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A linear assignment based conceptual lifecycle assessment method for selecting optimal agri-industrial materials production pathway: A case study on Nigerian yam value chain

I. S. Dunmade

Mount Royal University, Faculty of Science & Technology, Department of Earth & Environmental Sciences, 4825 Mount Royal Gate SW, Calgary AB T3E 6K6, Canada
*Correspondence: idunmade@mtroyal.ca; israel_dunmade@yahoo.ca

Abstract. Lifecycle assessment is a robust tool for comprehensive environmental impact assessment of products and processes. It provides users opportunities to identify the hotspots along the lifecycle of a system and thereby enable them to implement improvement opportunities as deemed appropriate. Production of agri-based industrial raw materials could be energy and water intensive. Such endeavour could take a heavy toll on the environment in terms of resource consumption and environmental pollution. The goal of this study was to develop an easy to use and less data intensive conceptual LCA methodology for selecting optimal pathway along a value-chain under two decision scenarios: the optimal techno-environmentally friendly pathway, and optimal sustainability pathway. This proposed Linear Assignment Method integrated LCA is a less data intensive conceptual LCA method that facilitates the selection of an optimal production and processing pathway for agri-industrial materials, minimizes resource consumption and reduction of potential climate change impact of agri-industrial materials value chain. The LCA ISO 14040s aligned conceptual LCA method will be found useful in identifying potential hotspots in a agri-industrial production process lifecycle, in selecting activity options that would result in minimum ecological footprint, and help in removing obstacles in implementing a scoping lifecycle analysis where cost, time and data availability are the impediments.

Key words: Africa, agri-industrial materials, ecological footprint, LAM (linear assignment method), yam.

INTRODUCTION

Agri-industrial materials refer to agricultural produce used as feedstocks in the textile, dairy, fashion, food, beverage and paper industry. It includes crops like cocoa, coffee, tea, orange, sorghum, millet, cassava, yam, cocoyam, kenaf, sisal, and jute. Their industrial applications include in the production of starch, biofuels, pharmaceuticals, and other industrial chemicals. Decisions in this sector of the economy are often based on profitability and regulatory compliance. The emerging trend in this sector is the incorporation of corporate social responsibility and concept of sustainability.

Production of agri-based industrial raw materials could be energy and water intensive. Such endeavour could take a heavy toll on the environment in terms of resource consumption and environmental pollution. There is, therefore, a need to address environmental issues along with other social and economic factors. Lifecycle assessment (LCA) is a robust tool for evaluating environmental-, social-, and social sustainability of a product, a process or a system. Originally, LCA is utilized for comprehensive environmental impact assessment of products and processes. It provides users with opportunities to identify the hotspots along the lifecycle of a system and thereby enable them to implement improvement opportunities as deemed appropriate. Lifecycle tool has been used for evaluating environmental impacts of products and processes from various sectors of our economy. Its use in agriculture includes using it to determine the ecological footprint of various types of crops cultivation (Avadí et al., 2020; Romero-Gámez & Suárez-Rey, 2020); livestock production systems (Ottosen, 2020), and products from agro-based companies (Mfitumukiza et al., 2019; Farahani et al., 2019). Although LCA is a comprehensive tool has been widely used in the agricultural sector but its use is mostly in the developed countries. Its complexity and associated cost has limited its utilization by agricultural stakeholders in the developing countries. The goal of this study was to develop an easy to use and less data intensive conceptual LCA methodology for selecting optimal pathway along a value-chain. This study proposed the use of Linear Assignment Method based, less data intensive conceptual LCA method that facilitates the selection of an optimal production and processing pathway for agri-industrial materials, minimizes resource consumption and reduction of potential climate change impact of agri-industrial materials value chain. The LCA ISO 14040s aligned conceptual LCA method will be found useful in identifying potential hotspots in an agri-industrial production process lifecycle, in selecting activity options that would result in minimum ecological footprint, and help in removing obstacles in implementing a scoping lifecycle analysis where cost, time and data availability are the impediments.

One of the contributions of this research is that this is the first time that Linear Assignment Method (LAM) is integrated with the Lifecycle Assessment (LCA) methodology to simplify the LCA process by eliminating the need for intensive data as is the case with the traditional LCA (Fava and Cooper, 2004). There is no known literature on the use of LAM integrated LCA approach. The use of the LAM integrated LCA approach enables the stakeholders in the agri-industrial materials production value chain to select the 'best' (i.e. optimal) pathway along the value chain under two decision scenarios: environmental friendly pathway or sustainability pathway.

Environmentally friendly pathway is the decision scenario that evaluates the value chain to select the combination of technically sound processes with the lowest ecological footprint. This pathway favors processes with the lowest resource consumption and minimum emissions. The sustainability pathway goes beyond the environmental sustainability to include the consideration of economic and sociocultural factors in the process of designing/selecting the best pathway along the value chain.

This conceptual LCA methodology is particularly beneficial to agri-industrial materials producers, processors and marketers in developing countries that may want to carry out an LCA but cannot afford to purchase commercial LCA software necessary to carry out the traditional LCA. It is also suitable for those that may not be able to handle the complexity, data requirement and time commitment necessary for the conventional LCA (Udo de Haes, 2004; Rebitzer & Hunkeler, 2006).

MATERIALS AND METHODS

This proposed conceptual LCA method involved hybridization of linear assignment decision method (LAM) with the ISO 14040s based LCA process in an easily understandable and utilizable manner. The integration of LAM with the LCA process was done at the lifecycle inventory stage of LCA. This proposed method is easy to employ and it produces actionable results that would be found useful in decision-making processes along agri-industrial materials value-chain.

Linear assignment method and reasons for its choice as a method to integrate with LCA

Linear assignment method (LAM) is one of the multiple attribute decision making (MADM) methods that utilize quantitative and qualitative data in facilitating the decision maker's selection of the best choice out of a small number of possible options. In LAM, the choices are ranked based on their points of each criterion and are rank ordered on the basis of their overall performance across the criteria. The evaluation of the available choices often involve considering multiple conflicting attributes (Abdolazimi et al., 2015; Azar, 2000). At each stage of agri-industrial material production, a farmer/processor is often confronted with the need to choose among a small number of options. Their choices at each stage often have to be based on a set of weighted or unweighted criteria that may eventually have far reaching effect on profitability, environmental impacts and socio-cultural consequences. So, their decisions are of multiple attributes in nature.

Although there are many MADM methods, LAM was selected because it is simpler/easier to understand and to use. In addition, it is technically sound and has been used in many real-life situations requiring making choices from a small number of options on the basis of a set of criteria. Examples of areas of applications of LAM were in logistics (Liu and Wang, 2009); material selection (Jahan et al., 2010); optimum maintenance strategy selection (Bashiri et al., 2011), and spare parts inventory classification (Baykasoglu et al., 2016). Further literature on the theory and applications of MADM and LAM specifically can be found in the works of Herrera & Herrera-Viedma, 2000; Liu & Wang, 2007 and Chen, 2013.

The ISO 14040s based LCA process

Life-cycle assessment (LCA) is a robust tool for evaluating potential environmental impacts of products, processes and systems. LCA enables the users to determine the potential environmental impacts of their products or process even before they are developed, thereby facilitating taking preventive measures rather than curative steps that may be necessary after the facts. LCA also allows for consistent comparisons of alternative system designs with respect to their environmental performance. LCA consists of four major steps, namely: goal and scope definition, inventory analysis, impact analysis, and LCA interpretation (Fig. 1) (ISO, 2006a and 2006b; Dunmade, 2013a and 2013b; Kazulis et al., 2018; Dunmade, 2019a).

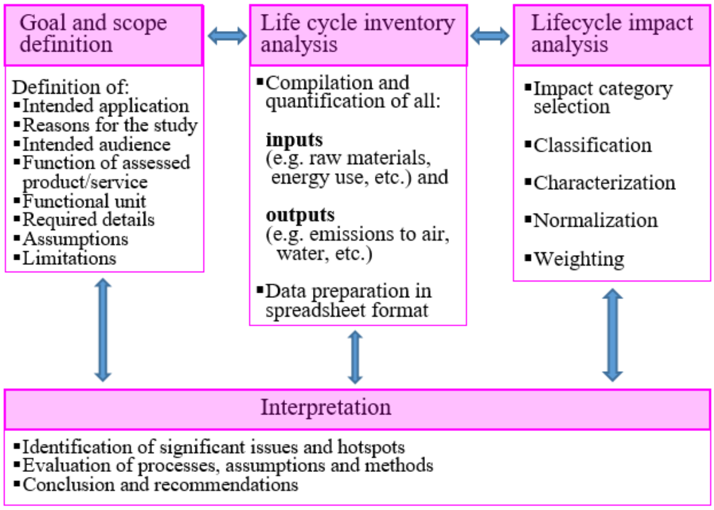

Figure 1. The four steps life cycle assessment process.

Conceptual LCA

The conceptual level of LCA, which is also referred to as scoping LCA or lifecycle thinking, generally involves the use of generic secondary data and scoring of possible alternative course of actions over a set of criteria. It is often used for selecting a more promising option from among two or more available options. It is commonly used in selecting conceptual product designs pending a more detailed analysis of the selected option. It is useful when there are cost, time or data availability issues affecting carrying out a more rigorous LCA. This level of LCA facilitates getting a rough idea/ identification of potential hotspots in a process, products, or system without the use of a more rigorous level of LCA.

Goal and scope definition

ISO 14040s require that the goal of an LCA should articulate the intended applications, reasons for implementing the LCA and the audience that will use the information from the results. The scope definition set the boundary for the LCA study. It specifies the function of the system, the functional unit, the data cut-off criteria.

Lifecycle inventory (LCI)

This second stage of the LCA involves quantification and compilation of data, usually in spreadsheet format. This is the most time consuming step in the LCA process. This is because the needed data are either not kept or it is not available in a usable form. Intended users of LCA are usually discouraged/ frustrated for those reasons. Consequently, an effort to address this problem would greatly enhance utilization

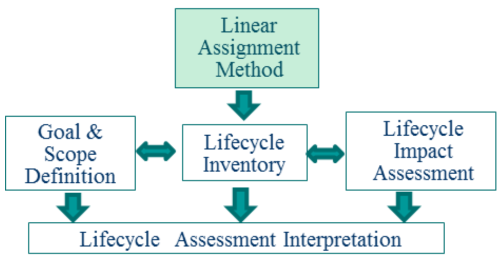

Figure 2. An illustration of LAM integrated LCA process.

of LCA for various purposes. This is where the use of LAM comes in handy because of its simplicity and less data demanding. Fig. 2 is an illustration of LAM incorporated LCA. It shows that LAM is integrated at the lifecycle inventory analysis stage of the LCA.

The incorporation of LAM to the LCA process

The integration of LAM into the life cycle inventory stage involves a professional or manager evaluating each of the available options A_j, $_{j=1, 2,..., n}$ for a production unit process against a set of criteria S_1 .... S_m that are essential for the successful implementation of that unit process. The professional comparatively rate the options in terms of how good they are on each of the criteria and compile the numerical score of each option across all the criteria. He/she then rank order the options based on their total scores. The option with the least total score across the criteria is the best option while the option with the highest total score is the worst option for the unit process/opperation of the value chaim. The professional or manager repeats the rank ordering and totaling the score for each of the unit processes in the value chain. The rank ordering of the options on the basis of their total score at the unit process/operational level enables the decision maker to easily see the best and the worst options. Assemblage of all the (operation level) best options is the optimal production pathway along the value chain (Dunmade, 2013b; Dunmade & Anjola, 2019b).

Metrics of measurement

The aforemention rank ordering process starts with articulating the criteria by which the various unit process options would be assessed and the metric for measuring the performance of each process. The framework allows the use of mixed qualitative and quantitative metric or purely qualitative metric wherever necessary/relevant. The qualitative evaluation is done on the basis of a six ordinal linguistic scale that ranks available choices in order of their goodness and assign numerical values according to the ranking. Generally, in ordinal scales, it is the order of the choices/values that is important and significant because the magnitude of the differences between the choices may not really be known. Ordinal scales therefore provide good information about the order of choices (Triola, 2007; MRK, 2020). Table 1 shows the six ordinal linguistic scale levels and the numerical conversion of the linguistic ratings.

Table 1. The six linguistic scale levels

Linguistic rating	Assigned numerical value
The best	1
Second best	2
Third best	3
Fourth best	4
Fifth best	5
Sixth best (i.e. worst case)	6

Decision analysis

Having determined the available options and articulating the basis for their evaluation, it is necessary to determine the characteristics of the decision maker. This methodology is premised on a single decision maker that is assumed to be rational and wants to choose a unit process option that maximize his utility. Furthermore, it is also assumed that in choosing the best out of the available options, he/she may set some minimum limits/value on the performance of the options below which he will not be ready to accept to choose any of the options.

For a specific decision scenario, let A_j, $_{j=1, 2,\ldots, n}$ be the identified unit process options from which he/she wants to choose while S_{i}, $_{i = 1, 2, \ldots, m}$ are criteria/attributes on which the options are to be evaluated. As a rational decision maker who intends to maximize his utility, he/she will select the option with the lowest total score (Dunmade, 2004):

$$A_j = min \sum_{i=1}^{m} w_i \, S_{ij} \qquad (1)$$

But if he/she has set some minimum performance limit for any acceptable option on the sustainability factors, this limit can be written as

$$\sum_{i=1}^{m} w_i S_i^o \qquad (2)$$

where S_i^o is the required minimum performance for any acceptable option A_j on criterion S_i.

Thus, he/she will choose process A^* that both satisfy his/her minimum performance requirements and maximize his/her utility. This can be written as

$$A^* = min \sum_{i=1}^{m} w_i S_{ij} < \sum_{i=1}^{m} w_i S_i^o \qquad (3)$$

Lifecycle impact analysis (LCIA)

This third step in LCA is the point at which the data collected and processed regarding resource use and environmental releases at lifecycle inventory stage are mapped/ modelled into environmental effects. This stage conventionally consists of three mandatory steps of impact category selection, classification and characterization. The other non-mandatory steps at this stage in the LCA process are normalization, grouping and valuation. For this LAM integrated conceptual LCA method, the LCIA step involves trying, compiling and diagrammatic illustration of possible combinations of operational options and determining the outcomes. The set of best choice (A^*) from individual operations of the value chain (Fig. 3) constitute the optimal pathway for the scenario under consdideration.

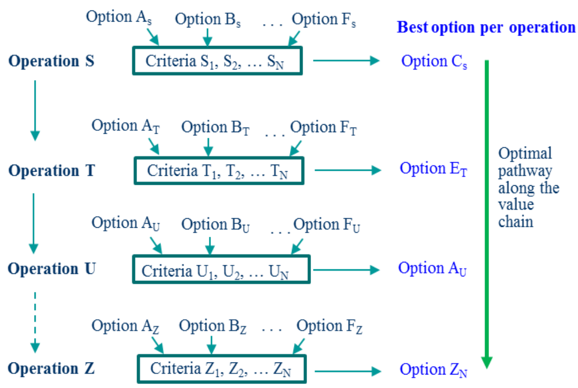

Figure 3. An illustration of the optimal pathway selection in LAM integrated LCA process.

Lifecycle interpretation

This last step in the LCA process involves evaluating the LCI and LCIA data, and determining environmentally significant issues from those data. Significant issues can be identified by doing contribution analysis or anomaly assessment of the data. This stage of LCA also involves evaluating the soundness of the decisions taken and validity of assumptions made at each stage of the LCA process. Such evaluation ensures correct interpretation of the results, and adequacy of conclusions and recommendations. It also improves confidence in the outcomes of the LCA study. Conclusion on the outcomes of the study and recommendations for necessary actions are made after the evaluation. The results of the LCA study may also be subjected to either internal or external peer/critical review before the report is submitted to the client or published.

An illustration on the use of LAM integrated conceptual LCA method for the selection of an optimal agri-industrial material production value chain/pathway

Agri-industrial material production system: yam as an example.

The process of producing and transforming a typical agricultural produce to a final industrial material or products involve so many activities. Using yam as an example, the production process involves land clearing, mound/ridge making, seed yams planting, weeding, fertilizer and chemicals application, staking and harvesting (Hori & Oshima, 1986; Diop, 1998; IITA, 2013; Ike & Inoni, 2006; Maroya et al, 2014; Bassey, 2017; Eze, 2018; FMAWRRD, 2020). And according to ANOL (2018), the postharvest processing of yam into instant pounded yam flour, involves yam selection and weighing, washing, peeling and slicing, parboiling, drying, milling, and packaging. Fig. 4 illustrates the various processes involved in yam value chain resulting in multiple industrial products obtainable from yam processing (Suzan & Gameiro, 2007; Sadh et al., 2018; USOTA, 2020).

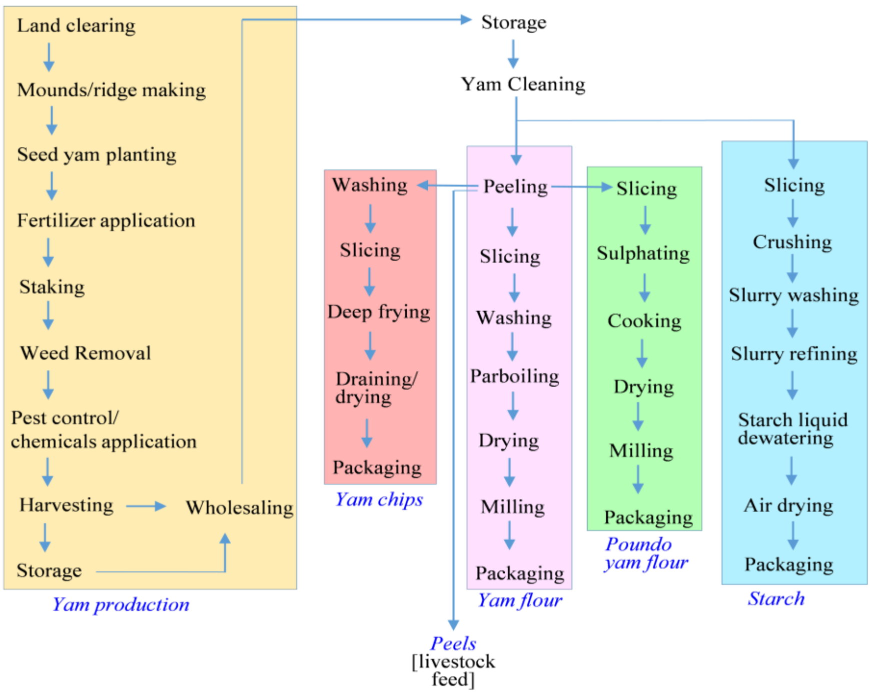

Figure 4. A network of main operational activities involved in yam production value chain system boundary and its products.

Yam production process

Land clearing is the process of removing vegetation cover from a piece of land for crop planting planting. It often involves removing trees, stumps, brush, stones and other obstacles from an area as required to increase the size of the crop producing land base of an existing farm or to provide land for a new farm operation. Methods used to clear land will vary depending on the type and density of native cover, prevailing regulations, available technology, and affordability of modern methods. The choice of land clearing method would in turn affect soil properties and agricultural produce yields. Umeghalu & Ngini (2013) in their article on the effect of poor land clearing on soil and agricultural produce highlighted five methods of land clearing operation. However the four commonly used methods in Nigeria are:

1. Manual method involving the use of hand tools such as matchet, hoes, axes and diggers for land clearing. It is a tedious method that leads to drudgery. Land cleared by this method may be difficult to later work with machines as some stumps and roots may be left in the soil.

2. Burning method involves setting the vegetation on fire. It is commonly used in the savanna vegetation region of Nigeria. It is fast and not labor intensive. It however can lead to decrease in the soil organic matter, nitrogen content, earthworm and microbial population, as well as general fertility of the soil.

3. Chemical method utilizes arboricides to kill stumps and forest regrowth thereby avoiding the utilization of the commonly used mechanical means of land clearing. However some arboricides are highly poisonous and could have unexpected consequences on humans and other organisms.

4. Mechanical method employs heavy machinery such as bulldozer and tractors to clear vegetation. This method is adopted by large scale farmers. It is more costly than the other three methods.

The rank ordering and scoring of the land clearing operational options is as shown in Table 2 below.

Table 2. Land clearing options and their scores

Option	Resource consumption	Environmental pollution	Efficiency of operation	Total	Path ID
Manual	1	1	4	6	A1
Burning	2	2	2	6	A2
Chemical	3	4	3	10	A3
Mechanical	4	3	1	8	A4

Mound/ridge making

This refers to the piling up of earthen materials either in rounded forms (mounds) or continuous earthen elevation in a row or rows (ridges) above the plane. It is done in preparation for seed yam planting to facilitate easy penetration of seed yam roots thereby fostering its growth and eventual yield. There are three commonly used methods in Nigeria, namely:

1. Manual method involving the use of hoes designed for the purpose. The use of manual methods for mound /ridge making is generally plagued with drudgery and is only suited for small scale farming.

2. Animal draught methods involve the use of animals such as donkey and bull to which farm implements such as disk or mouldboard plough are attached, which draw those implement to make ridges. This method is commonly utilized in Northern Nigeria.

3. Mechanical method. This is similar to animal draught method except that tractors are used instead of donkey or bull. This method is often used for large scale farming.

The rank ordering and scoring of the mound/ridge making operational options is as shown in Table 3 below.

The same rank ordering and scoring process was used for the rest unit processes in the yam production value chain.

Table 3. Mound/ridge making options and their scores

Option	Resource consumption	Environmental pollution	Efficiency of operation	Total	Path ID
Manual	1	1	3	5	B1
Animal	2	1	2	5	B2
Mechanical	3	2	1	6	B3

Seed planting

Yam seed planting and fertilizer application operations are often carried out manually by small scale farmers while large scale farmers use mechanical methods involving the use of planters and fertilizer applicators.

Staking involves the insertion/erection of long sticks in the soil near each sprouting yam seed is used to train the yam vine to hang onto those stakes in order to facilitate healthy growth. The staking operation involves cutting sticks of about 40–70 mm thick and about 180–200 cm height, transporting them to the site, inserting each stick for one or two growing yam vines, and training the vines to wind around the stakes. The staking design could be in various patterns, namely: standalone, 4-across two rows, or stakes in each row linked by horizontally lying top ones that are tied to the top of the standing ones. To date it is only done manually. Transportation of the stakes may be manual, animal drawn carriage or by a machine.

Weed control is often necessary at the early growth stage of the yam seedling before the vines form a canopy. There are four commonly used weed control methods.

1. Manual method. This often involves the use of hoe and cutlass. This method is often plagued with drudgery and suited for only small sized farms, just like other manual farming operations.

2. Chemical method. This method involves the use of herbicides. It requires careful handling as it may kill other things that were not the target of the application. It could be done manually or mechanized.

3. Animal draught weeding method. This involves the attachment of weeding implement to a set of farm animals such as donkey and bulls, and directing their movement.

4. Mechanical weeding method. This involves the use of weeding tool mounted farm machinery that may be self-propelled or manually driven. The weeding tool may be cutters that farm machinery like mower or trimmers can be used. It may also involve a tool that turns the soil on the weed.

Pest control/chemical application

1. Chemical method. This common method involves the use of pesticides/insecticides. It also requires careful handling as it may kill other things that were not the target of the chemical application. It could be done manually or mechanized.

2. Biological method. This involves raising and releasing insects, birds or animals that kill/feed on the pests.

3. Mechanical method. This usually involves the use of noise making devices that scare away the pest. The most common one consists of string suspended metal gongs that periodically hit each other as wind blows. The level of effectiveness of this method is yet to be established.

Harvesting

There are two usable methods for yam harvesting.

1. Manual method. Majority of yam harvesting is done by using hoes or cutlass to dig out the tuber from the soil. It usually involves cutting off the vine from the tuber, removing the soil around the tuber, shaking the tuber and lifting it up from the soil.

2. Mechanical method. Tuber harvesting implement can also be attached to a tractor that digs out the yams from the soil. This is suitable for mechanized large farms.

Storage

Losses in farm produce in many developing countries are largely due to lack of appropriate storage facilities for storing harvested produce. This is often because small holders can not afford the cost of modern storage facilities and these losses poses threat to food security and constitute serious economic losses in many developing countries. Yam is one of the farm produce that suffer from such losses (Amponsah et al., 2015). There are two common methods of yam storage in Nigeria:

1. Traditional method. There are various versions of this method. One common version involves tying yams unto erected stakes. The stakes are fenced to prevent human theft and easy access by animals such as rodents that may want to feed on the yams. This version allows cross circulation of air that elongates the lifespan of the tubers by preventing decay and mold growth on the tubers.

2. Improved yam storage facility. In recent years, there are concerted efforts being devoted to the design and development of modern yam storage facilities in Nigeria and in Ghana (FAO, 1990; Amponsah et al., 2015 and Knoth, 2020). Improved storage methods generally consist of ventilated buildings of various sizes with shelves on which yams are stored. The storage facility may be naturally or artificially ventilated.

Yam post-harvest processing

Cleaning

The processing of yam to any industrial material or product requires the removal of remaining soil that may still be clinging to it after harvesting it. A number of marketers do put identification marks on their yams. The markings may be with paints, chalk or charcoal. All these would need to be removed by washing before further processing. There are two main methods of tuber washing which are also applicable to yam washing:

1. Traditional method involves hand washing each yam tuber in water usually with a sponge. Like other operations involving the usual manual method, this method is tedious and generally applicable to small scale processing.

2. Mechanized methods could be either continuous or batch type. The most common ones involve a motorized sieve-like cylinder rotating in a pool of water that is fed with yams. The continuous version is often fitted with an auger or worm like device that moves yams from feeding point to the output end.

Other yam processing operations to various industrial materials/products such as slicing, crushing, frying, parboiling/cooking, drying, milling and packaging are amenable to both traditional manual method and mechanized method depending on the scale of operations as well as availability and affordability of the technology. Options available for each operation are comparatively assessed in terms of their energy, material and water consumption. Their environmental impacts are also comparatively evaluated with regards to the extent to which they affect land degradation, water contamination, air pollution and loss of biodiversity.

This example to illustrate this conceptual LCA method involves the use of the method by a corporate organization that produce 'pando yam' flour, chips, and starch from yam. The company has two farms under cultivation for the production of yams and other crops. It also has a facility that process the yam into pando yam flour.

Limitations to the utilization of the method

The use of this method requires in-depth knowledge of operations required to produce a product. The method is also based on the user's sufficient knowledge of all methods that could be used to accomplish a task/operation and his/her ability to correctly evaluate and rank order them in terms of the various attributes developed to assess the usable methods.

RESULTS AND DISCUSSION

Lifecycle inventory

Two decision scenarios were evaluated. The first scenario is that of that individual that wants to choose the best environmentally friendly pathway along the value-chain. The second scenario went beyond the consideration of just the technical and environmental factors to include the economic and social factors (Zamagni et al., 2013).

1. Techno-environmental Scenario:

The LAM integrated LCA process starts with setting the goal and scope of the LCA study using the ISO 14044 standard. Then comes the role of a decision maker that is knowledgeable in: the operations constituting the value chain, available choices within each operation, and the various characteristics of each choice in relation to the environmental factors such as resource requirements and environmental releases. He/she considers these factors and rank order the choices from the best to the worst. If there are three available choices for an operation, the best choice in term of environmental performance is assigned 1 while the worst choice is assigned 3. If there are six possible choices, rank ordering them means the best choice is assigned 1 while the worst choice is assigned 6. The decision maker goes through the rank ordering of available choices for each operation till the last operation in the value chain. The set of choices that is ranked 1 for each of the operations in the value chain constitute the optimal environmentally friendly pathway along the value chain. Table 4 is an extract of environmental focus analysis results where the goal of the conceptual LCA analysis is only to select a technically sound and environmental friendly optimal pathway for yam production value chain.

Table 4. A sample results of technical effectiveness and environmental friendliness based analysis

Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Land clearing operation					
Manual	1	1	4	6	A1
Burning	2	2	2	6	A2
Chemical	3	4	3	10	A3
Mechanical	4	3	1	8	A4
Mound/ridge making operation					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	3	5	B1
Animal	2	1	2	5	B2
Mechanical	3	2	1	6	B3
Seed planting					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	3	5	C1
Mechanical	3	2	1	6	C3
Fertilizer application					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	2	4	D1
Mechanical	2	2	1	5	D2
Staking					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	3	5	E1
Manual-animal	2	2	2	6	E2
Manual-mechanical	3	3	1	7	E3
Weed control					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	2	4	F1
Chemical	2	3	1	6	F2
Animal	2	2	3	7	F3
Mechanical	4	3	4	11	F4
Pest control					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Chemical	2	3	1	6	G1
Biological	1	1	2	4	G2
Mechanical	3	2	3	8	G3
Harvesting					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Manual	1	1	2	4	H1
Mechanical	2	2	1	5	H3
Storage					
Option	Res. cons.	Env. pol.	Tech. eff.	Total	Path ID
Traditional	1	1	2	4	I1
Improved	2	2	1	5	I2

Res. cons. – resource consumption; Env. pol. – environmental pollution; Tech. eff. – technical effectiveness; Econ. – economic sustainability.

2. Sustainability Scenario

There are three main dimensions of sustainability: namely, environmental, social, amd economic sustainability. Consequently, this scenario considers the three dimensions in the selection of the optimal pathway. This is particularly important in view of the ongoing trend in agri-industrial system analysis that necessitates going some steps further to include potential economic and sociocultural/sociopolitical impacts of our choices. Social factors consider various aspects of human well-being. The methods are evaluated in terms of elimination/reduction of drudgery, minimization of exposure to health risk, emotional trauma, and other possible hazards that could affect human well-being (Jørgensen et al., 2008). Looking at the options available for each operation, the use of mechanical methods facilitate the attainment of the aforementioned goals. This scenario follows the same process as in the case of techno-environmental scenario. However, in addition to evaluating the available choices for each operation on the basis of environmental factors, it also consider social and economic factors (Roos, 2016). The choice that has the lowest total of the combination of the environmental, social and economic factors is ranked first. The choices are thus ordered from the lowest total to the highest total for each operation. The set of choices that are ranked first over the value chain operations constitutes the optimal pathway. Table 5 shows a sample results of sustainability based analysis that included economic and social considerations along with the technical effectiveness and environmental friendliness.

Table 5. A sample results of sustainability based analysis

Land clearing operation							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	4	4	4	14	A1
Burning	2	2	2	1	2	9	A2
Chemical	3	4	3	2	2	14	A3
Mech	4	3	1	3	1	12	A4
Mound/ridge making operation							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	3	3	3	11	B1
Animal	2	1	2	1	2	8	B2
Mech	3	2	1	2	1	9	B3
Seed planting							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	3	2	2	9	C1
Mech	3	2	1	1	1	8	C2
Fertilizer application							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	2	2	2	8	D1
Mech	2	2	1	1	1	7	D2
Staking							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	3	3	3	11	E1
Manual-animal	2	2	2	1	2	9	E2
Manual-mech	3	3	1	2	1	10	E3

Table 5 (continued)

Weed control							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	2	4	4	12	F1
Chemical	2	3	1	2	3	11	F2
Animal	2	2	3	2	2	11	F3
Mech	4	3	4	1	1	13	F4
Pest control							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Chem	2	3	1	3	3	12	G1
Biol	1	1	2	1	2	7	G2
Mech	3	2	3	2	1	11	G3
Harvesting							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Manual	1	1	2	2	2	8	H1
Mech	2	2	1	1	1	7	H2
Storage							
Option	Res. cons.	Env. pol.	Tech. eff.	Econ.	Social	Total	Path ID
Tradi	1	1	2	2	2	8	I1
Improv	2	2	1	1	1	7	I2

Res. cons. – resource consumption; Env. pol. – environmental pollution; Tech. eff. – technical effectiveness; Econ. – economic sustainability.

Lifecycle impact analysis

An evaluation of the results shown in Tables 4 and 5 provides us some insights into the best pathway for each of the two yam production value chain decision scenarios. Fig. 5 shows the best yam production value chain pathway for the techno-environmentally focussed decisions while Fig. 6 shows the best yam production value chain pathway for an all encompassing sustainability based decision. It would be observed that the environmentally friendly optimal pathway largely consist of manual methods. The reason for this is because manual methods generally require less resource to operate and they generate no or smaller emissions than other approaches.

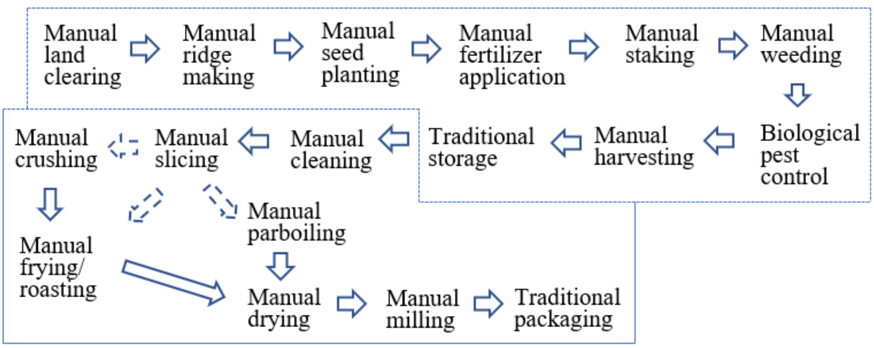

Figure 5. An illustration of the best pathway for techno-environmental focused yam production value chain.

The sustainability optimal pathway (Fig. 6) mainly consist of mechanical approaches. The main reason is because the use of mechanical methods generally protect workers from drudgery and facilitates higher productivity. Thus, it is preferred to the manual and other approaches. The combine effect of economic and social sustainability balances the environmental sustainability for the attainment of all round sustainability.

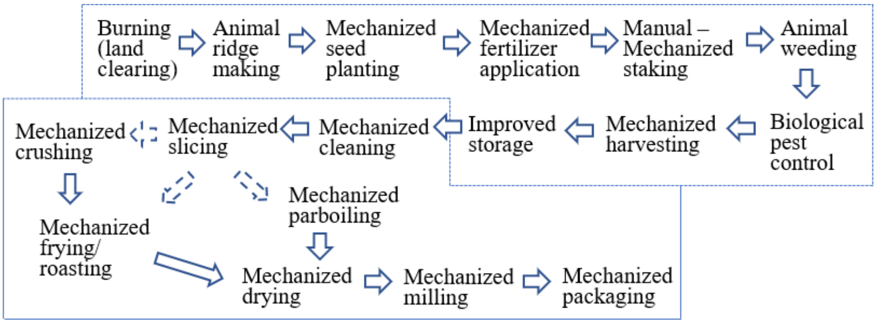

Figure 6. An illustration of the best pathway for sustainability focused yam production value chain.

Systems Lifecycle Interpretation

Techno-environmental focused analysis results in Table 4 and Fig. 5 revealed an emphasis on the use manual labour in majprity of the operaions along the yam production value chain. The reason is not far fetched. Manual labour based operations minimizes resource consumption and eliminates environmental releases that could lead to resource depletion, loss of biodiversity, air polltion, water contamination and a number of other environmental problems. However, business decisions would need to also consider economic implications of its choices. Consequently, there is a need to include economic and social factors in the analysis. A look at results of sustainability analysis results in Table 5 and Fig. 6 showed that major emphasis is on the use of mechanized systems. The reason being that mechanized systems facilitate mass production, reduced unit cost, increased profit margin and drudgery elimination. A comparison of the environmental results and sustainability results revealed only in pest control operation that both analysis recommed the same approach, that is biological pest control.

Comparing both decision scenarios, sustainability based optimal pathway is more comprehensive and it is a more balanced decision than environmentally optimal pathway as it also consider social and economic factors. The only challenge is that the sustainability decision scenario require someone with not only the indepth knowledge of environmental characteristics of the system to implement the LCA process, it also requires the decision maker to have the knowledge of the social and economic characteristics of various choices available along the value chain.

CONCLUSIONS

This paper presented a simplified less data intensive linear assignment based conceptual LCA method. The used of the LCA methodology was illustrated with a case study yam production value chain. Contributions of this study includes its provision of opportunity to choose the best pathway to produce agri-industrial materials in technically efficient and environmentally friendly manner. It also facilitates the use of lifecycle concepts in selecting agri-industrial material production operations without going through the rigour of data collection and related analytical issues. The methodology would enable small to medium scale farmers and agri-processors in developing countries to conduct an LCA of their products because many of the LCA software and databases are beyond their affordability. In addition, this methodology is much easier to use than the conventional lifecycle assessment method. Moreover, this LCA approach is less costly and less time consuming than other known methods. The methodology can be used by a manager, a policy maker or any professional to identify the best operational pathway that is technically sound, environmental friendly, warrants economic profitability and incorporate human welfare consideration. This methodology would be found useful, not only for any agri-industrial material production value chain but also for other production or service systems decision scenarios that require an evaluation of environmental and socioeconomic consequeces of our choices.

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