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Potential social lifecycle impact analysis of bioenergy from household and market wastes in African cities

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Abstract. Bioenergy is touted as a viable source of stable and affordable energy in a number of remote sub-urban centres. This study evaluates the potential social lifecycle impacts of bioenergy production from household wastes and agri-wastes in some African cities. The assessment considered the use of rotten and unsold fruits, vegetables and other related agri-wastes from central open markets in Lagos and Johannesburg as case studies. The 2009 UNEP/SETAC's social lifecycle assessment (sLCA) guidelines and the associated sLCA methodological sheets are used to evaluate the potential social impacts of bioenergy production from agri-waste on operators/workers, the consumers, the value chain, and the local community. Preliminary results showed that it will provide a lot of benefits such as alternative employment opportunities, improved profits for small businesses, waste minimization, cleaner environment and improved communal health. It will also lead to improvement in energy supply, and alleviation of poverty. However, care has to be taken to protect the bio-digestion facility's neighbourhood from unpleasant odour, rodents and other organisms that may attempt to feed on the rotting agri-waste. The outcome of this study provides an insight to the necessity for the development of appropriate bioenergy policy/regulation and for the need to take preemptive steps to eliminate/minimize potential negative consequences of bioenergy production on the stakeholders.

Key words: bioenergy, household wastes, market wastes, social impact assessment, social lifecycle assessment (sLCA).

List of acronyms used:
GRCC – Grand Rapids Community College;
LCC – Lifecycle costing;
LCI – Lifecycle Inventor;
LCIA – Lifecycle Impact Assessment;
LCIO – Lifecycle Initiative Organisation;
NWIBP – Net Wellness Impact of the Bioenergy Production System;
PSI – Puget Sound Institute;
SiMSAW – A multi-level Social Impacts Aggregation Simple Additive Weighting;
UNEP – United Nations Environment Programme;
SETAC – Society of Environmental Toxicology and Chemistry;
sLCA – Social Lifecycle Assessment.

INTRODUCTION

The choice of energy supply sources is a major factor affecting our environmental sustainability. There are ongoing global efforts aimed at weaning people and organizations from dependence on fossil fuel and transitioning them to renewable energy sources. Bioenergy is widely recognized as a renewable form of energy. It has enormous potential to solving energy problems in developing countries that are dependent on fossil fuel and/or experiencing erratic electric energy supply. While significant progress has been made in many regions, Africa needs to catch up with the tempo of the ongoing changes. Currently, majority of rural dwellers in Africa, especially Nigeria depends on fuel wood/firewood while the urban dwellers depend on Kerosene (a derivative from fossil fuel) (Agunbiade, 2014). There is a need for changes in the choice of energy sources. There is a very high potential for sustainable bioenergy production from agri-industrial wastes, biodegradable municipal waste, food wastes and agri-wastes in many countries of Africa. For example, a study on the characterization of domestic and market wastes in Lagos metropolis by Oyelola & Babatunde (2008) found the putricible fraction of the domestic waste to be 68.16% while the putrescible fraction of market waste was 68.98%. In another study, Agunbiade (2014) reported that Nigeria generate 39.1 million tonnes of Fuel wood, 11.24 million tonnes of agri-waste, 4.08 million tonnes of municipal waste, and 1.8 million tonnes of sawdust annually. In Nigeria, a lot of foods such as bananas, tomatoes, pineapples, oranges, pawpaw, mangoes and all manner of produce perish after few days of harvest due to inadequate storage capacity. Francis (2016) estimated the worth of the food waste in Nigeria to be about $ 750 billion yearly. This incredibly large amount of food wastes in Nigeria could be a valuable source of feedstock for bioenergy generation. Quoting Danfoss, Francis (2016) stated that there is 80% food wastage in Nigeria as opposed to 33% wastage worldwide. He also hinted that 1.9 tonnes of CO_2 is emitted for every tonne of food waste generated. In the same vein, Bakare (2018) hinted that Lagos State Nigeria, with a population of over 21 million and per capita waste generation of 0.5 kg per day, generates more than 10,000 tonnes of urban waste every day. The same trend is observed in many other African countries, as Okot-Okumu (2012) revealed that 65% – 77.2% of solid waste generated in many of the East African cities is biowaste. All these are pointers to the viability of bioenergy facilities in many African cities. In addition, bioenergy has great potential to create employment, boost the economy and improve citizens' standard of living. According to Agunbiade (2014), 'Lagos state government is looking into ways of converting saw dust generated from its many saw milling plants into energy'. Realizing the potential benefits of harnessing this enormous bioenergy resource, the State government is investigating the possibility of developing bio-energy and other renewable sources for its development projects (Dunmade, 2013a, Obasiohia, 2014; Dunmade, 2016 and 2017a; Den, 2017; Tribune, 2017).

Despite all the aforementioned and other potential benefits of developing bioenergy facilities in cities with enormous bio-wastes in Africa, development of bioenergy facility have both perceptible and non-apparent social, economic and environmental implications. At a global level, most of the studies on bioenergy were focused on the technical functionality/ performance of bioenergy systems. There are only few studies on socio-economic aspects of bioenergy (Buchholz et al., 2007; Luchner et al., 2012; Dale, 2013; Segon & Domac, n.d.). Assessment of social impacts of bioenergy systems from lifecycle perspective has not received much attention. The significance of this study therefore stems from the fact that although there are several studies on the assessment of bioenergy potentials and utilization in Africa in particular, no research report was found on the social lifecycle impact assessment of bioenergy systems in Africa (Ackom et al., 2013; Okello et al., 2013; Simonyan & Fasina, 2013; Agunbiade, 2014; Mohammed et al., 2015; Shane et al., 2016 and Arogundade, 2018). And there is a need to fully understand the pattern and effects of bioenergy production systems on various stakeholders. Hence, there is a gap regarding the social sustainability assessment of bioenergy production systems. This is particularly true about the potential social impacts evaluation of bioenergy development in Africa from a lifecycle perspective. This study is therefore focused on the social lifecycle impacts assessment of bioenergy facilities from a Nigerian context (Dunmade, 2012 and 2013a).

Social Sustainability

There are questions and several explanations on what sustainability is, on what social sustainability is and what is involved. Sutton (2000) declared that sustainability is about maintaining something. And various discussions since 1987 have mainly focused on three pillars of sustainability, namely environmental, economic and social sustainability. While environmental and economic sustainability are a bit easier to define and measure, social sustainability is not only more difficult to define and measure but it has not received as much attention as the other two (GRI, 2000; Barron & Gauntlet, 2002). Mckenzie (2004) defined social sustainability as a life-enhancing condition within communities, and a process within communities that can achieve that condition. He further explained that 'Social sustainability occurs when the formal and informal processes, systems, structures and relationships actively support the capacity of current and future generations to create healthy and liveable communities. Social sustainability refers to those social resources and processes that foster good quality of life/well-being now and in the future. It includes 'social homogeneity, equitable incomes and access to goods, services and employment'. It also includes inter and intra-generational equity, the distribution of power and resources, employment, education, health, the provision of basic infrastructure and services, freedom, justice, access to influential decision-making fora and general 'capacity-building (Littig & Grießler, 2005; Vallance et al., 2011)

MATERIALS AND METHODS

Social and socio-economic lifecycle assessment (sLCA) methodology was used to evaluate the potential social impacts of bioenergy production from household wastes and agri-wastes in some African cities. The lifecycle methodology was used because it is robust tool for evaluating various impacts of products, processes and activities from cradle to grave. The methodology facilitates an examination of the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal (UNEP/SETAC, 2009). sLCA technique is important for this kind of evaluation because it complements environmental LCA and Life Cycle Costing. As a toolbox, the three techniques facilitate full assessment of goods and services within the context of sustainable development.

Although UNEP and SETAC have developed guidelines for sLCA, it is still a work in progress as a socio-economic assessment tool (Jorgensen et al., 2010; Norris, 2014; Dubois-Iorgulescu, 2018; Grubert, 2018). It is progressively gaining widespread utilization for soical impacts the assessment of products, systems and activities. Some of the areas of its previous applications include social impact evaluation of urban sugar production in Brazil (Du et al., 2019); an Irish diary farm (Chen & Holden, 2017); comparison of building materials in Iran (Hosseninijou et al., 2014), comparison of domestic water reuse alternatives (Opher, Shapira & Friedler, 2018).

The UNEP/SETAC's sLCA guidelines and the associated sLCA methodological sheets is a framework that has to be adapted to suit specific application. The framework was adapted for social impacts assessment of bioenergy industry and the African context by incorporating features such as metrics for evaluating human wellbeing in the aforementioned context. Probability of occurrence of articulated social indicators of human wellbeing and severity of their impacts are other features incorporated for the evaluation of social impacts of bioenergy industry in Africa. The aforementioned features were introduced and implemented at the lifecycle inventory analysis phase. Results obtained at the lifecycle inventory (LCI) stage was aggregated at the lifecycle impact assessment (LCIA) stage to identify hot spots along the product/system value chain. The aim was to determine the stakeholder category or categories that is/are affected and how they were affected. The conversion of linguistic qualitative ratings of probability and severity of each social indicator to numerical values and the aggregation of social indicators' impacts into groups were implemented by using SiMSAW model. Details on how SiMSAW method is used was discussed later in this paper. The compilation into various impact categories was done for each stakeholder groups assessed along the value chain. Results obtained is then diagrammatically illustrated/displayed for comparison of impacts across the stakeholders' groups. Details on the goal and scope of this study is discussed in the next section. This is followed by discussion on the lifecycle inventory (LCI). Lifecycle impact results was discussed after LCI. Interpretation of results obtained at LCI and LCIA stage were discussed in the following section before conclusion drawn from the study were finally explained.

Goal and scope definition

A. Goal of the study

According to Dunmade (2013a), the goal of a lifecycle assessment should specify the intended application, objectives of the study, and intended audience. The goal of this study therefore is to provide awareness of the potential social consequences of bioenergy production from domestic and market wastes, so that policy makers and other stakeholders can make informed decisions relating to the associated socio-economic issues.

To meet the goal of this research, the following questions will be answered:

- What are the appropriate social criteria that should be used to assess the social sustainability of household and market waste based bioenergy systems?
- What are the potential social sustainability hotspots in household and market waste based bioenergy systems?
- What are the areas of possible improvements in the sustainability of household and market waste based bioenergy systems?

B. Scope of the study

At this stage of the study, we determined the function of the system, its functional unit, the system boundaries, data averaging, limitations and exclusions (Dreyer, 2009; Dunmade, 2013b and 2015; Dunmade et al., 2016; Dunmade, 2017b; and Dunmade et al., 2018). We also identified affected stakeholder groups, impact categories/ impact measuring criteria, and social indicators to be included in the analysis based on the goal of the study. Furthermore, we articulated the metric for scoring the performance of the bioenergy system in preparation for the lifecycle inventory.

B.1 Household/Market waste based bioenergy production system's lifecycle

The bioenergy production system's lifecycle (illustrated in Fig. 1) consists of gathering and preparation of household/market wastes into a usable form as feedstock, feedstock conversion to value added commodities/ products, and the use of the produced biogas for electric energy production.

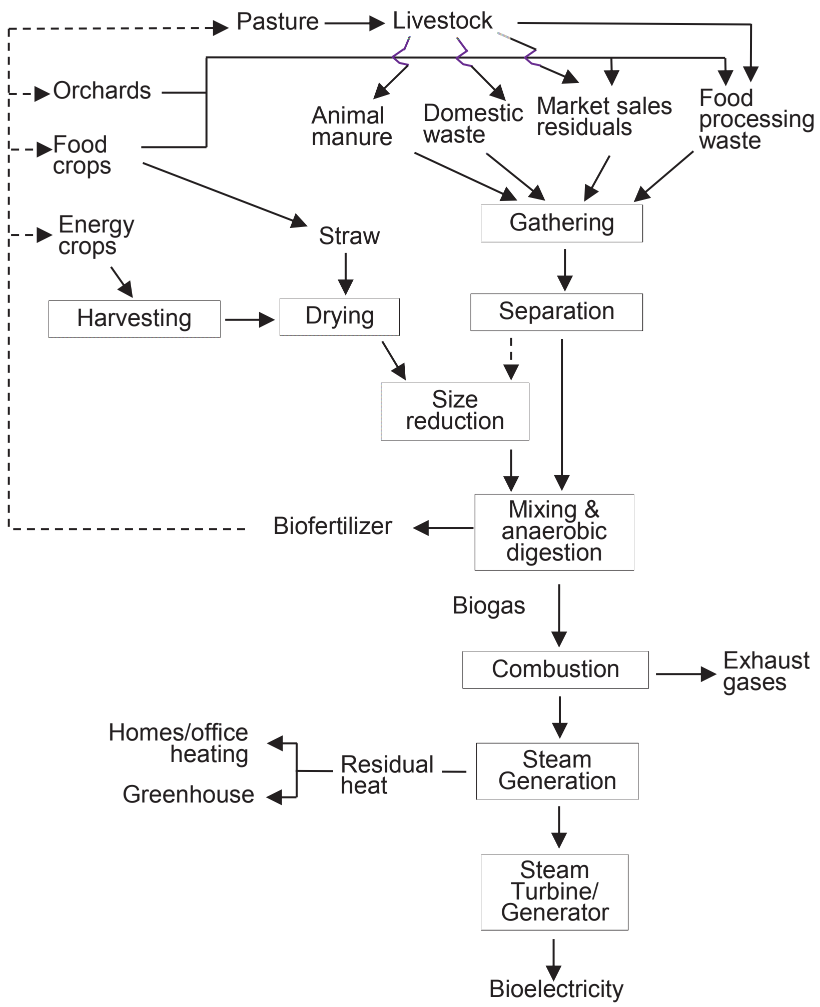

Figure 1. Household and market wastes based bioenergy production system's lifecycle.

Proper planning would involve on-site separation of the biodegradable fraction from other components of household and market wastes. On-site separation of the wastes that would be used as feedstock would be advantageous as it would ensure purity of the feedstock and ensure recovery of higher percentage of the feedstock than if the separation is done after commingling the wastes. The waste streams under consideration for this study consists of fruits, vegetables, animal manure and straw. Straw may need to be dried and subjected to dry milling to facilitate accelerated digestion. The anaerobic digester facility under study is fitted with stirring device for effective mixing to enhance biodigestion and to improve biogas yield. It also has electric heating device in case it is necessary to initialize the anaerobic digestion process. In addition, it has avenues for addition of fresh feedstock and for withdrawal of digested stock. The withdrawn old feedstock from the biodigester is then cured and eventually applied as fertilizer to grow crops or pasture. Produced biogas is then subjected to combustion to produce steam needed to drive steam turbine coupled to a generator that produces electric power. Excess biogas may be bottled for home cooking and various industrial uses.

B.2 Function and functional unit

The function of the bioenergy production system is defined in this study as the production of clean renewable energy products in a socially sustainable manner for homes, institutional, commercial and industrial use. The functional unit for measuring social impact of the bioenergy production system is defined in terms of the GRCC's seven categories of human wellness. The proposed functional unit is the 'net wellness of the impact of the bioenergy production system on each stakeholder category and customers' satisfaction resulting/derived from the product delivered' (NWIBPS). This metric was chosen because according to (Ashton & Jones, 2013), 'everyone around the world, regardless of geography, age, culture, religion or political environment, aspires to live well.' Thus, there is a need to measure how the bioenergy production systems affect various stakeholders within the circle of the system's influence.

B.2.1 Human Wellness

Human well-being includes many aspects of our everyday lives. Material well-being, relationships with family and friends, and emotional and physical health are among the components of human well-being. It also includes work and recreation, how one feels about one's community, and personal safety. Income level, individual's thoughts and feelings about how well they are doing in life, contentment with material possessions and having relationships that enable them to achieve their goals are other determinants of human wellbeing. In other words, human wellbeing is about quality of life, welfare, living well, life satisfaction, prosperity, needs fulfillment, empowerment, and happiness (McGillivray & Clarke, 2008; Dunmade et al., 2018; PSI, 2018). GRCC (2018) explained wellness as 'a full integration of physical, mental and spiritual well-being that leads to quality of life' and 'neglecting anyone dimension for a length of time has adverse effects on overall health.' This study adopted/adapted the principles of the seven dimensions of wellness described by GRCC (2018) for the evaluation of the social impacts of the bioenergy production facility.

B.3 System boundaries and exclusions

This is a cradle-to-grave sLCA involving an evaluation of household and market agri-waste feedstock gathering and associated logistics. It also include an assessment of a bioenergy facility's operations management for the production of biogas and bioelectricity. Other types of feedstock, bioenergy systems' development, bioenergy products' utilization except biogas utilization for electricity generation, and bioenergy facility's end-of-life management were not included in this study.

Lifecycle inventory (LCI)

This is the stage where requisite data for social impact assessment is collated and compiled in appropriate format for further analysis. LCI compilation for this study was in accordance with the method used by Dunmade et al., 2018. This study involved the use of locational/site specific data relating to Lagos metropolitan area. Relevant secondary data gathered from government websites, newspapers and publicly accessible corporate reports were also used where site specific data were not obtainable. The use of UNEP/SETAC methodological sheets based data collection approach focused on how bioenergy production system affect human wellbeing. The data collected was then processed in a spreadsheet format for the next stage of the study, which is social lifecycle impact assessment of the process. Tables 1 and 3 are samples of lifecycle inventory results of the bioenergy production system. They showed some of the social sustainability impact assessment criteria as they affect various stakeholder categories under consideration (Fan et al., 2015; Dunmade et al., 2016; Dunmade, 2017b; Dunmade et al., 2018).

Social lifecycle impact assessment (sLCIA)

This sLCIA study evaluated the net social effect of all/various stages of the bioenergy production system on stakeholders after considering all possible positive and negative consequences. The impact assessment process is modelled in similar pattern to the (environmental) lifecycle impact assessment. This consists of impact categories definition, classification, characterization, normalization, grouping and weighting. The adaptation of the eLCIA process for this sLCA study is as discussed below.

A. Selection of impact categories and classification

The choice of relevant impact categories (i.e. social indicators) in this sLCA is context dependent and were based on the local context (Emmanuel & Ajide, 2005; Mathe, 2014). The origin of the selected social indicators include social sustainability indicators for bioenergy developed by Oak Ridge National Laboratory and reported by Dale (2013) and Luchner et al. (2012); socio-economic sustainability issues articulated in Segon and Domac (n.d.), Johannesburg and Lagos socio-cultural observations. The classification of the social indicators was largely based on the sLCA guidelines published in 2009 by UNEP/SETAC. The guideline identified five groups of stakeholders. The focus of this study is the 'bioenergy facility workers, the neighbouring community, and the bioenergy value chain. The sLCA classification step in this study involved the mapping of relevant bioenergy systems socioeconomic impact indicators on the wellbeing of the three categories of stakeholders. The selection of impact categories and social indicators is based on (1) the principles of UNEP/SETAC methodological sheets; (2) currently relevant human wellbeing indicators of household and market waste management practices in Nigeria, (3) projected bioenergy facility maintenance attitude by the workers, and (4) on the scope of the study. The selected social indicators are defined by a set of semi-quantitative data (Dunmade, 2001, 2012 and 2013a). Social aspects of sustainable bioenergy, according to Dale (2013) involve 'preserving livelihoods and affordable access to nutritious food; guaranteeing the reliability of energy supply; and ensuring the safety of people, facilities, and regions. They also include using open and transparent participatory processes that actively engage stakeholders, establish obligations to respect human rights, and emplace a long-term sustainability plan with periodic monitoring.' Social aspects of bioenergy systems, according to Segon and Domac (n.d.) can be divided into two categories, namely: (i) those that relates with standard of living, and (ii) those that contribute to increased social cohesion and stability. Standard of living in this case was related to household income, education, surrounding environment, and health care while social cohesion and stability was defined in terms of peace and communal relationship, employment, rural population stability, infrastructure and support for related industries.

The social impact assessment is focused on household and market waste based feedstock, bioenergy conversion technology operation, and the management of biogas' utilization for electricity generation. On the positive side, development and operation of bioenergy facility or facilities in Lagos metropolis would significantly improve environmental cleanliness. Current approach to waste management mainly involves scavenging for valuables from the waste piles by private individuals and open air burning. There were incidences of explosions and plume of air emission enveloping large areas of Lagos. Such uncontrolled burnings has led to loss of properties such as public transit vehicles, houses and offices. Diversion of the municipal wastes for bioenergy production would eliminate such incidences and provide value-added commodities. It would also lead to cleaner community, improve public health, induce investment in associated businesses, create jobs, improve household income, improve energy supply, reduce social vices and crimes, enhance communal cohesion and improve government revenue. Improved revenue would ultimately make funds available for infrastructure improvement and lead to overall improved standard of living. Improved infrastructure and stable energy supply would lead to increased productivity and boost the regional economy.

Bioenergy facilities siting would necessarily have to be in the more rural areas of Lagos as the megacity is already congested. Similar suggestion is for the siting of bioenergy facility for Johannesburg. Locating such facilities in neighbouring rural areas would reduce the current tempo of high rural-urban migration to Johannesburg/Lagos, improve rural development and rural employment, and promote population stability. It would also help rural businesses to flourish and lead to regional growth. In addition, locating the bioenergy facility in the rural areas would prevent worsening the current traffic lock jam in the Lagos metropolis, lead to income and wealth creation in the adjoining rural communities, boost energy supply in the rural area, attract related industries to rural areas and even out developments in Lagos state (Haberl et al., 2011; Dunmade, 2013b and 2014; EPA, 2014; Mokraoui, n.d.; Van den Braak et al., 2016).

The main negative impact is in relation to maintenance of the bioenergy energy facilities and the related logistic systems. Inadequate maintenance could result in widespread unpleasant odour in the communities surrounding the bioenergy facility and its feedstock storage facilities. A breakdown of the facility operation could result in spillover of the feedstock storage facilities. Improper management of the feedstock storage facilities could lead to infestation of the facilities by vermin. This could have serious implications for public health and lead to many other social-political problems.

B. Characterization and normalization

Characterization involves converting the social information obtained into interpretable indicators of a list of impacts. This study adopted a quantitative approach to characterization because it would enable us to compare the results obtained from this study with future studies. Consequently, we will be able to identify improvements that had occured over a time period. Table 1 shows the classification of the social indicators into the various human wellness impact categories, Table 2a consists of the five probability/likelihood of indicators' occurrence ratings, while Table 2b consists of the ratings for evaluating the extent to which the indicator would affect human wellbeing. Tables 1, 2a and 2b were used concurrently for the classification, characterization and normalization steps in sLCIA process. Column 1 and 2 of Table 1 shows the classification of the social indicators into the various human wellness impact categories. Table 2a was used to assess the probability of occurrence of each social indicator highlighted in Table 1 while Table 2(b) was used to evaluate the extent to which the indicator affected the impact category to which the indicator was mapped. The outcomes of the probability of occurrence and extent of impact ratings for each positive social indicators are shown in columns 3 and 4 of Table 1 while columns 5 and 6 of Table 1 showed the ratings for negative social indicators.

Table 1. Articulation and classification of the bioenergy production system's social indicators into human wellness impact categories for workers' category

Criteria	Indicator	Positives		Negatives	
		Probab.	Severity	Probab.	Severity
Economic wellbeing	Employment opportunities	Yes	EH		
	Career growth opportunities	Yes	EH		
	Household income	Yes	EH/VH		
	Food price volatility	May be	AV		
	Labour mobility	Yes	AV		
Physical wellbeing	Occupational injury			Yes	H/AV
	Risk of catastrophe			May be	AV
	Health	Yes	H/VH		
Emotional wellbeing	Socialization	Yes	H		
	Occupational injury			May be	H/AV
Intellectual wellbeing	Training opportunities	May be	H		
Social wellbeing	Socialization	May be	VH		
	Self-reliance and economic independence	May be	AV		
	Public acceptance/opinion	Yes	AV		
	Risk of catastrophe			May be	H/AV
Spiritual/cultural wellbeing	Socialization	May be	H		
Environmental wellbeing	Exposure to pollution			Yes	EH

B1. The sLCIA Calculation

Potential social lifecycle impacts of the bioenergy production system on each stakeholder group was assessed using the SIMSaW model. The first of the three steps simple additive weighting model involves multiplying the numerical values of the five probability ratings in Table 2a with the numerical seven severity of impact ratings in Table 2b that are corresponding to the linguistic scoring in Table 1. The score of each human wellness impact category is calculated by summing up the products of affecting social indicators'probability and extent of impact ratings as shown in Eq. 1. The overall (net) social impact of the bioenergy production system on each stakeholder group (i.e. workers, neighbouring community, the value chain, etc.) is the sum of the scores of the human wellness impact categories. Importance weights may be introduced by stakeholders in a participatory setting but importance weights were not used in this study. The overall social impact (score) of the bioenergy production system was calculated by adding all relevant stakeholders' scores together. According to Dunmade et al. (2018), 'the normalization at subcategories level becomes necessary to avoid certain subcategories dominating the final result.'

Table 2a. Probability of indicator occurrence

Probability	Rating
No (impossible)	0
Unlikely	2.5
May be	5
Likely	7.5
Yes (certain)	10

Table 2b. Severity of indicator effect

Severity	Rating
Extremely high (EH)	10
Very high (VH)	8.34
High (H)	6.67
Average/Moderate (AV)	5
Low (L)	3.34
Very low (VL)	1.67
Non-existent (N)	0

SiMSAW Method

SiMSAW model is a multiple levels simple additive valuation model developed by Dunmade et al. (2016) for aggregation of social indicators' impacts. The levels of aggregation of impacts could be two, three or four. This example used three levels of impacts' aggregation to illustrate the method for workers stakeholder group. A three levels of aggregation is done as follow:

1st level compilation: This involves converting the qualitative/linguistic LCI data in Table 1 into numerical values by multiplying the corresponding probability of occurrence in Table 2a with corresponding severity of the social indicator's rating in Table 2b. Results obtained for positive impact and negative impact of the indicator are then added together to obtain the net impact of the indicator. Steps taken at this point can be represented with Eq. 1 shown below.

Net social impact indicator score,

$$J_j = \left[P_j(d_j)\right]_{+ve} + \left[-P_j(d_j)\right]_{-ve} \tag{1}$$

where P_j – probability of the indicator's occurrence; d_j – severity of the indicator's effect on the stakeholder group S under the impact category K.

For example, looking at Table 1 and considering the occupational injury (a social indicator under physical impact category), the indicator has only negative impact. It does not have a positive component.

The indicator's numerical score,

$$J_j = \left[-P_j(d_j)\right]_{-ve} = -10(5.84) = -58.4 = -0.584 \quad (2)$$

The normalized value of -0.584 was obtained by dividing -58.4 with 100.

2nd level aggregation: Net impacts of social indicators in each impact category is summed up at this point. The total is then divided by the number of indicators in the impact category. The normalized value of impact category K can be mathematically represented as

$$K = \frac{1}{m}\sum_{j=1}^{m} J_j \quad (3)$$

where Jj – the net impact value of each social indicator under impact category K; m – number of social indicators considered under impact category K.

For example, continuing with the physical impact category in Table 1, substituting the net values of the social indicators under the physical well-being impact category K under workers stakeholder group S into Eq. 2 would yield

$$K = {}^{1}/_{3}[(-0.584) + (-0.25) + 0.75] = -\ 0.028 \quad (4)$$

This is the physical impact value of the bioenergy facility on the workers (stakeholder group S). This level of aggregation appear to be the most useful level of all levels of aggregation because it enables the analyst to see how various social impact category affect different stakeholders along the value chain.

3rd level aggregation: At this point, each impact category is multiplied by its importance weight and the product of the impact categories are summed together and afterwards normalized with the sum of importance weights to obtain the overall social impact of the facility/system on a stakeholder group. The Total social impact value for stakeholder group S can be mathematically represented as

$$S_k = \frac{\sum_{i=1}^{n} w_i K_i}{\sum_{i=1}^{n} w_i} \quad (5)$$

where K – normalized impact category i value; w – importance weight of the impact category i; n – number of social impact categories considered.

For this case study, all the impact categories were considered to be of equal importance. As a result, Eq. 5 reduces to

$$S_k = \sum_{i=1}^{n} K_i = K_1 + K_2 + \cdots + K_n \quad (6)$$

The overall social impact score of the bioenergy production system on workers,

$$S_k = 0.7334 + (-0.028) + 0.0625 + 0.3335 + 0.30225 + 0.375 + (-1) = 0.77865 \quad (7)$$

This process is repeated for each stakeholder group in the bioenergy production system value chain.

This level of aggregation provides a summary of social impact of a facility on each stakeholder group in the value chain.

4th level aggregation: This is the level when the overall facility performance across the value chain is assessed by summing up its performance for all stakeholder groups together and normalizing it by dividing with the number of stakeholder groups evaluated. was assessed by compiling its normalized indicators scores at sub-category level. The normalization at each level is necessary to avoid some subcategories dominating the final result. The overall social impact value of a bioenergy facility T can be expressed as

$$T = S_1 + S_2 + \cdots + S_r \tag{8}$$

where S_r – normalized impact value for stakeholder group r.

This 4th level of aggregation is only useful for comparative studies. That is when the study is to compare the overall social impacts of two or more facilities or when there are two or more options being considered for selection, or when the study is to be compared with a reference. Thus, the 4th level of aggregation was not performed for this study.

RESULTS AND DISCUSSION

Tables 1 is the qualitative result of the articulation, compilation, classification and evaluation of various social indicators affecting different dimensions of human wellbeing as it pertains to bioenergy production system on workers. Table 3 is the numerical conversion and levels 1 and 2 aggregation of the results in Table 1.

Table 3. Social impact indicators' assessment for bioenergy production system on workers

Criteria	Indicator	Indicators' normalized scores	Total per criterion
Economic wellbeing	Employment opportunities	1	**0.7334**
	Career growth opportunities	1	
	Household income	0.917	
	Food price volatility	0.25	
	Labour mobility	0.5	
Physical wellbeing	Occupational injury	-0.584	**-0.028**
	Risk of catastrophe	-0.25	
	Health	0.75	
Emotional wellbeing	Socialization	0.417	**0.0625**
	Occupational injury	-0.292	
Intellectual wellbeing	Training opportunities	0.3335	**0.3335**
Social wellbeing	Socialization	0.417	**0.30225**
	Self-reliance and economic independence	0.25	
	Public acceptance/opinion	0.834	
	Risk of catastrophe	-0.292	
Spiritual/cultural wellbeing	Socialization	0.375	**0.375**
Environmental wellbeing	Exposure to pollution	-1	**-1**

The aggregation involved looking at Tables 2a and 2b to replace linguistic ratings in Table 1 and implementing SiMSAW aggregation levels 1 and 2. The same procedure was used to obtain social impacts of the bioenergy production system on the community and the value chain. The overall social impact score on workers is 0.78 while the overall social impact score for the community and the value chain are 1.99 and 2.18 respectively. Fig. 2a, 2b and 2c are diagrammatic illustrations of level 2 aggregation of the bioenergy facility's social impacts on workers, neighbouring community and the value chain while Fig. 3 shows the overall impact of the bioenergy facility on each of the three stakeholder groups under study.

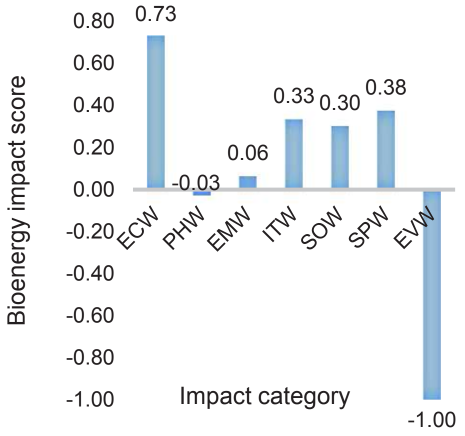

Figure 2a. The bioenergy production system's social impacts on the workers: ECW – Economic wellbeing; PHW – Physical wellbeing; EMW – Emotional wellbeing; ITW – Intellectual wellbeing, SOW – Social wellbeing SPW – Spiritual/cultural wellbeing; EVW – Environmental wellbeing.

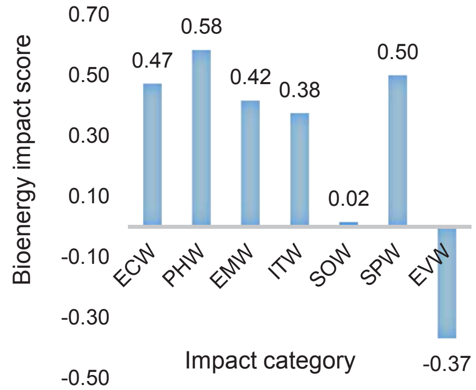

Figure 2b. The bioenergy production system's social impacts on the neighbouring community: ECW – Economic wellbeing; PHW – Physical wellbeing; EMW –Emotional wellbeing; ITW – Intellectual wellbeing; SOW – Social wellbeing; SPW – Spiritual/cultural wellbeing; EVW – Environmental wellbeing.

The sLCA Interpretation

According to ISO 1440/44, we are to examine the results obtained from lifecycle inventory and lifecycle impact assessment for interpretation of the results. An examination of the lifecycle inventory results in Tables 1 & 3 and lifecycle impact assessment results illustrated in Fig. 2a–2c revealed economic well-being, social well-being, emotional well-being and environmental well-being as significant issues. Positive values results are indications of beneficial social impacts while results with negative values are indications of adverse effects of the bioenergy production system on the stakeholder.

Fig. 2a–2c showed that the bioenergy production system will negatively affect the environmental wellbeing of the three categories of stakeholders unless some definite steps are taken to prevent it.

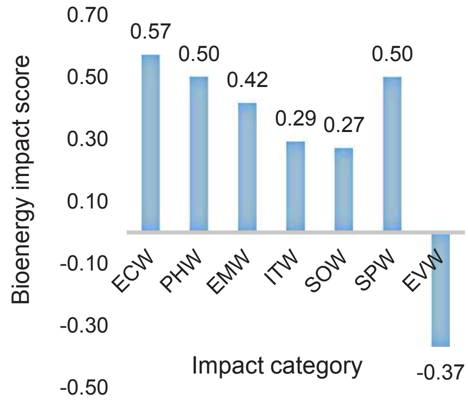

Figure 2c. The bioenergy production system's social impacts on the value chain: ECW – Economic wellbeing; PHW – Physical wellbeing; EMW – Emotional wellbeing; ITW – Intellectual wellbeing; SOW – Social wellbeing; SPW – Spiritual/cultural wellbeing; EVW – Environmental wellbeing.

Comparison of the three figures showed that employees at the bioenergy facility will be the most negatively affected of the three groups. In addition, it could be seen that the bioenergy facility will positively affect the economic wellbeing of all the three stakeholder groups. Employee will feel the positive economic impact more than the other two groups.

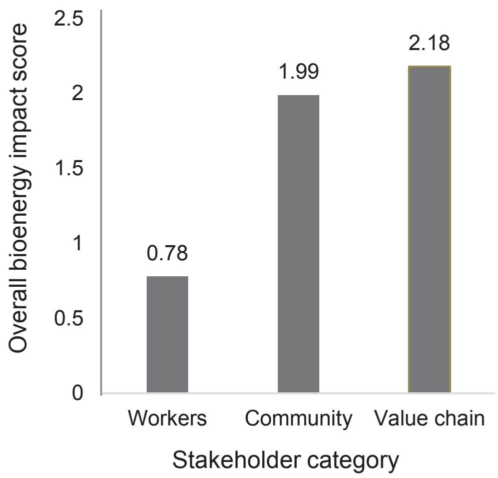

Figure 3. Overall social sustainability performance of the bioenergy system on the three categories of stakeholders.

Moreover, a look at the bioenergy facility's performance in other social dimensions showed that the employees will be negatively impacted physically and slightly positively impacted emotionally. Comparison of the facility's impacts on the three groups showed that apart from the environmental aspect, the neighbouring community and the value chain would benefit from the bioenergy facility in all social sustainability aspects. However, the value chain actors stand to benefit more than the neighbouring community. The implication of the overall social impact assessment score being positive is that the bioenergy production system is generally beneficial to these three categories of stakeholders in the (Lagos area) situation under consideration. These results also showed that the value chain would benefit most by implementing the bioenergy production project. This will be followed by the community and then the employees.

Further examination of the results showed economic wellbeing as the best social benefit of the bioenergy production system on workers, the community and the value chain across the board while environmental wellbeing is the most challenging adversarial social impact of the bioenergy production system.

CONCLUSIONS

This study revealed potential social impacts of bioenergy production systems in the African setting. It showed that establishment of bioenergy production systems in Africa will generally have positive social impacts on the employees, the community and the value chain. In addition it showed that environmental well-being is the only aspect of social concern that would need to be addressed to eliminate undesirable impacts of a bioenergy facility in Africa. Moreover, the study demonstrated that social lifecycle assessment is a useful technique for evaluating the social sustainability of system or an activity. The contribution of this study include its articulation of various social issues affecting bioenergy production system in a developing country. The study also provided a set of metrics for the assessment of various dimensions of human wellbeing as it pertains to bioenergy production system.

Results of this study provides some insight to social aspects of bioenergy production system that policy makers, investors and developers in that part of the world should pay close attention to, in order to eliminate or minimize unpleasant consequences of operating the bioenergy facility at the location. It is believed that the result of the study would spur responsible regulators to develop laws that would forestall the occurrence of the highlighted potential problems while promoting the positive impacts of the system. In addition, this study further increased the number of social sustainability studies carried out on products, processes and systems in Africa, especially Nigeria. This study would be a good reference for future sLCA studies on other products, processes and activities.

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