sustainability

Article

Streamlined Social Footprint Analysis of the Nascent Bio-Pellet Sub-Sector in Zambia

Ismail Gannan, Hussam Kubaji, Workson Siwale, Stefan Frodeson and G. Venkatesh *

Energy and Environment Group, Department of Engineering and Chemical Sciences, Karlstad University, 65188 Karlstad, Sweden
* Correspondence: venkatesh.govindarajan@kau.se

Abstract: Climate change concerns have goaded countries toward seeking renewable energy options (bio-energy being one of them) to replace/supplant the conventional fossil-fuel alternatives (coal, oil and natural gas) commonly used now. Fuel pellets—at the confluence of the forestry, agriculture, waste management and bio-energy sectors—when produced from biomass residues, serve the dual purpose of ensuring energy security and environmental sustainability. By valorizing more and more organic wastes to bio-energy products, one could, to use the old adage, 'kill two birds with one stone'. Social LCA is a method used to analyze a very wide range of social issues associated with the stakeholders in a value chain—workers, local community dwellers, society, global consumers, banks, investors, governments, researchers, international organizations and NGOs. In this analysis, the authors commence with a highly focused, niche literature review on the social dimension of sustainability in the African energy/bio-energy sector. The streamlined social footprint analysis inspired by the relatively lesser number of such studies for this sector in Africa is not a novel addition per se to the S-LCA knowledge base. The purpose of the application is to shed light on something in Zambia that must be understood better so as to bring about much-needed alterations in the direction of sustainable development. While the questions addressed to four different groups of stakeholders encompass a clutch of sustainable development goals, gender equality (SDG 5) and the need for greater interest on the part of governments and investors (SDG 9) to look at sustainable alternatives to the status quo stand out as concerns that need to be tided over. This paper and the streamlined social footprint analysis carried out are all the more relevant and timely when one considers some key changes that have happened in Zambia over the last five years—the implementation of the National Energy Policy in 2019 and the creation of the Ministry of Green Economy in 2021. These are verily harbingers of positive change auguring well for future developments in the bio-energy (and bio-pellets) sector, not just in Zambia but, by way of emulating and learning, in other countries on the continent.

Keywords: bio-energy; bio-pellets; bio-wastes; circular bio-economy; S-LCA; streamlined social footprint analysis; sustainable development goals (SDGs); Zambia

Citation: Gannan, I.; Kubaji, H.; Siwale, W.; Frodeson, S.; Venkatesh, G. Streamlined Social Footprint Analysis of the Nascent Bio-Pellet Sub-Sector in Zambia. *Sustainability* **2023**, *15*, 5492. https://doi.org/10.3390/su15065492

Academic Editors: Idiano D'Adamo and Barry D. Solomon

Received: 6 February 2023
Revised: 15 March 2023
Accepted: 16 March 2023
Published: 21 March 2023

1. Introduction

It is well-known by now that climate change concerns have goaded countries toward seeking renewable energy options to replace/supplant the conventional fossil-fuel alternatives commonly used now. 'Renewable', whether a part of a circular bio-economy [1] or otherwise, is considered to be 'clean' from an environmental perspective when it comes to the truncation of greenhouse gas (GHG) emissions. In other words, resorting to renewable energy alternatives (bio-energy being among them) is an effective way to truncate the GHG footprint/s of societies (and economies) and introduce carbon neutrality and eventually aspire for a degree of carbon negativity. Fuel pellets, which are at the confluence of the forestry, waste management and energy sectors, when produced from biomass (organic wastes, wherever possible to be availed of), serve the dual purpose of ensuring energy security and environmental sustainability. An insufficient supply of energy in poor societies is often caused by a lack of ability to pay, and this depresses productivity and incomes, resulting in a so-called 'poverty trap'. An additional goal ought to be to make energy affordable to more and more people over time. These purposes are integral to the sustainable development goals (SDGs) set for 2030 by the United Nations for the countries of the world. Attaining these goals is challenging in a situation characterized by rapid urbanization. This has, on the one hand, led to an increase in the generation of wastes (organic and otherwise), while on the other hand, it has resulted in a rise in the demand for energy (heat, electricity and transport fuels). One often hears that opportunities are hidden in the problems themselves, and it is true in this case too. The mountains of organic wastes can be looked upon as 'mines' of raw materials for energy production—bio-energy to be more precise.

1.1. Pellets vs. Charcoal

Bio-energy, which traces its origin to virgin feedstock from forests and fields cultivating energy crops, often raises questions regarding the food–fiber–fuel conflict [2], which needs to be meticulously managed. By valorizing more and more organic wastes to bio-energy products, one could, to use the old adage, 'kill two birds with one stone'. Quite clearly, handling one problem automatically finds a solution for another. Diverting some organic waste in a circular bio-economy to be valorized as fuel pellets helps to supplant charcoal in the households of developing world countries. Charcoal is less energy-efficient vis-à-vis fuel pellets, and its production and use are associated with a range of adverse environmental and health impacts, as elaborated by Hamatui and colleagues [3]. Thereby, a given service (cooking, for instance) can be performed with relatively lesser primary biomass, when charcoal is replaced with pellets. The decrease in environmental health impacts referred to is all the more conspicuous when residual (waste) biomass is blended into the raw material mix, wherever and whenever possible.

1.2. Social Acceptability as Important as Environmental Sustainability

The adjective 'clean' or rather the aspect of 'cleanness' is twofold, social and environmental, as pointed out in a review of S-LCA publications by Venkatesh [4]. The social dimension is much more broad-based and multi-pronged than the latter. It must, however, be pointed out that the environmental dimension of 'cleanness' must include more than just the reduction in the climate-change-inducing GHGs. The social aspect is researched and understood by means of S-LCA, a tool from the sustainability toolkit, which vis-à-vis its elder cousin, E-LCA, is still in its infancy [5]. S-LCA [6] is a method used to analyze a very wide range of social issues associated with the stakeholders in a value chain—workers, local community dwellers, society, global consumers and other value-chain actors such as banks, investors, local, provincial and national governments, media, researchers (academic and otherwise), international organizations (such as the arms of the United Nations, for instance) and non-governmental organizations (NGOs). A value chain may be wholly bounded by the national boundaries but may also have investors and researchers from abroad, providing the financial and knowledge capital, respectively. S-LCA, at the time of writing, is still an emerging field of study, which permits researchers to define, develop, refine and propose new approaches and methodologies based on the broad framework laid out by the United Nations Environment Programme and the Society for Environmental Toxicology and Chemistry (UNEP and SETAC, 2013) [7] and apply the same to different value chains in different sectors in different regions in the world. 'Energy and Fuels' is one of the many sectors the aforesaid review article [4] dwelt upon, and four S-LCA papers were discussed in that sub-section. Since then, over the last 4 years, more S-LCA-oriented publications focusing on the energy sector may certainly have been published.

1.3. Motivation for the Study

While studying the origins of the publications in the review, Venkatesh [4] identified articles originating from Uganda [8], Ghana [9], Mauritius [10], South Africa [11] and Algeria [12] (though none focused on the energy sector per se). Only 7% of academic publications on energy have investigated Africa, and of these, it goes without saying, those with a focus on social aspects (SLCA or otherwise) are few and far between, as observed by Röder et al. [13]. This is despite the fact that Africa is the region with the lowest energy access in the world and has been facing gargantuan challenges in this regard, which hinder socio-economic development. In this analysis, the authors commence by training the lens on a focused literature review on the social dimension of sustainability in the energy sector in Africa.

The reason and the motivation stem from the fact that the department the authors belong to has an ongoing partnership with industry professionals and researchers in Ghana, Gabon, Kenya, South Africa and Zambia when it comes to applied research in the area of pellets. While there is a general tendency on the part of the common man to generalize issues in what is referred to as the 'Dark Continent', it is mandatory to throw light on the nuances and differences that prevail in these countries. These five surely cannot be clustered in any one region in Africa. Ghana and Gabon are located in western Africa, Kenya is in the east, and the other two are in Southern Africa. With the medium-term intention to study the social aspects related to the bio-energy sector in general (and the pellet sector in particular) in these countries, the authors (one of whom hails from Zambia) were motivated to embark on this streamlined social footprint analysis of the nascent fuel pellet industry in Zambia. Some light needs to be shed on the word 'footprint' here. It has a negative connotation when used in connection to environmental sustainability. A bigger environmental footprint is undesirable and necessitates truncation. In other words, an environmental footprint is a measure of the 'adverse' environmental impacts—the environmental 'bads', if one may. However, a social footprint can be interpreted as a measure of the social 'goods'—the extent of well-being and prosperity in society. This implies that a larger social footprint (indicated by a higher number, which in the case of this paper would be a semi-quantitative measure in the range of 0–4) is indicative of more social 'goods'. It is thereby desirable, and decision making can focus on finding ways and means to increase it further. Indeed, all along, one would need to strike a fine balance among the three dimensions of sustainable development: social well-being, economic feasibility and environmental sustainability.

What follows is a focused literature review, an account of Zambia and its energy sector and a brief description of the potential organic wastes that could be circularized (or valorized, rather) to produce fuel pellets. It can be mentioned at the outset that the authors make no claim as regards the comprehensiveness of the literature review, apart from the fact that it is focused on S-LCA studies in the energy sector in Africa. The methodology—which, the authors would like to clearly state at this juncture, is not a novel addition per se to the S-LCA knowledge base—is explained and is followed by the presentation of the results, which are subsequently discussed. The authors humbly acknowledge the subjectivity of the results presented and posit this analysis as something that will serve as the basis for further research to add to the knowledge that would subsequently assist decision making to hasten the progress toward the sustainable development goals (SDGs). Also to be noted here is the fact that the environmental and economic aspects of sustainable development are not studied in this paper.

2. Literature Review and Background Summary

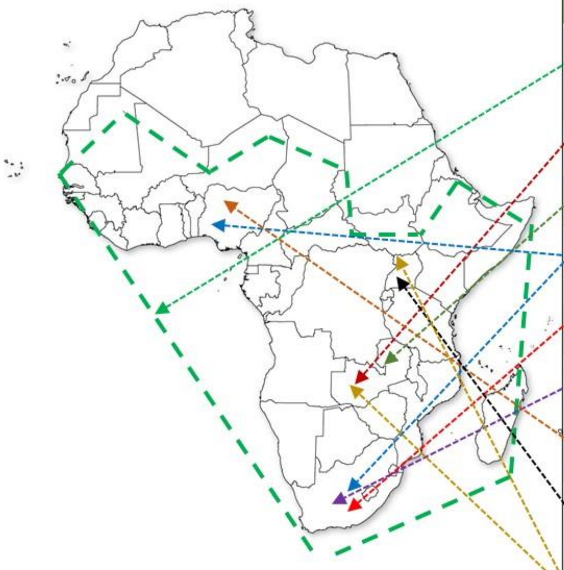
2.1. Social Aspects of the Energy/Bio-Energy Sector in Africa

It would be apt to commence this section with Röder et al. [13] who adopted a pan-sub-Saharan-African focus. Observing that biomass in the form of fuelwood and charcoal currently provides close to 5700 PJ of heat energy annually in sub-Saharan Africa as a whole (48 countries in all; refer to Figure 1), they point out that the number of sub-Saharan Africans lacking access to clean cooking fuel (SDG 6) will increase in the years to come if no suitable measures are undertaken. To avoid deforestation (SDG 15), which inevitably happens when the dependence on fuelwood and charcoal does not decrease, harness the synergies with agriculture (which is the dominant economic sector in most of the sub-Saharan African countries) and generate employment opportunities in the process in a circular bio-economy of the future (SDG 8), the authors named maize stalks and cobs, cassava stalks, rice husk and straw, cow slurry, chicken manure and vegetable and fruit wastes from fields and orchards as residues that could be collected and valorized into heat and electricity. However, they emphasize the indispensability of participatory decision making (SDG 17) and an inclusive business model that would take a host of stakeholders on board and set the ball rolling on more 'South–South collaborations' to replace 'North–South implementations'.

While the lens is trained on bio-heat and bio-electricity from organic residues in [13], Duvenage et al. [14] focused on bio-diesel (which may, of course, also be used for transportation, in addition) extracted not from organic wastes, but from the tough-and-hardy, perennial multipurpose *Jatropha* crop cultivated for that purpose. *Jatropha*, by virtue of being perennial, may be a guaranteed source of income (albeit lesser) to the marginalized poor farmers in the country (SDG 1 and the Leave No One Behind principle). If properly implemented, with a focus on minimizing trade-offs and maximizing synergistic benefits related to the SDGs, the authors are of the view that an integrated bio-diesel sub-sector—a 'Made and Used in Zambia' model serving the domestic market—may enable local Zambians (both men and women) to economically empower themselves (SDGs 5 and 8) through education and knowledge, improve self-sufficiency in clean and affordable energy (SDGs 6 and 13) and enhance their lifestyles in the process. It must, however, be remarked, as Duvenage and co-authors [14] did, that if the investors (value-chain actors) are foreign (non-Zambian African or non-African), the risk that locals would be excluded from the decision-making process and that shareholders would not be interested in their welfare must be forestalled and eliminated.

Women's empowerment, when it comes to access to 'smart' and clean energy in Zambia (SDGs 5 and 6), is the focus and leitmotif of Wampata and Mwanza [15]. These authors advocate a gradual transition from climate-change-inducing (SDG 13) kerosene and diesel and health-impacting (SDG 3) and deforestation-accelerating (SDG 15) fuelwood and charcoal to cleaner, renewable solar energy (SDG 6). Here, one may wish to add pellets fashioned out of biomass residues also, working shoulder to shoulder with solar energy as an alternative or a stop-gap whenever needed. Women and girls, it goes without saying, spend a lot of time daily collecting fuelwood, and efforts must be undertaken to spare them this burden. This will enable the latter to focus more on their education, thereby contributing to SDG 4. If solar energy or pellets could facilitate that change, women will play a key role in the sustainable development of countries in Africa, in general [16].

If Röder and colleagues [13] considered biomass residues from agriculture and forestry as valorizable sources for bio-energy, Dunmade [17] looked at urban metabolism and the inherent potential in household and market wastes (rotten and unsold fruits and vegetables) in Lagos (Nigeria) and Johannesburg (South Africa) to be sources of heat and electricity via biogas production through the anaerobic digestion route (SDGs 6 and 11). In the S-LCA performed in this paper, the authors defined 7 equi-weighted criteria and 17 equi-weighted indicators in all to analyze three stakeholder groups—workers, local community and value-chain actors—by grouping together the Nigerians and South Africans into each of the three. The probability–severity approach adopted using the SIMSaW model showed that the employees at the bio-energy facilities have the lowest social footprint (score, in other words), with their physical and emotional well-being (SDG 3) being drastically affected. The local community stakeholder group registered a low score for the criterion of social well-being. However, it turns out that from an economic point of view, employment and income generation are looked upon as much-needed positives (SDG 8). It is recommended that with a little more focus on the welfare enhancement of employees and community members, the overall sustainability of this arm of municipal solid waste management in a circular bio-economy can be significantly improved [17].



Source	Where?	What and how?	Main SDGs
Röder et al. 2022.	Sub-Saharan Africa (48 countries)	Mass- and energy balances of biomass residues. Emphasis on socially-inclusive/participatory decision-making	#6, #8, #15, #17
Duvenage et al. 2012.	Zambia	Multi-criteria sustainability analysis (MCSA) for jatropha- biodiesel; 16 social sustainability criteria	#1, #8, #13
Wampata and Mwanza, 2021	Zambia	Women empowerment by enabling access to clean energy alternatives; survey-based study	#4, #5, #6
Dunmade, 2019	Nigeria, South Africa	SLCA of bioenergy sourced from household and market wastes through the biogas route, encompassing 7 well-being dimensions	#3, #6, #8, #11
Vera et al, 2022	South Africa	MCSA - Job creation by culling invasive alien plant species, for bio-energy and combating water stress	#6, #7, #8
Nieder-Heitmann et al. 2019	South Africa	MCSA for different sugarcane biorefinery scenarios, producing bioenergy and biochemicals	#6, #8, #9, #13
Nubi et al. 2021	Nigeria	Comparative SLCA of electricity generation from municipal solid waste for Lagos and Abuja	#6, #8, #11
Buchholz and Volk, 2012	Uganda	Critique of large-scale and small-scale bio-energy systems from a socio-economic sustainability perspective	#8, #11
Stritzke and Jain, 2021	Uganda, Zambia	Socio-economic benefits and challenges associated with solar mini-grids in rural areas of Uganda and Zambia	#3, #4, #6, #10

Figure 1. Graphical summary of the focused literature review [13–15,17–22].

Residues from agriculture and forestry are exploitable in South Africa for energy generation (in addition, of course, to organic solid wastes from urban households and markets, which were dealt with in [17]). The authors of [18] focus on the multiple benefits of culling invasive alien plants (IAPs: acacia, eucalyptus, pine, among others)—combating water stress, adding to the acreage of pastureland and cropland (SDG 2) and producing fuel pellets for bio-energy, thus enabling rural electrification (SDG 6) and taking positive steps in the direction of finding solutions to the water crisis that has been plaguing the country for some time now (SDG 7). However, there is no reference made in that paper to a market for these pellets as cooking fuel in households. They also refer to the supply-chain employment generation potential (a social 'good', SDG 8) for the region in the Eastern Cape State studied in the paper—for the removal of the IAPs, chipping/debarking, pelletization and transport and eventually for agriculture—if the land is restored to arable cropland [18]. The number of jobs this would generate (600, as reported in the paper) may seem insignificant, but in a country where unemployment and underemployment have been chronic challenges, every opportunity to generate employment and provide income to households is a desirable step in the right direction. Employment generation also figures as a social sustainability indicator in the multi-criteria decision-making analysis for sugarcane biorefinery scenarios in South Africa, generating both energy and bio-chemicals [19]. The authors of that paper recommended the inclusion of sugarcane farmers, biorefinery project developers, end-users of the bio-chemicals and the bio-energy, equipment suppliers, investors and banks, policy makers and planners at the local, provincial, regional and national levels, for a more elaborate outlook of the social footprint of biorefineries in a future circular bio-economy in the country.

While Dunamade [17] compared two cities in two different countries, Nubi and colleagues [20] restricted themselves to Nigeria. They compared the two largest cities thereof, Lagos and Abuja, in an SLCA of prospective electricity generation from municipal solid waste (MSW). Here, the authors are not talking of 100% bio-energy per se. In addition to anaerobic digestion and landfill methane gas recovery, incineration, pyrolysis and gasification are also on the anvil, and though there is a preponderance of food waste in the MSW, paper and plastics also account for smaller but not-insignificant fractions of the mix. By structuring the social footprint around 11 sub-categories and 40 indicators and selecting four stakeholder groups—workers, consumers, local community and society—they arrived at overall averaged, equi-weighted scores for the two cities. Lagos ended up with a better score (higher, as the 'footprint' here is interpreted in a positive sense) than Abuja, the latter registering a lower score in all the eleven sub-categories. Readers are aware that Abuja is the current capital city while the seat of government used to be in Lagos earlier. Further, the population of Lagos is over thrice that of Abuja.

If overseas investors gobble up the lion's share of the financial benefits arising out of bio-energy facilities in the developing world, it would amount to a form of neo-colonialism. Small-scale bio-energy systems from which the local communities derive the maximum benefits—socio-economic (SDG 8) and environmental (SDGs 13 and 15)—are what Buchholz and Volk [21] recommend for Uganda and, by extension, to other sub-Saharan African countries. The term 'participatory planning' is quite hackneyed, but it is indispensable for not just the social sustainability but also the durability of projects undertaken in the developing world in the future [13,21,22]. The authors of this Ugandan case study draw attention to the oft-unrealized, simple-but-subtle fact that even a small amount of clean and affordable bio-energy (SDG 6) provided to rural households (which are otherwise 'energy-poor') can enhance their standard of living significantly. What is true of bio-energy is also true for solar power from mini-grids, if that would be affordable to end-users and economically feasible to the suppliers, simultaneously, as pointed out by Stritzke and Jain [22] in their comparative analysis of cases from Zambia and Uganda. The authors of that publication interacted with members of cooperatives and parent–teacher associations, local women's self-help groups, local businesses, councilors, health workers, off-grid energy companies and public sector stakeholders. They warned against a possible anomaly that may result from an improperly planned roll-out of mini-grid solutions, when rural users of solar power from a mini-grid solution may have to pay over 20 times more for their electricity as compared to urban electricity users who avail of the main grid. This, they opine, will cause a lot of social tension and conflicts, making the situation ungovernable, and decision makers are advised to respect the Leave No One Behind (LNOB) principle on the SDG agenda. As argued in [23], consideration of people's preferences and constraints with regard to energy is key to energy economics, and a transformation in the energy sector designed to achieve sustainability must be driven by social and ethical ideas, with the economic and technological ones being mere tools in the hands of these 'drivers'.

2.2. Zambia Energy Sector

In Zambia, wood fuel is the main source of cooking and heating energy, gasoline and diesel for transportation and electricity for mainly lighting but also cooking and heating. According to the national energy statistics [24], biomass accounts for more than 70% of the total primary energy supply, the main forms being wood fuel (charcoal and firewood), biogas, pellets, briquettes and liquid biofuels. While 84.5% of rural households use firewood and 13.2% take recourse to charcoal, most of the urban households (59.1%) use charcoal, with about 6% resorting to firewood and the others using either electricity or other forms of bio-energy—primarily biogas and more recently bio-pellets and briquettes [25].

Landlocked Zambia has a dominant primary economic sector, agriculture and forestry, and is blessed with an abundance of biomass resources that can potentially be used for energy generation. Its agriculture is diverse and is characterized by a wide variety of crops, which post-harvesting and post-processing generate large quantities of crop residues. The quantities are estimated to be 8.76 million tonnes per year, according to [26], of stovers, straws, husks, cobs and brans, for instance, from cereal crops (81%), tubers (8.3%) and cash crops (5.6%). Of these, maize stovers and cobs (accounting for 71.2%; maize being the dominant crop cultivated in Zambia) are the ones with the greatest energy potential. In addition, there are 60,000 tonnes of forestry plantation residues and 73,000 tonnes of wood processing residues.

However, the supply of biomass residues from agriculture and forestry far exceeds their current sustainable utilization rate, indicating a huge potential that can be harnessed in the years to come. These residues are potential feedstock that can be valorized to bio-energy products such as pellets. Depending on the target product, technology and raw-material availability, they can be used either independently or as blends. The lack of political will has previously been blamed for the low level of investment in the Zambian bio-energy sector. However, the good news is that this is slowly changing with the implementation of the new National Energy Policy (NEP) [24]. One of the objectives of the NEP is to promote sustainable utilization of biomass to harness alternatives to fuelwood and, by doing so, facilitate sustainable socio-economic development. Thanks to the NEP, new small and medium enterprises (SMEs) oriented toward bio-energy—Sunbird Bioenergy Zambia and Thomson Biofuels (both producing bioethanol) and Emerging Cooking Solutions (specializing in wood pellets)—have struck root in the recent past. A new ministry, the Ministry of Green Economy, which was formed by the incumbent Zambian national government two years ago, is also a much-needed step in the right direction.

2.3. Organic Wastes (Biomass Residues) as Raw Materials for Pellets

While biomass residues are certainly resources that can be valorized to bio-pellets for use as cooking fuels in Zambia, the techno-functional details—pelletisability and the properties of the pellets produced using different residues—need to be comprehended. The types of biomass residues available for processing vary seasonally, and to facilitate optimal usage, farmers in their capacity as suppliers and pellet-plant owners in their capacity as the processors of the residues need to have a good understanding of the exploitable potential. It would be apt to describe the pelletizing process in brief to shed some light on the residue-to-pellet journey of the bio-material/s.

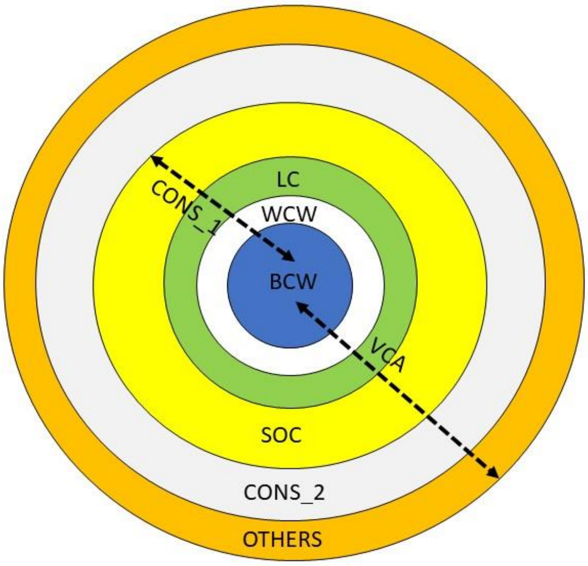
During pelletization, the raw materials (bio-residues in other words) are forced by rollers through holes in a die. If favorable conditions exist, strong inter-particulate bonds are created within the pellets, leading to the production of high-quality pellets. However, as Anukam and colleagues [27] remarked, the precise nature of these bonds cannot be determined easily. As the compaction pressure within the die increases, the particles are forced against each other while undergoing elastic and plastic deformation. Friction is generated in an active part of the channel, which is often referred to as the die press length. The length of the active part is based on the specific feedstock (in our case, biomass residue), implying that a pellet plant cannot switch from one type of feedstock to another. For a sustainable situation (where accessibility, affordability and availability are always guaranteed), the raw material base ought to be composed of different feedstock; considering the seasonal variations in availability referred to earlier. Moisture content [28–33], freshness [29,34] and particle size [35,36] are properties that affect the pelletization process. Woody biomass has 6–12% moisture, while agricultural biomass residues can hold up to 20% moisture. Lignin is an important binding agent in pellets [37]; the bridging action comes into play at the glass transition temperature [32–34]. Waxes and hemicelluloses (xylan and galactan especially) become more fluid at temperatures below the lignin's glass transition temperature, contributing to the strength of the inter-particulate bonds [36]. It is thus necessary to know how blending different biomass residues will impact the pelletization process, as the fractions of lignin, hemicelluloses of different types, waxes and extractives (low-molecular-weight organics) will be variable in that case [38–42].

It is encouraging to learn from Henriksson and colleagues [43] that twelve different types of biomass residues available in Zambia—bamboo, cassava peel, cassava stem, eucalyptus, gliricidia, peanut shell, lantana camara, miombo seed capsules, pigeon pea, pine, sicklebush and tephrosia—do not diverge much in their pelletisabilities. It follows that the required die press length can be the same for all of them, rendering the pellet plant a great deal of flexibility as regards the choice of the input feedstocks.

3. Methodology Adopted

Different published SLCA studies have adopted different approaches heretofore, focused on selected stakeholder categories and narrowed down the focus to aspects (or indicators) of concern to the cases they worked with. Some methods adopted by researchers in the past can be named at this juncture: analytical hierarchy process [44], SEEBalance® method for the chemical industry [45], sub-category assessment method in concert with the Social Hotspots Database [46], Disability-Adjusted Life Years or DALY approach to compare the social impacts of two automotive components and gold jewelry [47], social impact model for the construction sector [48] and a socio-economic cost approach for the textiles and garment industry [49]. The methodology adopted in this streamlined social footprint analysis is described hereunder.

Figure 2 depicts the stakeholder onion diagram, which depicts the different categories of stakeholders who could be considered in a detailed and comprehensive S-LCA. It is clear that an individual who is part of this 'onion' of socio-economic entities may very well belong to more than just one stakeholder category. For instance, a worker may be a resident of the local community. For this paper, which is not a comprehensive S-LCA but rather a streamlined social footprint analysis, the region focused on is in Ndola, in the Copperbelt Province of Zambia.



Stakeholder category	Description
BCW	Blue-collar workers
WCW	White-collar workers
LC	Local community
SOC	Society
CONS_1	Consumers who also belong to one or more of the first four stakeholder categories
CONS_2	Consumers who do not belong to the first four stakeholder categoriess
VCA	Value-chain actors (everyone who has an influence or is influenced from close proximity or otherwise)
OTHERS	Not belonging to any of the above, but influencing from a distance – global media, academic researchers, banks, governments, venture capitalists, etc.

Figure 2. The stakeholder onion diagram in an S-LCA, with the workers at the core.

The authors selected four different stakeholder categories: blue-collar workers (BCW) from Emerging Cooking Solutions (which is a pioneer in the nascent bio-pellet sector in Zambia and by far the only established player thus far), the inhabitants of local communities (LC) around the pellet-production units who may be influenced directly/indirectly by the existence of the units, the final domestic consumers (CONS_1 and CONS_2, identified jointly as pellet consumers or PC in the text hereafter), and academic researchers (R)/business leaders active in this field and/or with connections to Africa/Zambia, who belong to the 'Others' and the VCA stakeholder categories. One business leader, who is the CEO of Emerging Cooking Solutions in Zambia, was grouped together with the two academic researchers, in the VCA stakeholder group, and received the same set of questions as the latter. Some of the respondents belong to both the BCW and LC stakeholder categories—in other words, workers who belong to the local community.

Instead of thinking along the lines of categories, sub-categories and indicators, as conventionally done (in publications such as [17,20], for instance), the authors decided to frame the analysis on the basis of SDGs and questions tailormade for the different stakeholder groups. This may be considered to be a novelty and an addition to the S-LCA literature, though the authors would like to refrain from doing so. Four sets of questionnaires were drafted with 6, 4, 5 and 5 questions, respectively. The questions encompass the purely social as well as the socio-economic, socio-environmental, socio-technological and socio-political aspects (at once suggesting the interlinkages, synergies and conflicts among the different SDGs) and thereby can be related to a swathe of SDGs, as depicted in the pie-chart in Figure 3 and clarified in Appendix A.

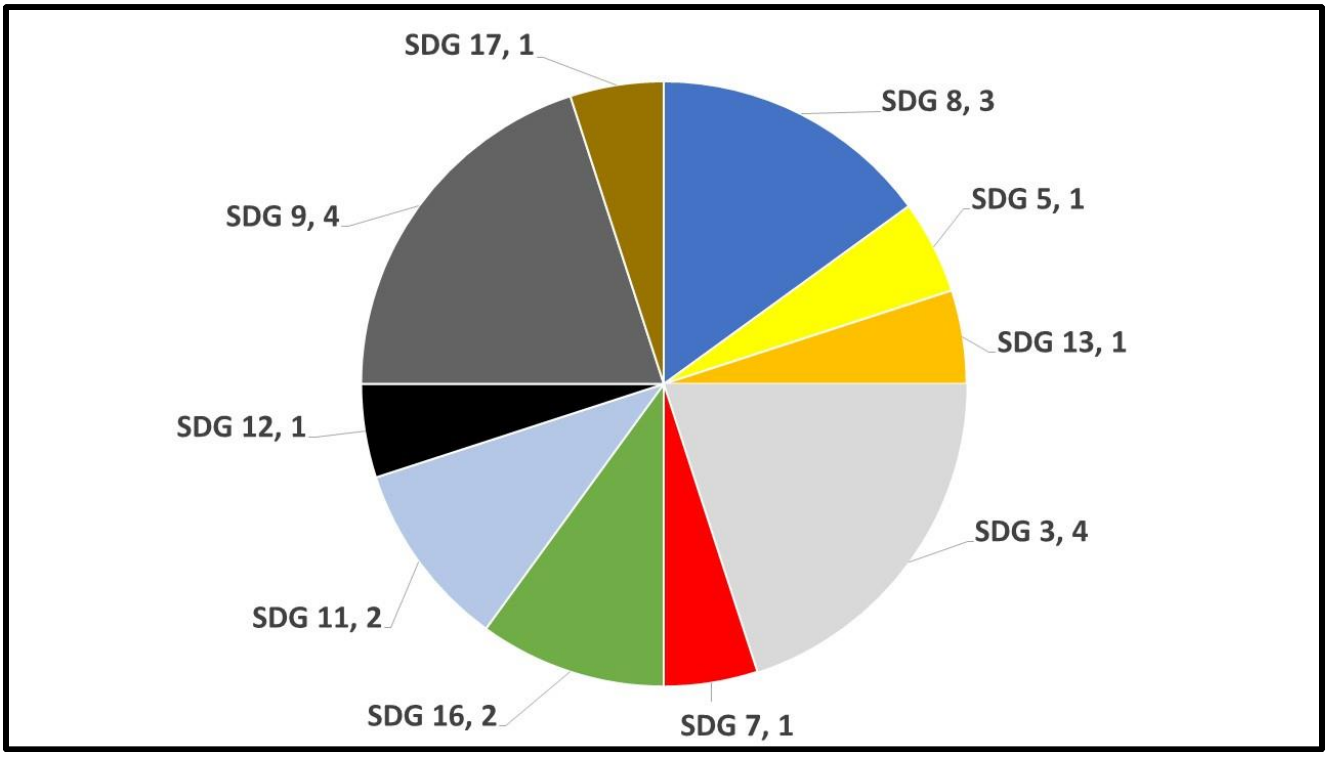


Figure 3. The distribution of the 20 questions among 10 SDGs (also refer to Appendix A; #3 Good Health and Well-being; #5 Gender Equality; #7 Affordable and Clean Energy; #8 Decent Work and Economic Growth; #9 Industry, Innovation and Infrastructure; #11 Sustainable Cities and Communities; #12 Responsible Consumption and Production; #13 Climate Action; #16 Peace, Justice and Strong Institutions; #17 Partnerships for the Goals).

One of the co-authors (Workson Siwale, who hails from Zambia) undertook the responsibility of personally interacting with the potential respondents from the first three stakeholder groups (whose identities were not known in advance), during his visit to Zambia, in January 2023. Owing to language barriers encountered in the field in Zambia, some communication with the respondents of the first three groups had to be carried out with the aid of an interpreter speaking the local language of the region. The respondents from the fourth stakeholder group (researchers and business leaders) were contacted over e-mail. The demographic data about the respondents were not gathered for this analysis. However, the authors would like to consider the stakeholder categories to be reasonable proxies for educational and economic backgrounds of the respondents and age to be not so relevant (in the absence of child labor). It is possible that men in the local community may have answered on behalf of the womenfolk in the household. However, it would have been interesting to know about the gender of the respondents, especially in light of the responses received to the question regarding gender equality in the workplace. The questions are tabulated stakeholder-groupwise, in Appendix A.

Five alternative options were provided to each question, ranging from 'very negative' to 'very positive' (similar to how it was done by Nubi and colleagues [20]). While the respondents viewed these questions as requiring 'qualitative' answers, the authors adopted a semi-quantitative approach (Likert's scale ranging from 0 (very negative) to 4 (very positive)), subsequently. All the questions were weighted equally when the arithmetic and geometric means were calculated for the (arithmetic) average values of the scores for each (refer to Table 1). The geometric mean (GM) tempers down the score for each stakeholder group vis-à-vis the arithmetic mean (AM). It must be stated, however, that this is merely shown in Table 1 as a possible alternative measure of the footprint for each stakeholder group. A grand overall social footprint can be calculated herefrom, and one may decide whether to proceed with the arithmetic (or geometric) averaging of the arithmetic means or the geometric (or arithmetic) averaging of the geometric means. Equi-weighting all the stakeholder groups would simplify the analysis; however, this would be context-specific, and the authors would recommend a closer look at the final aggregation step, bolstered by a very good understanding of the need or otherwise of prioritizing. However, if weightages are to be assigned, an unbiased approach would have to be followed, preferably by a neutral analyst acting without fear or favor.

Table 1. Summary of responses received from the stakeholder groups (refer to Appendix A for the questions corresponding to the abbreviations/notations used).

Blue-Collar Workers (BCW)		**Local Community (LcolumnsC)**		**Pellet Consumers (PC)**		**Researchers (R) and Business Leaders**	
Question	Arithmetic Mean; Standard Deviation	Question	Arithmetic Mean; Standard Deviation	Question	Arithmetic Mean; Standard Deviation	Question	Arithmetic Mean; Standard Deviation
BCWQ1	2;0	LCQ1	3.05; 0.158	PCQ1	3.95; 0.158	RQ1	3; 0
BCWQ2	2.55; 0.98	LCQ2	2.35; 0.47	PCQ2	4; 0	RQ2	3.67; 0.57
BCWQ3	3.3; 0.26	LCQ3	3.05; 0.158	PCQ3	3; 0	RQ3	3.33; 0.57
BCWQ4	3.1; 0.21	LCQ4	2.45; 0.49	PCQ4	4; 0	RQ4	1.67; 1.15
BCWQ5	3.05; 0.16			PCQ5	4; 0	RQ5	2; 0
BCWQ6	3; 0						
Equi-weighted arithmetic mean of the averages	2.83	Equi-weighted arithmetic mean of the averages	2.72	Equi-weighted arithmetic mean of the averages	3.79	Equi-weighted arithmetic mean of the averages	2.73
Equi-weighted geometric mean of the averages	2.79	Equi-weighted geometric mean of the averages	2.71	Equi-weighted geometric mean of the averages	3.77	Equi-weighted geometric mean of the averages	2.62

4. Results and Discussion

The authors came across a total of 17 instances (out of the total of $10 \times (6 + 5 + 4) + 3 \times 5$) in which the respondents had made a first choice, canceled it and then settled on another option. In a couple of cases, two initially made choices were revoked before selecting a third as the final one. For example, the initial response to a question could be 'Positive' (3 on Likert's scale), but on afterthought, that would be changed to 'Very Positive' (4 on the scale). If equal importance has to be accorded to both the initial, instinctive response and the final one made on afterthought, then an average value (3.5 in this case) can be assigned. This factors in, and rightfully so, a possible uncertainty in the mind of the respondent. Having a more-focused discussion with a small subset of these respondents was beyond the scope of this article, and infeasible, but can be recommended.

It would be misleading if statistical generalizations and identification of hotspots are made from semi-quantitative data gathered from a limited pool of respondents, and so the authors would desist from this conventional approach to data crunching. Table 1 summarizes the responses.

In Figure 4, the aspect of gender equality (BCWQ2; SDG 5) stands out as a potential hotspot, and this may perhaps be the case even if the sample set of respondents was enlarged. Equipping women in Zambia with the skills required to work in the pellet factories of the future would, by way of contributing to SDG 5, also aid in progress toward a clutch of other SDGs [16]. Indeed, it is women who use the pellets in their kitchens and are direct beneficiaries of the reduction in adverse health impacts arising out of the use of charcoal and fuelwood in less-efficient stoves. The authors hark back to Wampata et al. [15] and the focus on the need for women's empowerment—both in the production and use of renewable, 'smart' energy—in Zambia. Also conspicuous is the low rating the business leader gives to the question about the interest among investors, banks, venture capitalists and governments for waste-derived bio-pellets in developing countries in general (RQ4). He concurs with Buchholz and Volk [21] about the promise of the aggregation of decentralized small-scale bio-energy systems to uncover greater sustainability benefits in developing countries.

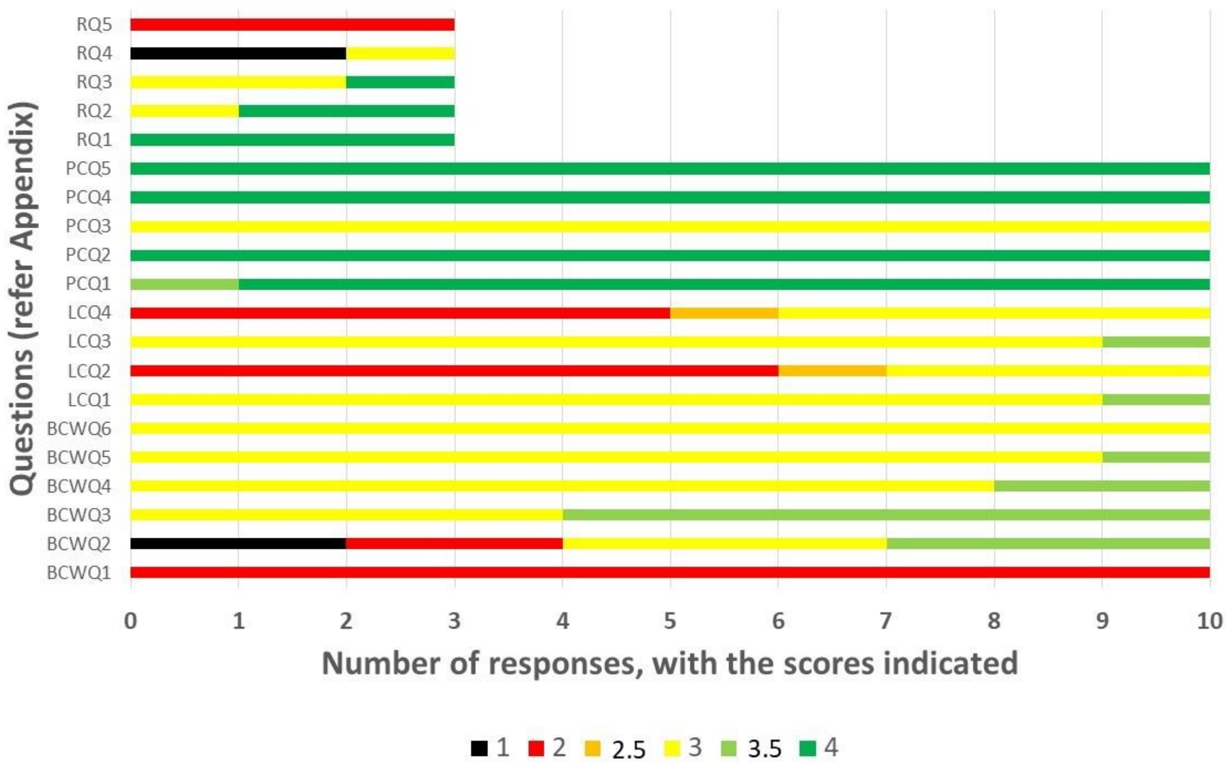


Figure 4. Overview of the responses to the 20 questions (6 + 4 + 5 + 5) posed to the four categories of stakeholders (refer to text for the reason behind the appearance of 2.5 and 3.5 among the values/scores).

As seen in Figure 5, the overall average hovers around 3 (the GM of the GMs being slightly lower than 3 and the AM of the AMs being marginally greater than 3). Such single-number scores serve the purpose of comparisons among different regions/cities/countries [20] if exactly the same methodology is adopted.

The consumers (PC) seem to be quite happy with the switch to bio-pellets for use as a heat source for cooking (with the progress toward SDG 3 being enabled), with a score close to 4, and this is a good sign. It proves that a wider market possibly exists for fuel pellets in Zambia. This can be an encouragement for entrepreneurs in Zambia and investors in southern Africa and beyond. As a researcher hailing from South Africa, adopting a slightly broader southern-African perspective commented, governments, investors, banks and other stakeholders did not really show any interest in promoting waste-biomass-derived pellets in the region. The business leader, while acknowledging the tremendous potential that exists in Zambia, to sustainably integrate the biomass industry into the local economy, observed that the focus can be on setting up many smaller decentralized units and availing of the greater social benefits that would ensue as a result. Political will and entrepreneurial vision ought to work hand in hand to manage the inevitable risks and uncertainties that come with the territory, so to state, in the journey toward sustainability, according to him. Noting that a mothballed wood pellet exporting plant in South Africa may soon start operating again thanks to assistance from Europe, the researcher quoted above observes that the future for biomass pellets in resource-rich southern Africa (of which Zambia is a part) looks promising. Developments in this area in any one member nation of the Southern African Development Corporation (SADC) are expected to have positive trickle-down effects in the others, with new partnerships emerging in the process (SDG 17). The bio-pellet sector in Zambia for one is nascent and needs top-down support until it entrenches itself. This means that creating a market and sustaining it in a developing country like Zambia, where the availability and accessibility of raw materials for bio-pellets (organic wastes from forestry and agriculture being prioritized, going forward) need to be guided by affordability. This rules out the possibility of the introduction of any green-circular premium which is being encouraged and recommended in the developed world and also in some developing-world countries which are transiting upward.

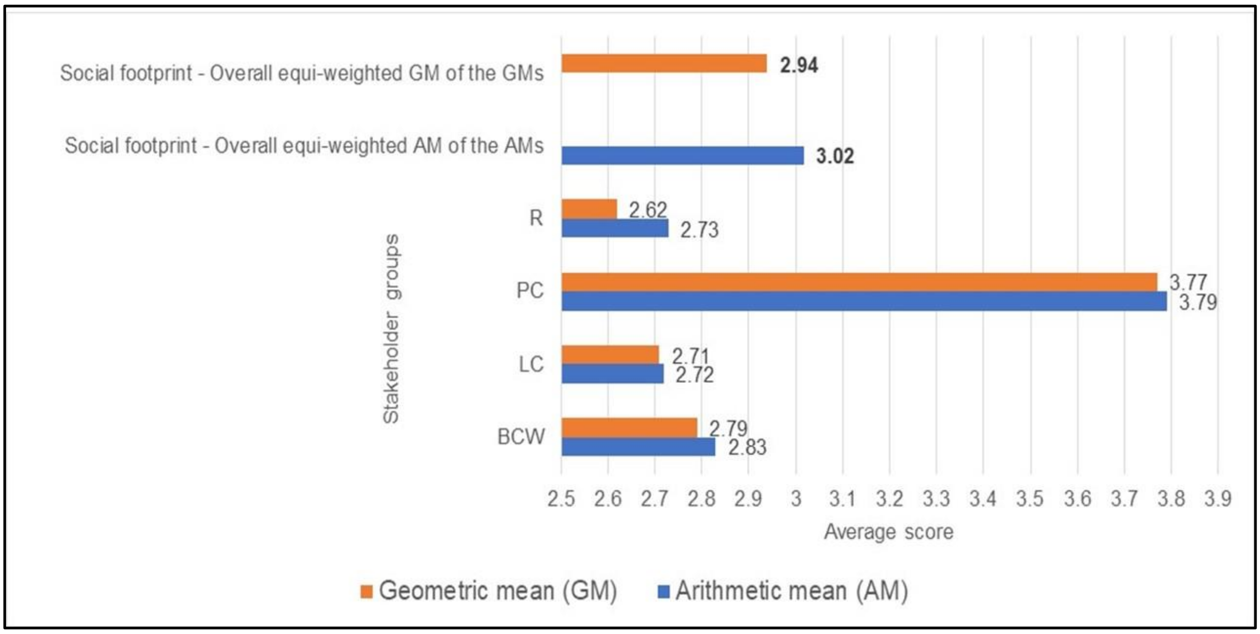


Figure 5. Average values for each stakeholder group and the overall social footprint.

While most of the blue-collar workers (BCW) have spoken in support of expanding pellet production by augmenting capital investment (in machinery and equipment) and thereby generating more employment opportunities for inhabitants of the local community, the consumers believe that improving transportation infrastructure will benefit both the producers and consumers of pellets in Zambia immensely. Commencing from servicing households by supplying pellets for use as fuel in cooking, capacity enhancement at the plant/s may support local, small-scale pellet-fueled combined heat-and-power plants in the future and help Renewable Energy Agency Zambia to meet the 51% rural electrification target set by it in 2005, for the year 2030 [22]. This will automatically spur progress toward other SDGs related to social well-being. If production has to continue unhindered by any slowing in the demand for the pellets, storage facilities are a must. Additionally, the quality of the pellets must not deteriorate rapidly during storage. This may not be a social aspect, but nevertheless quite interestingly, some respondents belonging to the local community (LC) stakeholder group pointed out that blending pine sawdust (organic waste which can thus be purposefully valorized) and eucalyptus may render the pellets more durable. An implicit awareness of the imminent deforestation (total reliance on biomass from the forests in the country) can be detected here. Also interesting to note is the fact that both eucalyptus and pine are invasive alien species in South Africa, which Vera and fellow researchers [18] recommend as raw materials for fuel pellets that can be combusted for electricity generation and Henriksson and colleagues [37] consider as among the suitable biomass residues in Zambia that could be harnessed for this purpose. Pine and eucalyptus are fast-growing tree species that store more carbon in the biomass carbon pool vis-à-vis other vegetation types, as pointed out by the South African authors in [18].

5. Conclusions and Recommendations

This streamlined social footprint analysis was motivated by:

- The limited number of publications pertaining to the social aspects of the energy/bio-energy sector in Africa (uncovered by the literature review);
- The ongoing bio-pellet research partnerships between the department in Karlstad University the authors belong to and some countries in Africa, which uncovered the huge potential that exists in biomass residues from the agricultural and forestry sectors in Africa to be valorized to bio-energy products such as pellets.

The implementation of the National Energy Policy in Zambia in 2019 and the setting-up of the Ministry of Green Economy in 2021 are promising developments that are likely to support the entrenchment of bio-pellets in the Zambian bio-energy sector. Overseas investors may also show interest in this sub-sector in the years to come. Social LCA is not as straightforward as a techno-economic or environmental analysis but cannot be dispensed with hereafter when decisions will have to be made with multiple dimensions of sustainability in mind [22]. The streamlined social footprint analysis is not a novel addition per se to the S-LCA knowledge base. The purpose of the application was to shed light on what needs to be known and understood better, in order to bring about much-needed alterations in the interest of sustainable development.

The exercise undertaken by the authors of this paper can (and will) motivate further research entailing:

- The diversification of the stakeholder groups further to include more entities representing the value-chain actors in the bio-pellet sector in Zambia (as also recommended in [19]);
- The expansion of the scope of the analysis by including more questions and reaching out to more potential respondents in the future, as and when the bio-pellet sector will expand from Ndola in the Copperbelt Province to other regions of Zambia;
- Dialogues with stakeholders to inform a possible weighting approach other than equi-weighting (as also recommended by [14]) and thus encourage expression, communication and agreement;
- The introduction of a hybrid measurement approach by including purely quantitative measures (as different from the qualitative-to-semi-quantitative approach adopted in this analysis);
- A comparison among different alternatives (ethanol-burning stoves and solar cookers, for instance, vis-à-vis pellet-fired stoves) and among different regions/countries in southern Africa (quite like Nubi and colleagues [20] did for Lagos and Abuja in Nigeria);
- Multi-criteria decision-making analyses by including the economic and environmental dimensions as well (as in [14,19]) for this sector in the country.

To quote from [23], 'Access to energy resources, energy supply security, slow market entry of renewables, and sluggish progress in greenhouse gas emission reductions are well-known issues and concerns. Solutions to these issues cannot be found without an in-depth analysis of energy markets that acknowledges not only their physical and technological constraints, but also their structural idiosyncrasies and the behaviour of market participants.' S-LCA, as mentioned earlier, is still an evolving tool [5], and that gives analysts some room to experiment with different methodologies to gain and disseminate understanding and thereby add to the knowledge base of the social dimension of sustainable development—the 'structural idiosyncrasies and behaviour of market participants', alluded to by Zweifel and colleagues [23].

Author Contributions: Conceptualization, G.V., I.G. and H.K.; methodology, G.V., I.G., H.K. and W.S.; formal analysis, I.G. and H.K., investigation, W.S.; data curation, G.V. and W.S.; writing—original draft preparation, I.G. and H.K.; writing—review and editing, G.V., W.S. and S.F.; visualization, G.V.; supervision, G.V.; project administration, G.V. All authors have read and agreed to the published version of the manuscript.

Funding: The manuscript received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable. The respondents are aware of the purpose of the survey conducted.

Data Availability Statement: All data have been transparently presented in the Results section. No data have been withheld.

Acknowledgments: The authors thank all the respondents from the different stakeholder categories in Zambia, Anthony Ike Anukam, Magnus Ståhl, Mattias Ohlson (for granting access to the Emerging Cooking Solutions production facility and permission to interact with the blue-collar workers thereof) and the Bioeconomy course led by one of the co-authors (Stefan Frodeson) and offered at the department the authors belong to, which provided the platform for this article.

Conflicts of Interest: The authors declare no conflict of interest with any entity.

Appendix A

Table A1. Questionnaire for blue-collar workers (abbreviated as BCW) in the pellet sector.

		Question	Options Given for All the Questions (Score on Likert's Scale)
BCWQ1	SDG 8	How would you rate the work-hours in the pellets sector? Ranging from 7–8 h/day with paid overtime being rated as the best, and anything above 10 h per day considered to be extremely undesirable.	Very positive (4) Positive (3) Neutral (2) Negative (1) Very negative (0)
BCWQ2	SDG 5	How would you rate the gender balance in the work-force? In other words, the inclusion of women as fellow-workers, with a higher proportion being more positive?	
BCWQ3	SDG 3	How would you rate the incidence of accidents in the workplace? (Obviously, lower the rate, the better)	
BCWQ4	SDG 3	How would you rate the exposure of the workers to pollutants in the workplace? (Lesser, obviously, is desirable and more positive)	
BCWQ5	SDG 13	How would you, as a worker, assess the opinion of the people, as regards the use of bioenergy in general instead of fossil fuels?	
BCWQ6	SDG 3	As a worker in this sector, how would you rate the effect of the increasing use of pellets (or bio-energy in general) on the environment and social well-being?	

Table A2. Questionnaire to the local community (abbreviated as LC) around the pellet factory/factories.

		Question	Options Given for All the Questions (Score on Likert's Scale)
LCQ1	SDG 11	How would you rate the involvement/integration of the residents of the local community around pellet-production units; and the utilization of existing skill-sets thereof? Is adequate awareness of the operations disseminated?	Very positive (4) Positive (3) Neutral (2) Negative (1) Very negative (0)
LCQ2	SDG 8	How would you rate the career growth opportunities in the future in this sub-sector, especially benefiting the local community in a significant way?	
LCQ3	SDG 16	How would you rate the state of security and respect for human rights in your country, in general?	
LCQ4	SDG 3	How would you rate the impact of the pellets-production operations on the ambient atmosphere? (This is particularly with regard to the presence of bad odours wafting in the air, which may affect the quality of the air one breathes)	

Table A3. Questionnaire for the bio-pellets' consumers (abbreviated as PC).

		Question	Options Given for All the Questions (Score on Likert's Scale)
PCQ1	SDG 7	How would you rate your experience withthe adoption of bio-pellets?	Very positive (4) Positive (3) Neutral (2) Negative (1) Very negative (0)
PCQ2	SDG 11	How would you rate the effect of the use of bio-pellets on the increase in comfort and convenience in the household?	
PCQ3	SDG 3	In addition to comfort and convenience, how do you rate its effect on health?	
PCQ4	SDG 12	This is a question which concerns the supplier-consumer relationship. How would you assess the ease of communicating with the supplier about your complaints and feedback?	
PCQ5	SDG 16	Your opinion about the comprehensiveness regarding the information provided to you as a consumer by the supplier, about the pellets-raw materials used, risks involved during use (if any) etc.?	

Table A4. Questionnaire for the researchers (R).

		Question	Options Given for All the Questions (Score on Likert's Scale)
RQ1	SDG 9	How would you rate the challenge associated with working on a topic such as this, focusing on a region which would benefit a lot if developments would happen steadily and surely? The question pertains to the satisfaction you derive from conducting constructive and meaningful research.	Very positive (4) Positive (3) Neutral (2) Negative (1) Very negative (0)
RQ2	SDG 9	How would you rate the possibility of motivating younger researchers into this field, particularly to work with issues which would benefit a continent which has the potential to skip the learning curve and avail of knowledge necessary to advance on the path of sustainable development, to attain the SDGs?	
RQ3	SDG 9	As a researcher who has observed and experienced, and have seen how things keep oscillating when it comes to setting the ball rolling on much-needed developments, how sure are you about the entrenchment of waste-biomass-derived-pellets in the heat-energy sector of Africa in general before the end of this decade?	
RQ4	SDG 9	How would you assess the interest among investors–governments, banks, venture capitalists etc.–in promoting waste-biomass-derived-pellets in southern Africa for instance?	
RQ5	SDG 17	How do you envisage the role of the media in Africa in supporting such transitions?	

References

1. Venkatesh, G. Circular bio-economy—Paradigm for the future: Systematic review of scientific journal publications from 2015–2021. *Circ. Econ. Sustain.* **2021**, *2*, 231–279. [CrossRef]
2. Chia, E.L.; Fobissie, K.; Enongene, K. Food-fuel-fibre production policies and strategies in the context of climate change in Central Africa. *Afr. For. Forum* **2017**, *3*, 66.
3. Hamatui, N.; Naidoo, R.N.; Kgabi, N. Respiratory health effects of occupational exposure to charcoal dust in Namibia. *Int. J. Occup. Environ. Health* **2016**, *22*, 240–248. [CrossRef]
4. Venkatesh, G. Critique of selected peer-reviewed publications on applied social life cycle assessment: Focus on cases from developing countries. *Clean Technol. Environ. Policy* **2018**, *21*, 413–430. [CrossRef]
5. Mattioda, R.A.; Mazzi, A.; Canciglieri, O.; Scipioni, A. Determining the principal references of the social life cycle assessment of products. *Int. J. Life Cycle Assess.* **2015**, *20*, 1155–1165. [CrossRef]
6. Venkatesh, G. *Social LCA—An Introduction. The What, the Why and the How*; Bookboon: Copenhagen, Denmark, 2019; ISBN 978-87-403-2841-7.
7. United Nations Environment Programme (UNEP); SETAC. 2013. Available online: https://unep.org/resources/report/guidelines-social-life-cycle-assessment-products (accessed on 10 January 2023).
8. Musaazi, M.K.; Mechtenberg, A.R.; Nakibuule, J.; Sensenig, R.; Miyingo, E.; Makanda, J.V.; Hakimian, A.; Eckelman, M.J. Quantification of social equity in life cycle assessment for increased sustainable production of sanitary products in Uganda. *J. Clean. Prod.* **2015**, *96*, 570–579. [CrossRef]
9. Agyekum, E.O.; Fortuin, K.P.J.K.; van der Harst, E. Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana. *J. Clean. Prod.* **2017**, *143*, 1069–1080. [CrossRef]
10. Foolmaun, R.K.; Ramjeawon, T. Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius. *Int. J. Life Cycle Assess.* **2013**, *18*, 155–171. [CrossRef]
11. Pastor, M.M.; Schatz, T.; Traverso, M.; Wagner, V.; Hinrichsen, O. Social aspects of water consumption: Risk of access to unimproved drinking water and to unimproved sanitation facilities—An example from the automobile industry. *Int. J. Life Cycle Assess.* **2018**, *23*, 940–956. [CrossRef]
12. Bouzid, A.; Padilla, M. Analysis of social performance of the industrial tomatoes food chain in Algeria. *New Medit.* **2014**, *13*, 60–65.
13. Röder, M.; Chong, K.; Thornley, P. The future of residue-based bioenergy for industrial use in Sub-Saharan Africa. *Biomass Bioenergy* **2022**, *159*, 106385. [CrossRef]
14. Duvenage, I.; Taplin, R.; Stringer, L. Bioenergy project appraisal in sub-Saharan Africa: Sustainability barriers and opportunities in Zambia. *Nat. Resour. Forum* **2012**, *36*, 167–180. [CrossRef]
15. Wampata, M.; Mwanza, B.G. Smart Energy Access and Women Empowerment: A Case Study of Chitandika Village in Zambia. *Int. J. Eng. Manag. Res.* **2021**, *11*, 117–128. [CrossRef]
16. Venkatesh, G. A small beautiful example of sustainability in the heart of Zimbabwe. *Stud. Ecol. Bioethicae* **2023**, *21*, 1. [CrossRef]
17. Dunmade, I.S. Potential social lifecycle impact analysis of bioenergy from household and market wastes in African cities. *Agron. Res.* **2019**, *17*, 1599–1616. [CrossRef]
18. Vera, I.; Goosen, N.; Batidzirai, B.; Hoefnagels, R.; van der Hilst, F. Bioenergy potential from invasive alien plants: Environmental and socio-economic impacts in Eastern Cape, South Africa. *Biomass Bioenergy* **2022**, *158*, 106340. [CrossRef]
19. Nieder-Heitmann, M.; Haigh, K.F.; Görgens, J.F. Life cycle assessment and multi-criteria analysis of sugarcane biorefinery scenarios: Finding a sustainable solution for the South African sugar industry. *J. Clean. Prod.* **2019**, *239*, 118039. [CrossRef]
20. Nubi, O.; Morse, S.; Murphy, R.J. A prospective social life cycle assessment (SLCA) of electricity generation from municipal solid waste in Nigeria. *Sustainability* **2021**, *13*, 10177. [CrossRef]
21. Buchholz, T.; Volk, T.A. Considerations of Project Scale and Sustainability of Modern Bioenergy Systems in Uganda. *J. Sustain. For.* **2012**, *31*, 154–173. [CrossRef]
22. Stritzke, S.; Jain, P. The sustainability of decentralized renewable energy projects in developing countries: Learning lessons from Zambia. *Energies* **2021**, *14*, 3757. [CrossRef]
23. Zweifel, P.; Praktiknjo, A.; Erdmann, G. *Energy Economics: Theory and Applications*; Springer Texts in Business and Economics; Springer: Berlin/Heidelberg, Germany, 2017. [CrossRef]
24. MOE (Ministry of Energy, Government of Zambia). *The National Energy Policy*; MOE: Lusaka, Zambia, 2019.
25. FAO (Food and Agricultural Organisation, UN). Sustainable Wood Fuel For Food Security: A Smart Choice: Green Renewable and Affordable. Available online: https://fao.org/3/i7894e/i7894e.pdf (accessed on 10 January 2023).
26. FAO; MOE (Government of Zambia). *Sustainable Bioenergy Potential in Zambia—An Integrated Bioenergy and Food Security Assessment*; Environment and Natural Resources Management Working Papers No. 84; FAO: Rome, Italy; MOE: Lusaka, Zambia, 2020. [CrossRef]
27. Anukam, A.; Berghel, J.; Henriksson, G.; Frodeson, S.; Ståhl, M. A review of the mechanism of bonding in densified biomass pellets. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111249. [CrossRef]
28. Filbakk, T.; Skjevrak, G.; Høibø, O.; Dibdiakova, J.; Jirjis, R. The influence of storage and drying methods for Scots pine raw material on mechanical pellet properties and production parameters. *Fuel Process. Technol.* **2011**, *92*, 871–878. [CrossRef]
29. Obernberger, I.; Thek, G. Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass Bioenergy* **2004**, *27*, 653–669. [CrossRef]

30. Li, H.; Jiang, L.-B.; Li, C.-Z.; Liang, J.; Yuan, X.-Z.; Xiao, Z.-H.; Xiao, Z.-H.; Wang, H. Co-pelletisation of sewage sludge and biomass: The energy input and properties of pellets. *Fuel Process. Technol.* **2015**, *132*, 55–61. [CrossRef]
31. Nguyen, Q.N.; Cloutier, A.; Achim, A.; Stevanovic, T. Effect of process parameters and raw material characteristics on physical and mechanical properties of wood pellets made from sugar maple particles. *Biomass Bioenergy* **2015**, *80*, 338–349. [CrossRef]
32. Huang, Y.; Finell, M.; Larsson, S.; Wang, X.; Zhang, J.; Wei, R.; Liu, L. Biofuel pellets made at low moisture content—Influence of water in the binding mechanism of densified biomass. *Biomass Bioenergy* **2017**, *98*, 8–14. [CrossRef]
33. Serrano, C.; Monedero, E.; Lapuerta, M.; Portero, H. Effect of moisture content, particle size and pine addition on quality parameters of barley straw pellets. *Fuel Process. Technol.* **2011**, *92*, 699–706. [CrossRef]
34. Arshadi, M.; Gref, R.; Geladi, P.; Dahlqvist, S.-A.; Lestander, T. The influence of raw material characteristics on the industrial pelletizing process and pellet quality. *Fuel Process. Technol.* **2008**, *89*, 1442–1447. [CrossRef]
35. Stelte, W.; Sanadi, A.R.; Shang, L.; Holm, J.K.; Ahrenfeldt, J.; Henriksen, U.B. Recent developments in biomass pelletisation—A review. *BioResources* **2012**, *7*, 4451–4490. [CrossRef]
36. Bergström, D.; Israelsson, S.; Öhman, M.; Dahlqvist, S.-A.; Gref, R.; Boman, C.; Wästerlund, I. Effects of raw material particle size distribution on the characteristics of Scots pine sawdust fuel pellets. *Fuel Process. Technol.* **2008**, *89*, 1324–1329. [CrossRef]
37. Whittaker, C.; Shield, I. Factors affecting wood, energy grass and straw pellet durability—A review. *Renew. Sustain. Energy Rev.* **2017**, *71*, 1–11. [CrossRef]
38. Kaliyan, N.; Morey, R.V. Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass. *Bioresour. Technol.* **2010**, *101*, 1082–1090. [CrossRef] [PubMed]
39. Stelte, W.; Holm, J.K.; Sanadi, A.R.; Barsberg, S.; Ahrenfeldt, J.; Henriksen, U.B. A study of bonding and failure mechanisms in fuel pellets from different biomass resources. *Biomass Bioenergy* **2011**, *35*, 910–918. [CrossRef]
40. Stelte, W.; Clemons, C.; Holm, J.K.; Ahrenfeldt, J.; Henriksen, U.B.; Sanadi, A.R. Fuel Pellets from Wheat Straw: The Effect of Lignin Glass Transition and Surface Waxes on Pelletizing Properties. *BioEnergy Res.* **2012**, *5*, 450–458. [CrossRef]
41. Stelte, W.; Clemons, C.; Holm, J.K.; Ahrenfeldt, J.; Henriksen, U.B.; Sanadi, A.R. Thermal transitions of the amorphous polymers in wheat straw. *Ind. Crops Prod.* **2011**, *34*, 1053–1056. [CrossRef]
42. Frodeson, S.; Lindén, P.; Henriksson, G.; Berghel, J. Compression of Biomass Substances—A Study on Springback Effects and Colour Formation in Pellet Manufacture. *Appl. Sci.* **2019**, *9*, 4302. [CrossRef]
43. Henriksson, L.; Frodeson, S.; Berghel, J.; Andersson, S.; Ohlson, M. Bioresources for sustainable pellet production in Zambia: Twelve biomasses pelletized at different moisture contents. *BioResources* **2019**, *14*, 2550–2575. [CrossRef]
44. Fan, L.; Pang, B.; Zhang, Y.; Zhang, X.; Sun, Y.; Wang, Y. Evaluation for social and humanity demand on green residential districts in China based on SLCA. *Int. J. Life Cycle Assess.* **2018**, *23*, 640–650. [CrossRef]
45. Schmidt, I.; Meurer, M.; Saling, P.; Kicherer, A.; Reuter, W.; Gensch, C.-O. SEEbalance ®: Managing sustainability of products and processes with the socio-eco-efficiency analysis by BASF. *Greener Manag. Int.* **2004**, *45*, 79–94.
46. Lenzo, P.; Traverso, M.; Salomone, R.; Ioppolo, G. Social life cycle assessment in the textile sector: An Italian case study. *Sustainability* **2017**, *9*, 2092. [CrossRef]
47. Arvidsson, R.; Hildenbrand, J.; Baumann, H.; Islam, K.M.N.; Parsmo, R. A method for human health impact assessment in social LCA: Lessons from three case studies. *Int. J. Life Cycle Assess.* **2018**, *23*, 690–699. [CrossRef]
48. Dong, Y.H.; Ng, S.T. A modeling framework to evaluate sustainability of building construction based on LCSA. *Int. J. Life Cycle Assess.* **2016**, *21*, 555–568. [CrossRef]
49. Van der Velden, N.M.; Vogtländer, J.G. Monetization of external socio-economic costs of industrial production: A social-LCA-based case of clothing production. *J. Clean. Prod.* **2017**, *153*, 320–330. [CrossRef]