ENHANCING THE ENVIRONMENTAL PROFILE OF AN AFRICAN COTTON TEXTILE THROUGH BIOWASTE RECOVERY AND VALORIZATION

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Abstract - *The African Kitenge[1] is a resource intensive cotton-based textile product having profound popularity and widespread use, especially in the vast sub Saharan Africa. Kitenge is made of 100% cotton and for every kilogram of Kitenge produced in a textile factory, 3.96 kilograms of cotton have to be produced at the farm level with concomitant generation of about 10.33 kilograms of biowaste. The generation of such an amount of biowaste demands closer attention owing to the inherent adverse potential consequences to the environment. In the present study, the enhancement of the environmental profile of a typical African cotton textile popularly known as Kitenge is investigated. The assessment is carried out considering three alternatives in which biogas and nutrient rich digest are produced and used to replace different proportions of fossil fuels and mineral fertilizers in the Kitenge production chain. The assessment is performed using the life cycle sustainability assessment methodology based on the ISO 14040 and 14044 principles. The environmental assessment metrics employed in the study include the Intergovernmental Panel on Climate Change with a timeframe of 100 years and the cumulative energy demand. It is observed that valorization of about 50% of the biowaste from Kitenge production has the capacity to offset the Kitenge's carbon footprint and cumulative energy demand by up to 25% and 37% respectively. These results unveil interesting insight for sustainable management and branding of the African Kitenge.*

Key Words: Cotton textile, biowaste valorization, carbon footprint, cumulative energy demand.

1.INTRODUCTION

In Africa, wax prints are referred as Kitenge, an ever in vogue textile product popular in almost all the African countries. The African Kitenge (Figure 1) is a high ethnic value - multicolored wax print that represents various moods, culture and tradition of the native African people. Besides, Kitenge is an effective communicative clothing that differs from other communication gadgets in that it does not have to integrate a number of different technical elements such as control interfaces, sensors, data processing devices, etc. [1] but instead makes use of simple artwork and or literature as a means of communication between the wearer and the surrounding people. The Kitenge garment is typically unisex by nature and it is worn by either simply wrapping it over the body or by tailoring it into a custom designed dress. Being made from 100% cotton, the garment is effective against perspiration [2, 3] and suits the hot environment of Africa besides keeping alive the traditional sentiments in the minds of the African people [4]. Owing to the diversity of the processes preceding the finished Kitenge as well as its profound popularity and widespread use, the sustainability assessment of the African Kitenge is therefore warranted so as to identify any potential sustainability hot spots besides informing its prudent management. The Kitenge production is a component of the cotton system in Kenya that is broadly composed of cotton farming, ginning and transformation (spinning, weaving and refining) in a textile factory.

[1] In this work the words "African kitenge" and "Kitenge" are used interchangeably.

Fig -1: The African Kitenge subject to biowaste valorization assessment [5].

1.1 Cotton Production and Waste Management

Cotton farming in Kenya is predominantly carried out in the country's coast, eastern and western regions by small-scale farmers whose farms mostly range from 0.5 to 5 acres. Generally, the estimated potential land for cotton farming is over 400,000 hectares capable of producing over 270,000 bales of cotton lint per annum through rain-fed cotton production. The harvested cotton is transported by road to the ginnery where it is mechanically processed to get rid of trash (cotton gin waste) and to separate the cotton lint from the seed. The ginned cotton is transported by road to the textile factory where it is subsequently spun into yarn and then woven prior to being subjected to various refining processes before it is finally deemed to be a finished Kitenge. Waste management is a significant problem facing the cotton industry, for example, at the ginning stage about 40 –147 kg of cotton gin waste is produced per bale of cotton (227 kg) [6]. This waste is normally disposed off by means of combustion in dumpsites thus presenting health and environmental problems. Furthermore the entire cotton transformation process in a textile factory is associated with substantial material and energy consumption [7]. Hence it is prudent besides being a worthwhile Corporate Social Strategy for Kitenge producers to track its impacts on the environment. However the impact tracking ought to be through suitable indexes that can be easily interpreted by different stakeholders [8]. With this regard, substantial in-depth sustainability assessment is warranted. However such investigation can be of greater value if an effort is put first, to integrate the cotton system so as to present comparable and comprehensive results, and secondly, to strive to maximize the utilization of the entire biomass and resultant biowaste encompassed in the Kitenge chain.

1.2 Cotton Biowaste Valorization

Generally, biowaste valorization to produce energy from many agricultural residues has been carried out in the in the last decade [9 - 17]. However, little attention has been paid to the cotton production chain over the same period [6, 18]. Data on cotton biowaste valorization is even more scarce [19]. Thus, there is a need to evaluate the added potentials of the Kitenge waste.

The objective of this study was therefore to evaluate the implications of cotton biowaste valorization to the environmental profile of the African Kitenge. The study is based on a cradle to gate case study of a typical Kitenge production chain (Figure 2) in Kenya that consists of cotton farming, ginning, spinning, weaving and refining to produce a finished Kitenge. The assessment is undertaken in line with the Life Cycle Assessment (LCA) methodology based on the ISO 14040 and 14044 principles [20, 21]. The production of Kitenge is associated with resource and energy inputs as well as various emissions to air, soil and water.

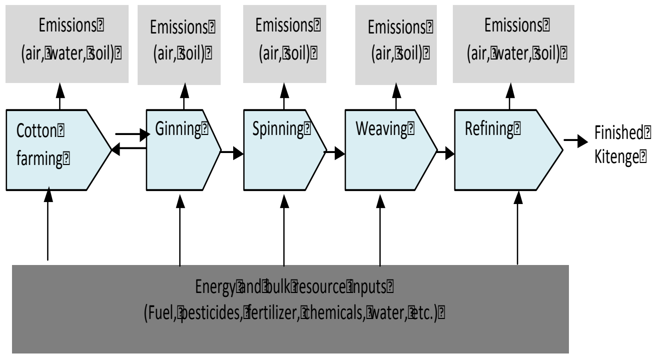
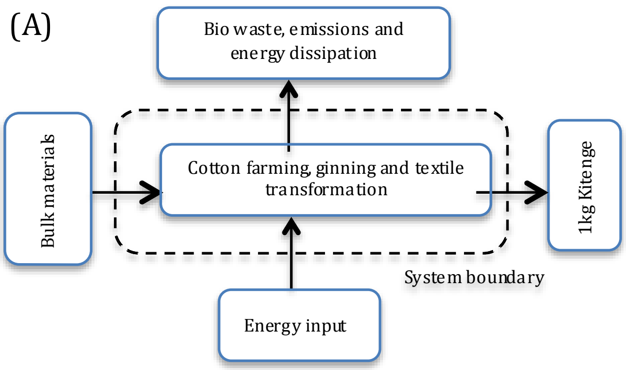


Fig -2: Resource flows and emissions in the Kitenge production chain system

2. MATERIALS AND METHODS

The present study emanates from data collected from a textile factory in Kenya that integrates cotton farming in its operations besides having Kitenge as one of its niche products. The environmental profiling was done by means of Life Cycle Analysis (LCA) based on the ISO 14040 and 14044 environmental management standards [20] pertaining to the goal and scope definition, inventory analysis, impact assessment and interpretation). The LCA was carried out using SimaPro software and the Ecoinvent 2.2 database [22, 23]. The goal of the study was to employ LCA concepts to evaluate the environmental implications of biowaste valorization in the production of African Kitenge based on a typical case study of Kitenge production in Kenya. The simplified system boundary for the Kitenge LCA study (Figure 3) consisted of "cradle to gate" which entailed bulk raw material extraction, cotton farming, ginning and textile transformation (spinning, weaving and refining) to produce the finished Kitenge. The functional unit for the study was therefore the production of one metric kilogram of Kitenge. The marketing, sales, usage and end of life scenarios of the Kitenge were excluded from the system boundary.



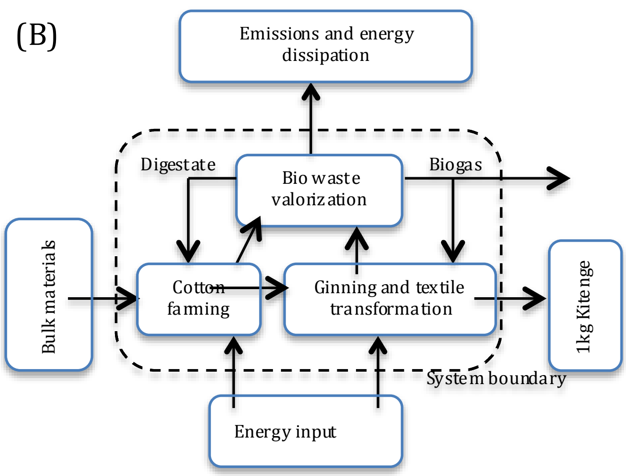


Fig - 3: Simplified system boundary for the production of the African Kitenge showing present scenario "A" and alternative scenario(s) "B" with expanded system boundary to incorporate biowaste valorization through biogas and nutrient rich digestate production

2.1 Inventory analysis

All the resource and emission flows (Table 1) into the system boundary were identified and quantified for each unit process of the Kitenge production chain. The inventory was therefore carried out in a manner that reflects the typical situation for Kitenge production in Kenya. Data gaps especially for air emissions were however filled using secondary data gathered from literature [23]. In general, for every woven and refined part of Kitenge, correspondingly 1.01, 1.27 and 3.96 parts were respectively required to be produced at spinning, ginning and farming stages with concomitant generation of about 10.33 kilograms of biowaste.

Table -1: The Kitenge life cycle inventory analysis.

Unit Process	Unit Process Exchanges	Details	Units	Quantity	Source of data
FARMING	Reference Product				
	cotton fibers (farm gate)	seed cotton	kg	1	*
	From Nature (RESOURCES)				
	Resource/Land	occupation arable	ha a	7.73E-04	*
	Resource/in water	rain	m³	1.39E-01	*
	From Technosphere (RESOURCES)				
	Pesticides	Bulldock (Beta-Cyfluthrin)	kg	4.42E-04	*
	Fertilizer	Di-Ammonium Phosphate	kg	1.28E-01	*
		Calcium Ammonium Nitrate	kg	1.28E-01	*
	Diesel fuel	ploughing / tillage, harrowing	kg	4.34E-02	*
	Planting seeds	Cotton seeds	kg	2.57E-02	*
	To Nature (EMISSIONS)				
	Soil	Biowaste	kg	7.37E+00	*
	air/low population density	Heat	MJ	1.96E+00	**
		Dinitrogen monoxide	kg	5.12E-03	**
		Ammonia	kg	2.07E-02	**
		Nitrogen oxides	kg	1.08E-03	**
	Water/river	Phosphate	kg	3.87E-04	**
		Phosphorus	kg	3.92E-04	**
	Water/Ground	Phosphate	kg	1.24E-04	**
		Nitrate	kg	8.84E-02	**
	Soil/agricultural	Cadmium	kg	1.35E-06	**
		Chromium	kg	9.26E-05	**
		Copper	kg	-4.46E-08	**
		Mercury	kg	-6.23E-08	**
		Nickel	kg	3.07E-06	**
		Lead	kg	3.00E-06	**
		Zinc	kg	2.88E-06	**
		Cyfluthrin	kg	8.29E-05	**
GINNING	Reference Product				
	cotton fibers	Ginned Lint	kg	1	*
	From Technosphere (RESOURCES)				
	Transport systems (road)	3.5-16t lorry	tkm	2.43E-01	*
	Electricity production mix	Electricity, low voltage, KEN	kWh	5.43E-01	*
	To Nature (EMISSIONS)				
	Air/unspecified	Heat, waste	KJ	1.96E+00	**
	Soil	Biowaste	kg	2.71E+00	*
SPINNING	Reference Product				
	Spinning, cotton	Spun Yarn	kg	1	*
	From Technosphere (RESOURCES)				
	Electricity production mix	Electricity, low voltage, KEN	kWh	4.77E-01	*
	Transport systems (road)	3.5-16t lorry	tkm	2.43E-01	*
	To Nature (EMISSIONS)				
	Soil	Biowaste	kg	2.57E-01	*
	Air/unspecified	Heat, waste	KJ	1.96E+00	**
WEAVING	Reference Product				
	Weaving, cotton	Woven Kitenge	kg	1	
	From Technosphere (RESOURCES)				
	Electricity production mix	Electricity, low voltage, KEN	kWh	1.07E-01	*
	To Nature (EMISSIONS)				
	Soil	Solid waste	kg	1.00E-01	*
	Air/unspecified	Heat, waste	kJ	36.4	**
REFINEMENT (FINISHING)	Reference Product				
	refining, Kitenge	Refined Kitenge	kg	1	
	From Technosphere (RESOURCES)				
	Electricity production mix	Electricity, low voltage, KEN	kWh	4.73E-02	*
	Oil/heating systems	Light fuel oil	MJ	3.05E+01	*
		Wood fuel	kg	1.16E+01	*
	Transport systems (road)	3.5-16t lorry	tkm	1.16E+00	*
	Water supply	tap water at user	kg	24	*
	Chemicals/inorganics	Sodium chloride powder	kg	9.69E-04	*
		Hydrogen peroxide	kg	3.04E-02	*
		Caustic soda	kg	0.19487	*
		(Sodium) Silicate	kg	1.38E-03	*
		Tristearin	kg	1.45E-03	*
		Sulphonic acid	kg	2.18E-03	*
		Acrylic polymer (Thickener)	kg	9.69E-05	*
		Urea	kg	2.91E-02	*
		Amine-Cobalt PhthaloCyanine	kg	9.69E-03	*
		Hemi -Zinc chloride (Black K salt)	kg	4.84E-03	*
	Chemicals/organics				
	Washing agents	Acetic acid		4.84E-04	*
	Wastewater treatment	wastewater	m³	24	*
	To Nature (EMISSIONS)				
	Air/unspecified	Heat, waste	MJ	3.993	**

Key: * - Primary data; ** – Secondary data from Ecoinvent database

2.2 Impact assessment

The effects of resource use and emissions generated were grouped and quantified from a LCA perspective using the SimaPro 7.2 software and the Ecoinvent 2.2 database [22, 23]. The LCA modeling in terms of GHG emission and energy demand, Equations 1 and 2 respectively took cognizance of the background processes in Kitenge production such as the production of fertilizers, electricity and fuel oil using secondary data from Ecoinvent. The impact quantification in terms of global warming (Green house Gas production) and energy demand was consequently done using two environmental indicators namely CO_2 equivalent and energy equivalent respectively [23 - 25].

$$GHG_{kitenge\ prod} = \sum_j X_j.m_j \qquad (1)$$

where:

$GHG_{Kitenge\ prod}$ = Green House Gas potential of the emissions due to Kitenge production ($kgCO_2eq/kg_{kitenge}$)

X_j =characterization factor of emission j (kg $CO_{2\ eq}$/kg)

m_j =mass of emission j (kg/ $kg_{kitenge}$)

$$CED = \sum_j X_j * a_j \qquad (eq.\ 2)$$

Where:

CED = cumulative energy demand (MJ/kg)

X_j = characterization factor of resource j (MJ_{eq}/kg, MJ_{eq}/Nm^3, MJ_{eq}/m^2a),

a_j =amount of resource j (kg, Nm^3, m^2.a)

2.3 Biowaste valorization scenario formulation and assumptions

The cotton biowaste valorization scenarios in the modified cotton system (Figure 4) entailed biogas and digestate production and use at the textile factory and the farm level. The valorization scenarios were categorized into three different alternatives namely:

- B1 – biogas produced and used for domestic purposes at the farm level while the digestate is used to replace 10% of mineral fertilizers.
- B2 – biogas produced at the textile factory level where the biogas is used to replace 50 % of fuel oil consumption while the digestate is transported to the farms where it is used to replace 50% of mineral fertilizers. The remaining biogas potential is used to produce electricity but since electricity in Kenya is predominantly from renewable sources, the effect of this portion of biogas potential to Kitenge will be mainly economical.
- B3 – biogas produced at the textile factory level where the biogas is used to replace 100 % of fuel oil consumption while the digestate is transported to the farms where it is used to replace 10% of mineral fertilizers.

Under scenario B2 and B3, it is assumed that the digestate produced at the textile factory would be allowed to dry after which it is transported to the cotton collection points where farmers can pick it after delivering their cotton. Under such an arrangement, the otherwise idle capacity of the return trip for both parties is fully utilized. The biowaste valorization was structured to reflect mesophilic biogas production and nutrient recovery. The biogas production from cotton waste was carried out at ambient temperature regime [19] whereas the analysis of nutrient parameters in terms of NH4+-N, PO43--P and K+ was performed using a photometer NANOCOLOR 500D (Filter Service NV, Belgium). Specifically, the cotton waste emanating from the cotton production chain was subjected to biochemical methane potential analysis at 30°C and the methane production and nutrient recovery were profiled. Consequently, in the scenario analysis (Table 2) biowaste methane and nutrient recovery were taken into account to reflect a BMP of 0.365 m3 CH4/kg VS, 91% DM, 88% VS in DM as well as nutrient NPK content (%DM) of 0.509%, 0.257% and 0.715% respectively.

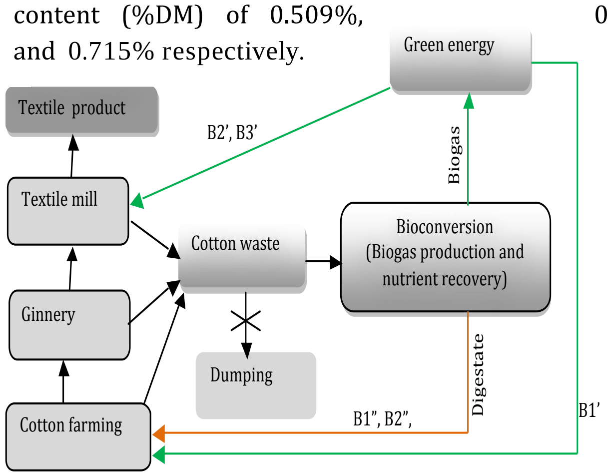


Fig -4: The modified cotton system ("B "scenario) showing elimination of dumping of biowaste to nature and incorporation of additional flows for biowaste valorization in:

(a) Scenario B1: biogas energy (B1’) and digestate (B1”) produced and used at farm level.
(b) Scenario B2 and B3: respective biogas energy (B2’ & B3’) produced and different proportions utilized at textile factory while the digestate produced (B2” & B3”) is utilized at farm level.

The study took into account 25% biowaste recovery at the farming level and 50% biowaste recovery from ginning to the refining levels. The assigned lower biowaste recovery at the farming level was attributed to the presence of higher proportion (about 50%) of woody matter in the cotton farm waste, which is deemed to present biomethanation challenges during anaerobic digestion due to the presence of recalcitrant lignin. The LCA study in this work focuses on resource and emission flows of Kitenge production in Kenya however it is assumed that the results could be valid in the larger East Africa and other African regions with Kitenge production conditions similar to that of Kenya.

Table -2: The biowaste parameters considered during the impact quantification in Kitenge production.

Parameter	Scenario			
	Reference	B1	B2	B3
Biowaste generation from farming to refining (kg/kg Kitenge)	10.330	10.330	10.330	10.330
Biowaste available (kg/kg Kitenge) (assuming 25% and 50% waste recovery at farming and ginning to refining respectively)	3.320	3.320	3.320	3.320
Methane content in the available cotton biowaste (m^3 CH_4/kg Kitenge)	0.967	0.967	0.967	0.967
Methane recovered (m^3/kg Kitenge)	0.000	0.967	0.967	0.967
Energy equivalent of available methane (MJeq/kg Kitenge)	34.610	34.610	34.610	34.610
Energy recovered at textile factory per (MJeq/kg Kitenge)	0.000	0.000	34.610	34.610
Mineral fertilizer application (kg NPK/kg Kitenge) *	0.256	0.2307	0.256	0.2307
Nutrient content of digestate (kg NPK/kg Kitenge) *	0.0253	0.0253	0.139#	0.0253
Digestate nutrients recovered for farming (kg NPK /kg Kitenge)*	0.000	0.0253	0.139#	0.0253
Mineral fertilizer replaced by digestate (%)	0.000	10.000	50.000	10.000

* NPK nutrient content by mass based on Nitrogen + Phosphorus + Potassium.
#Projected NPK nutrient content of the biowaste if 100% waste recovery is achieved
$^{\beta}$50% of the recovered energy is reserved for electricity generation

2.4 Interpretation

The results emanating from the impact assessment were analyzed and interpreted, based on which conclusions and recommendations were drawn for the possible improvement in the management of the African Kitenge. Pertaining to energy demand, generally the magnitude of energy demand (MJ) expresses the minimum external work needed to be done on the environment to obviate the depletion of energy [9, 14] hence the more energy demand a resource use carries, the more it deviates from the natural environment. The life cycle of Kitenge involves the consumption of an array of resources however the energy indicator [24] raises a unified thermodynamic metric for objectively evaluating resources and environment. On global warming [13], the carbon footprint embodied in the various Kitenge emissions offers a fairly reliable measure of the potential for typical environmental harm and represents the ecological status of the Kitenge system.

3. RESULTS AND DISCUSSIONS

3.1 Global warming

The current practice (reference scenario) of Kitenge production is associated with net emission of 15.58 kg CO_2 eq/kg product over the cradle to gate production chain (Figure 5) of which fiber farming and refining contribute about 73% and 22% respectively. The carbon footprint of the Kitenge can be equated to the environmental impact of driving an average car for 63 Km in a highway or the total carbon sequestered by three healthy trees per year [26, 27] implying that enhancing forest cover could provide a good counter footprint for Kitenge production. The main background processes (Figure 6) behind the carbon footprint [24] of Kitenge due to farming are the manufacture of diammonium phosphate as P_2O_5 and ammonium nitrate both of which have a combined contribution of about 33%. On the other hand the main background processes behind the carbon footprint of Kitenge due to refining process are production of electricity and light fuel oil both of which have a combined contribution of about 22%.

Valorization of the cotton biowaste for biogas and digestate production at farm level and at textile factory is observed to have different positive implications for the Kitenge production chain. When the biogas is produced and used at the farm level and digestate is applied in the cotton farms to replace 10% of the mineral fertilizers (scenario B1), the carbon footprint of Kitenge production is seen to decline by 7% (from 15.58 to 14.45 kg CO_2 eq/kg Kitenge). The observed decline in the carbon footprint of Kitenge is principally due to the decline of the carbon footprint of the farming process that declines from that of the reference scenario by 10% owing to the lower mineral fertilizer usage. This observation implies that usage of digestate at the cotton farms has a positive influence on the environmental profile of the Kitenge chain. On the other hand, when the biogas is produced and used at the textile factory to replace 50% of fuel oil while the digestate is transported to the cotton farms where it replaces 50% of mineral fertilizers (scenario B2), the carbon footprint of Kitenge production is seen to decline from the reference scenario by 45% (from 15.58 to 8.59 kg CO_2 eq/kg Kitenge). Another important feature of scenario B2 is the decline of the carbon footprint due to refining which declines from that of the reference scenario by 41% (from 3.35 to 1.99 kg CO_2 eq/kg Kitenge). Finally, when the biogas is produced and used at the textile factory to replace fuel oil (100% replacement) while the digestate is transported to the cotton farms where it replaces 10% of mineral fertilizers (scenario B3), the total carbon footprint of Kitenge production is seen to decline from the reference scenario by 25% (from 15.58 to 11.73 kg CO_2 eq/kg Kitenge). Another key feature of scenario B3 is the decline of the carbon footprint due to refining which declines from that of the reference scenario by 81% (from 3.35 to 0.62 kg CO_2 eq/kg Kitenge).

From the foregoing discourse, it can be surmised that possible ways to diminish the net impact of Kitenge production to the environment include enhancement of the counter footprint through investment in natural capital protection (increasing forest cover, pasture land, marine reserve, etc.) or cascading the utilization of cotton biomass to incorporate valorization of the biowaste. Whereas the benefits of natural capital protection cannot be gainsaid [27], it is also clearly demonstrated from these results that cascading the usage of cotton biomass to incorporate valorization of cotton biowaste for biogas and digestate production could potentially improve the environmental profile of Kitenge.

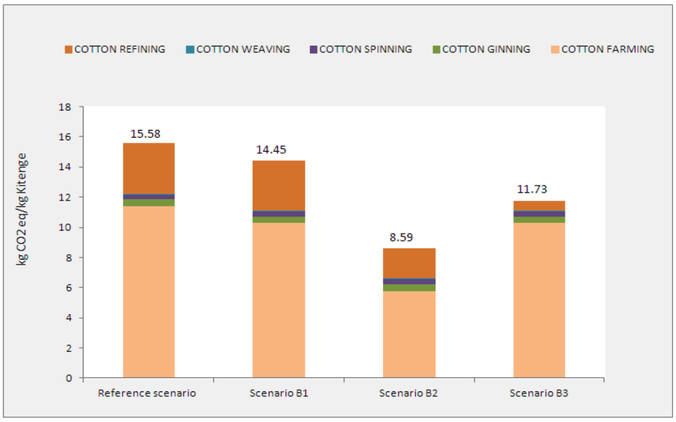


Fig -5: Carbon footprint (Kg CO_2 eq/kg Kitenge) in Kitenge production comparing the reference scenario (current status) with alternative scenarios B1, B2 and B3 (for different configurations of biowaste valorization).

3.2 Energy demand

The Cumulative Energy Demand (CED) in the Kitenge production chain (in the reference scenario) is computed as 120.5 MJeq/kg Kitenge (Figure 7). Noticeably, the contribution of farming and refining processes to the CED are respectively 46% and 43% thus underpinning the energy intensiveness of the two processes. The CED at the farming level translates to 13.98 MJ/kg of cotton produced. Other researchers [28] have reported comparable values (16.67 MJ/kg) of cumulative energy use in cotton production. However it is also reported that the net return per kilogram of cotton produced is insufficient to cover costs of production hence underscoring the need for exploring other options for valorizing the cotton biomass. The main background processes impacting heavily on the CED of Kitenge production (Figure 8) are seen to be the production of calcium ammonium nitrate fertilizer and light fuel oil both of which have a combined contribution of 60% (26% and 34% respectively). It is therefore envisaged that a reduction in the usage of mineral fertilizer and the fuel oil in the subsequent scenarios could have a positive influence in the CED of Kitenge production.

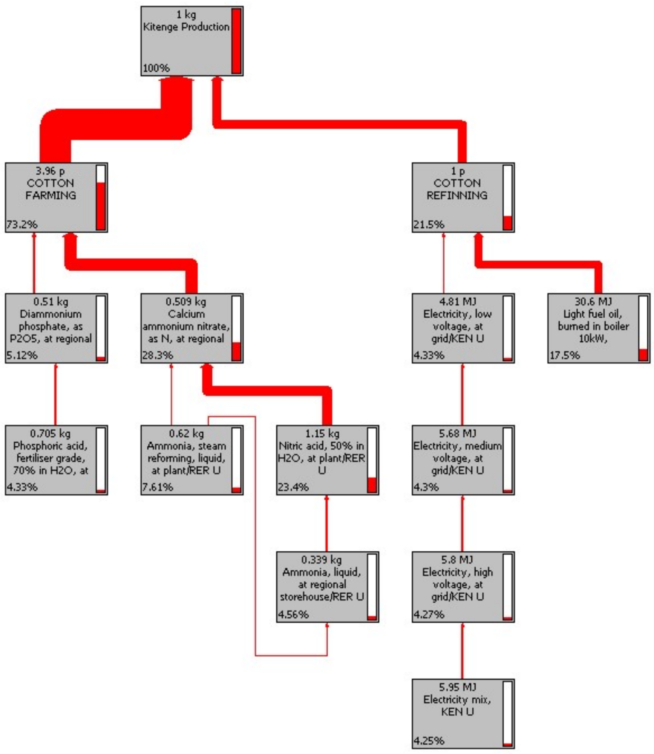


Fig -6: Unit process contribution to the carbon footprint of Kitenge production in the reference scenario at 4.25% node cut-off.

The valorization of biowaste for biogas production and use at the farm level while concomitantly the digestate is used to replace 10% of fertilizers (scenario B1) is observed to reduce the CED of the Kitenge production chain by about 4% (from 120.57 to 116.29 MJ/kg Kitenge). Noticeably under scenario B1, it is also observed that the CED at farming level declines by 8% from the reference scenario (from 55.38 to 51.11 MJ/kg Kitenge). Such a reduction in CED could potentially translate into energy savings by the farmers. Besides, there are other benefits that accrue to farmers owing to the usage of biogas such as cleaner fuel, reduced expenditure on fuel costs and reduction on deforestation owing to reduced usage of firewood.

When the biogas is produced and used at the textile factory while the digestate is transported to the cotton farms under scenario B2 and B3 substantial reduction in the CED is observed. Under scenario B2, the CED is observed to drop by 35% (from 120.57 to 78.79 MJ/kg Kitenge). Moreover in this scenario, the CED at the cotton refining process is noticeably seen to drop by 40% (from 51.65 to 31.23 MJ/kg Kitenge). On the other hand under scenario B3, the highest drop in the CED is observed, that is by 37% (from 120.57 to 75.45 MJ/kg Kitenge) while for the cotton refining process the drop in CED is as much as 79 % (from 51.65 to 10.81 MJ/kg Kitenge). The observed drop in CED in scenario B2 and B3 can be attributed to the effect of replacing light fuel oil with biogas. These results therefore show that valorization of cotton biowaste for biogas and digestate production could potentially improve the environmental profile of the Kitenge.

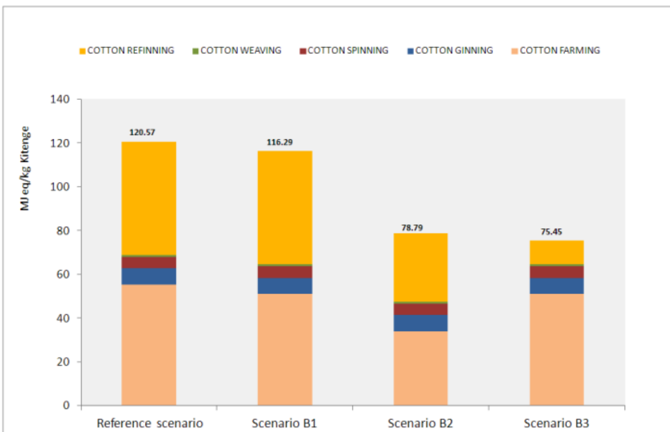


Fig -7: Cumulative Energy Demand (MJ eq/kg Kitenge) in Kitenge production chain comparing the reference scenario (current status) with alternative scenarios B1, B2 and B3 (for different configurations of biowaste valorization).

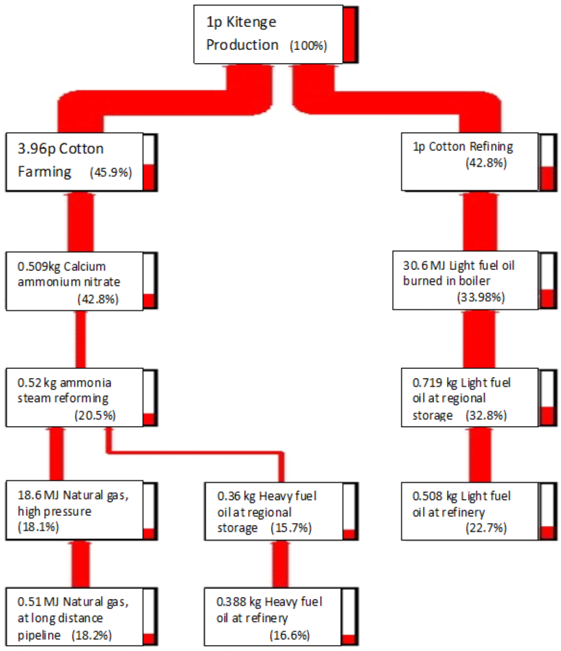


Fig -8: Unit process contribution to the Cumulative Energy Demand in Kitenge production in the reference scenario at 15 % node cut-off.

4. CONCLUSIONS AND RECOMMENDATIONS

This study has considered the implication of biowaste valorization to the environmental profile of the African Kitenge. The current practice (reference scenario) of Kitenge production is associated with a carbon footprint of 15.58 $kgCO_2eq/kg$ product and a corresponding cumulative energy demand of 120.5 MJ eq/kg product. The major background processes impacting heavily on the environmental profile of Kitenge are found to be the production of mineral fertilizers and light fuel oil hence it can be concluded that intervention measures targeted at the two background processes could be of immediate benefit to the environmental profile of Kitenge. The incorporation of biowaste valorization in the Kitenge production chain to yield biogas and digestate under the three alternative scenarios (B1, B2 and B3) is noted to yield improvements of up to 45% and 37% for carbon foot print and cumulative energy demand respectively. It can therefore be further concluded that incorporation of biowaste valorization in the Kitenge production chain can improve the environmental profile of Kitenge. In addition, since the usage of the digestate at the cotton farms could lead to other economic benefits not tackled in the present study, further work should endeavor to evaluate the economic consequences of biowaste valorization to the Kitenge production chain.

ACKNOWLEDGEMENT

This work has benefited with funds from Hivos, The Netherlands and the Flemish Inter-University Council - Institutional University Cooperation, Belgium. The authors are grateful for the financial support. Contribution of staff members from the MIT department at Moi University and Rivatex (EA) limited in the data collection is also appreciated.

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