, the surface water drains into rivers which are normally inlets of ocean. Once in the ocean these substances will contribute to marine ecotoxicity. The site is located in Morogoro which is a landlocked city hence no direct impacts into marine ecosystems therefore the impact category was not considered as a potential environmental impact.

Climate Change

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The flow contributions of climate change include 116.60% CO_2, 1.34% N_2O, -1.45% SO_2 and -16.87% NOx and this leaves CO_2 as the main and most significant contributor. A negative flow contribution means that the value contributed fossil fuel in this case diesel in tractor and truck. Diesel consumption and use is more in tractor than truck considering many farm operations are done with the use of tractor and the truck only used to haul harvested rice from the farm to the company's gate. Though the climate change impact appears to be the major environmental impact of rice production at KPL, its total impact of 139.70808 kg CO2 –Eq. Rice fields after irrigation was not done because the research was done during the harvesting season of rice at KPL.

Freshwater Ecotoxicity

Freshwater ecotoxicity follows climate change with a total impact of 84.49062 kg 1, 4-dichlorobenzene eq. The flow contributions include zinc emissions into soil from fertilizer application, glyphosate emissions into soil from spraying of pre-plant glyphosate herbicide, carbendazim which is a fungicide used in seed treatment and 2, 4-D emissions into soil. These substances remain in soil and can either be leached into groundwater or washed into surface waters by surface runoff. Other flow contributions include zinc, nickel and copper emissions from combustion of diesel in tractor which contribute to freshwater ecotoxicity. Mngeta River is located near the farm and is a major source of water for irrigation for the KPL farm and other farms at Mngeta. Though the impact is not high, freshwater ecosystems could be affected by this toxicity caused from the emitted substances if their levels were to accumulate over the set water standards over the years therefore making it a potential environmental impact.

Human Toxicity

Human toxicity followed with a total impact of 59. 57244 kg 1, 4-dichlorobenzene eq. the flow contributions include zinc, 2, 4-D and carbendazim into soil. Cadmium, chromium, copper, nickel, zinc, nitrogen oxides and benzene at lower amounts into air from combustion of diesel in tractor and nitrogen oxides released from diesel combustion in truck. The human toxicity rate will depend on route of exposure and dose taken among other factors. The impact to humans who will inhale the toxic heavy metal air emissions will not be significant due to the very low concentrations of these substances released into the atmosphere. Unless the soil containing carbendazim and 2, 4-D is ingested by humans, no direct toxicological effects will be faced by humans from their presence in soil. Human contact with the pesticides is further prevented by wearing of personal protection equipment while handling by the workers. The zinc concentration in soil is also too low to cause any human health effects. This impact category was not considered to be a potential environmental impact.

Eutrophication

The flow contributions include N, P and NOx. When these materials are carried out of root range by water draining through the soil, they are said to have been leached. Nitrate

is less than zero whereas a positive one means its value was above zero making it significant. The CO_2 is due to releases of burning of

is lower compared to results of other LCA studies on paddy rice production like "Life Cycle Assessment of Rice Production in Thailand" [9] and "Life-Cycle Assessment of rice production systems: Comparison of Lao PDR, Japan and Australia" [10]. The main reason for this is because methane emissions from

(from inorganic nitrogen fertilizers or derived from organic manures) is leached especially rapidly because it is very soluble. This is particularly the case during rainfall if nitrogen fertilizer has been over-applied and the soils themselves are free draining. In areas where there are sandy soils overlying permeable rocks, there are particular risks of nitrate leaching into groundwater. If these nutrients are leached in excessive amounts, they can cause eutrophication in water bodies. Phosphorus can also reach rivers as dissolved P from field drains and as suspended solids in some soils [11]. The main effect of eutrophication is it leads to nutrient enrichment in water which will lead to algal bloom. Decomposition of the algae and phytoplankton by microbes consumes a lot of dissolved oxygen reducing its availability for other aquatic organisms affecting mostly fish and shell fish. Other negative impacts include decrease in the value of rivers, lakes and aesthetic enjoyment. Health problems can occur where eutrophic conditions interfere with drinking water treatment [12]. Analysis of the aquatic eutrophication potential indicates that when nitrogen fertilizer application rates exceed 144 kg N ha-1, changes in AEP (Aquatic Eutrophication Potential) are mainly determined by the amount of nitrate leaching; phosphorus, which mainly comes from phosphorus fertilizer production, accounts for only 9% of AEP even when the fertilizer is applied at the highest rates [13]. Also the SPRI Emission Reporting Threshold of Phosphorous is 5,000 Kg/yr, and the amount applied by KPL annually for rice production is less than this amount. The total nitrogen and phosphorous applied per hectare at KPL is 97.9 and 9.6 kg respectively. The total fertilizer application at the Mngeta farm is not high and therefore the nutrients leached are not in excess and the significance of this impact category is low. However, due to the adverse environmental effects that result from eutrophication the impact category was considered to be a potential impact.

Terrestrial Ecotoxicity

The flow contributions for the impact category were carbendazim, 2.4-D, glyphosate and zinc into soil. Zinc, copper, nickel and chromium into air. Terrestrial ecosystems that will mostly be affected from the presence of these substances in soil are the broadleaf rice weeds, fungus and insect species that attack rice during its growing stage. The impacts faced from terrestrial ecotoxicity will be positive since death or destruction of rice weeds, fungus and pests will cause the rice to thrive and increase percentage yields. Therefore the impact category was not considered to be potential.

Acidification

It follows with a total impact of 1.63279 kg SO2 eq. The contributing flows were 94.38% NOx and 05.47% SO2 in air from combustion of diesel fuel. Environmental impacts that result from acidification include formation of acidic rain and ocean and freshwater and marine acidification of aquatic ecosystems and life. The main contributor to acid rain formation is SO2 whose value was determined to be low and the substance that leads to water acidification is carbon dioxide which in this case was not among the impact category flows. The acidification potential of rice production at KPL was low and its impact was generally of low significance compared to other impact categories hence it was not a potential environmental impact.

Photochemical Oxidation

It was the environmental category with the least total impact and the flow contributions were CO and SO2. Photochemical oxidant formation (or photochemical smog) refers to a phenomenon that occurs under certain atmospheric conditions when pollutant-forming emissions are present. It is particularly commonplace in relatively stagnant air when there is sunlight and low humidity, and in the presence of NOx and VOCs, excluding methane (Manahan, 1994). The concentrations of NMVOC and NOx released from diesel combustion were not high enough to contribute to formation of photochemical smog. Therefore the impact category was not a potential environmental impact for rice production at KPL.

3 PROPOSED MITIGATION MEASURES

Mitigation measures were proposed for three environmental impact categories: climate change, eutrophication and freshwater ecotoxicity which were considered to be potential after the assessment.

Climate change

- Carbon sequestration mitigation technologies for CO2
- Use of biogas as fuel for tractors and trucks
- Reduction of dinitrogen monoxide through agricultural practices
- Reduction of exhaust emissions from diesel engines using a Whale filter

Eutrophication

- Maintenance of the present fertilizer types and application rates at the farm to avoid increase in concentrations of nitrogen and phosphorous emissions into the environment from change in fertilizer use or application.
- Soil sampling and analysis can be done to assess Phosphorus levels prior to determining the application rate of fertilizers.

Freshwater ecotoxicity

- Developing rice varieties with built-in resistance to common pests and diseases. This will reduce the need to use carbendazim as one of the components of fungicide and insecticide solution used in seed treatment sub-process.
- Implementation of IPM (integrated pesticide management)

3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

When fully irrigated, Mngeta Farm will produce annually 20,000 or 35,000 tons of milled rice, depending on market prices. Hence the environmental impacts can be multiplied by a factor of 14 or 29 respectively to get the total amount of impacts caused by rice production annually at KPL.

Eight impact categories were assessed in this study out of which three were identified to be the potential environmental impacts: climate change (139.70808 kg CO2 –eq.), freshwater ecotoxicity (84.49062 kg 1, 4-dichlorobenzene eq.) and eutrophication (34.13508 kg PO4--- eq.).

Generally the environmental impacts of paddy rice production at KPL were (less than 100 kg for all the impacts except marine ecotoxicity and climate change with 242.89384 kg and 139.70808 kg respectively). And this is because of the use of modern farming practices and farm machinery at the farm, employment of skilled labor, good management, use of quality standard fertilizers, herbicides and pesticides which release emissions at relatively low concentrations reducing the environmental impacts caused from rice production at the Mngeta farm**.**

3.2 Recommendations

Consideration of any of the proposed mitigation measures for climate change which happens to be the most significant potential environmental impact of rice production on a global scale.

Continued chemical fertilizer management or a switch to organic farming to prevent the occurrence of eutrophication in the Mngeta River.

Use of IPM which is an effective and environmentally-sensitive approach that offers a wide variety of tools to reduce contact with pests and exposure to pesticides achieving sustainable pest management or elimination of pesticide usage. This will reduce the total impact of the environmental emissions that contribute to ecotoxicity and human toxicity.

If the limitations faced in this LCA study can be overcome, a full life cycle study of rice production for small scale and large scale farming is recommended to be done. The study will identify and assess all the environmental impacts of rice production from cradle to grave and can be used as a reference for other LCA studies about rice production in Tanzania or Africa.

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