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Article

Appraising Bioenergy Alternatives in Uganda Using Strengths, Weaknesses, Opportunities and Threats (SWOT)-Analytical Hierarchy Process (AHP) and a Desirability Functions Approach

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Abstract: Poor access to clean and reliable energy technologies is a major challenge to most developing countries. The decision to introduce new technologies is often faced by low adoption rates or even public opposition. In addition, the data required for effective decision making is often inadequate or even lacking, thus constraining the planning process. In this study, a methodology for participatory appraisal of technologies, integrating desirability functions to the strengths, weaknesses, opportunities and threats (SWOT)-analytical hierarchy process (AHP) methodology was developed. Application of the methodology was illustrated with an example for participatory appraisal of four bioenergy technologies in Uganda. Results showed that the methodology is effective in evaluating stakeholder preferences for bioenergy technologies. It showed a high potential to be used to identify and rate factors that stakeholders take into consideration when selecting bioenergy systems. The method could be used as a tool for technology screening, or reaching consensus in a participatory setup in a transparent manner.

Keywords: analytic hierarchy process; bioenergy technologies; multi-criteria analysis; decision making; participatory appraisal; developing countries

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1. Introduction

Ensuring a sustainable supply of energy is one of the major challenges of the 21st century. The need for renewable energy supplies is becoming increasingly more urgent as conventional sources are blamed for the increasing levels of atmospheric greenhouse gases, global warming, and climate change. Moreover, reserves of fossil fuels are finite, and threatened by depletion [1]. Also, fossil fuels reserves are not uniformly distributed over the World, therefore compromising the energy security of countries without the resources. However, developing countries have more diverse concerns including lack of access to adequate clean energy, extensive deforestation due to fuelwood harvesting and expansion of agricultural land. The end results are negative impacts such as soil erosion, loss of biodiversity and reduced availability and access to fuelwood resources by the population. With reduced accessibility to fuelwood, households fall down the energy ladder; thus, resorting to low quality energy sources such as agricultural residues and dried cattle manure, which have adverse impacts on the health of users due to increased indoor air pollution from cooking devices [2], which is known to be a serious health burden in developing countries. It is estimated that close to two million [3] people die prematurely every year due to ailments caused by indoor pollution, of which 400,000 [4] cases are in sub-Saharan Africa (SSA).

Nevertheless, biomass combustion in inefficient devices remains the dominant household energy in most SSA countries. In Uganda, for example, over 90% of energy needs is provided by biomass, mainly in form of firewood, charcoal and agricultural residues [5]. Despite the high potential of renewable energy resources in the country, it is estimated that only 5% of the population has access to electricity [6]. Currently, the country is experiencing high rates of increase in demand for biomass energy, estimated at 3% and 6% for firewood and charcoal per annum, respectively [7]. The increasing demand, coupled with agricultural land expansion, is leading to accelerated deforestation and consequently fuelwood deficit in many parts of the country [8]. To ensure sustainability of energy supply, the country developed the Renewable Energy Policy [9] with the aim of increasing use of modern energy technologies that are cleaner and more sustainable than existing practices. Under the policy, the use of improved stoves with higher efficiency is being promoted. The policy also aims at increasing the use of domestic biogas systems for household cooking and lighting. Consequently, several agencies are now promoting improved bioenergy technologies in the country. Examples of technologies promoted include improved biomass stoves, domestic biogas systems, biomass briquettes, and plant oil based systems. However the level of adoption of improved bioenergy technologies in Uganda remains low, with over 70% of the population still using inefficient combustion devices [5].

Generally, efforts to introduce improved renewable energy technologies in many communities are faced by multiple challenges, including low adoption rates [10]. In some cases, there is even direct public opposition, a phenomenon commonly referred to as the not-in-my-backyard (NIMBY) effect [11]. This is probably due to public concerns such as competition with food production, changes in land use and aesthetics. In some cases, renewable energy technologies are less economically competitive than fossil fuels or even against the cultural norms and beliefs of the target population. In the case of Uganda, specific reasons for the slow rates of adoption of improved bioenergy technologies are not clearly known.

Involving stakeholders is critical in understanding barriers to dissemination of bioenergy technologies and is recognised as the key to the successful implementation of projects. Suitable tools are required to ensure successful consultation of stakeholders in the bioenergy decision making process. So far, several tools are available for the purpose, but one of the most popular is the analysis of strengths, weaknesses, opportunities and threats (SWOT). The method has been widely used for participatory decision making. For example, Liu *et al.* [12] used it to evaluate the social, economic and environmental impacts of bioenergy production on marginal land. Lee *et al.* [13] also employed SWOT analysis to analyse and develop strategies for the development of the Korean energy sector. A similar study using SWOT analysis was conducted in China for planning the strategic development of the shale gas industry [14]. The main weakness of the SWOT analysis, however, is that the results are not quantified and therefore it is difficult to attach levels of importance to the individual identified SWOT factors.

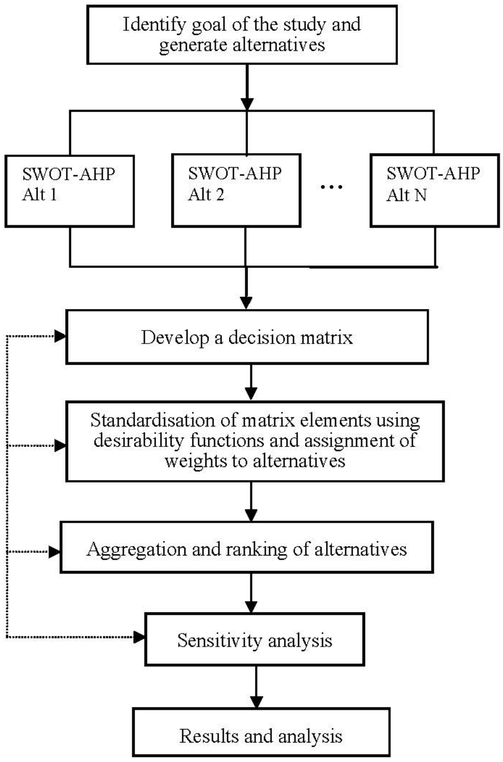
Consequently, Kurtilla *et al.* [15] developed a method that incorporates the results of SWOT analysis in the analytical hierarchy process (AHP). The method, commonly abbreviated as SWOT-AHP or A'WOT has been widely used in forest policy decision analyses [16–18]. Other examples of the application of the method include studies in the field of safety and environment [19], agriculture [20], and water resource management [21]. Ramirez *et al.* [22] conducted one of the first studies applying the SWOT-AHP method to bioenergy technologies in developing countries to assess stakeholders' perception about non-traditional cooking stoves in Honduras. However, all these studies are limited to the quantification of SWOT factors for a single scheme of intervention. The use of the SWOT-AHP method as a tool for comparative analysis of strategic alternatives is generally limited in the literature; an example was proposed by Pesonen *et al.* [23].

Against this background, the objectives of this study were to: (1) improve the capability of the SWOT-AHP methodology as a tool for participatory appraisal of alternative bioenergy technologies; and (2) illustrate the use of the proposed methodology with an application example. The present study gives a detailed description of the SWOT-AHP methodology and its proposed extension with desirability functions [24]. An application example for participatory appraisal of four different bioenergy technologies in Uganda is also given.

2. Methodology

The proposed methodology incorporates desirability function [25] into the SWOT-AHP method [15–17], followed by synthesis of results using a weighted summation method [26]. In the SWOT analysis phase, SWOT of the technology is analysed [27]. The AHP methodology, developed by Saaty [28] in the 1970s, can then be used to convert SWOT factors into quantifiable indicators [15]. Desirability functions [25] are then used to transform the weights of the SWOT group factors into measures of suitability of each technology. In the last step, ranks of technologies can then be subjected to sensitivity analysis [29] so as to evaluate their robustness to changes in weights of criteria. The flow chart of proposed method is illustrated in Figure 1, and detailed explanations are given in the following sections.

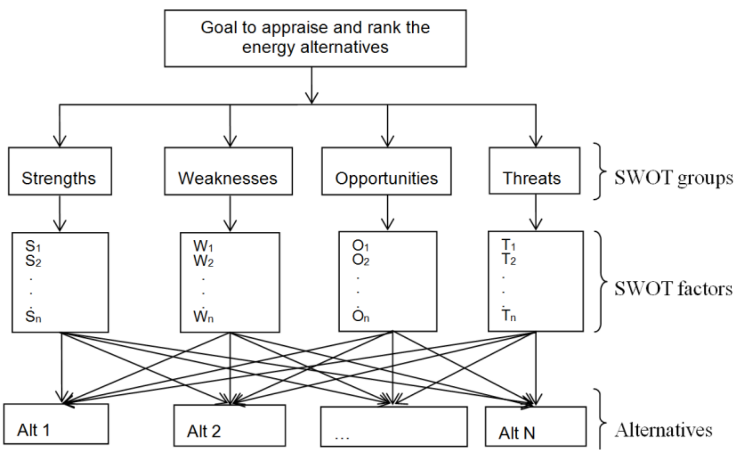
Figure 1. Flow chart of the proposed methodology. Note: doted lines show feedback between the stages). Alt 1, Alt 2, …, Alt *N*, represent the technologies under appraisal. SWOT-AHP: strengths, weaknesses, opportunities and threats-analytical hierarchy process.



2.1. Incorporating SWOT in Hierarchical Decision Model (HDM)

The first step is to perform a SWOT analysis of all the alternative bioenergy systems and incorporate the results in the HDM [30], illustrated in Figure 2. At the top of the hierarchy is the decision goal. The criteria used in the decision model are the SWOT groups [31] of the respective energy systems. The more explicit SWOT factors are used as the sub-criteria in the model. At the bottom of the hierarchy are the alternative bioenergy technologies to be prioritised.

Figure 2. Hierarchical decision model (HDM). S_1, S_2, …, S_n; W_1, W_2, …, W_n; O_1, O_2, …, O_n and T_1, T_2, …, T_n represents SWOT factor of each technology Alt 1, Alt 2, …, Alt *N*, respectively.



2.2. Quantifying SWOT Factors Using AHP

In the second step, the SWOT factors (or sub-criteria) and SWOT groups (or criteria) are prioritised using a pairwise comparison method [31]. First, pairwise comparison of SWOT factors is done, followed by that of SWOT groups using a suitable scale, usually ranging from one to nine [32]. Results of the pairwise comparison exercises are transformed into positive pairwise comparison matrices ***A***, illustrated by Equation (1):

$$A = \begin{bmatrix} 1 & c_1/c_2 & \cdots & c_1/c_n \\ c_2/c_1 & 1 & \cdots & c_2/c_n \\ \vdots & \vdots & \ddots & \vdots \\ c_n/c_1 & c_n/c_2 & \cdots & 1 \end{bmatrix} \quad (1)$$

where c_i are the relative importance of SWOT factors or SWOT groups obtained from pairwise comparison. Values of c_i equal to one denote equal importance between a given pair of factors or groups while nine indicates that one factor is absolutely more important than the other [33]. Then, matrix ***A*** is normalised by dividing each element of a columns by the sum of the column elements, to generate Equation (2):

$$B = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \quad (2)$$

where ***B*** is the normalised pairwise comparison matrix. The weighted matrix, ***W***, is then generated from the mean of each row of matrix ***B***, as illustrated by Equation (3):

$$W = \frac{\sum_{j=1}^{n} x_{ij}}{n} = \begin{bmatrix} w_{11} \\ w_{12} \\ \vdots \\ w_{1n} \end{bmatrix} \quad (3)$$

where w_{ij} are the overall weights or scores of SWOT groups or factors of a given alternative. The result is then checked through consistency test by evaluating the value of consistency ratio, calculated using Equation (4):

$$CR = CI/RI \quad (4)$$

where *CR* is consistency ratio; *CI* is consistency index given by Equation (5); and *RI* is random index given in Table 1 [32]:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

where *CI* is the consistency index; $\lambda_{\max}$ is the largest eigenvalue of matrix ***A***; and *n* is the number of SWOT groups or factors. It is a general rule that if the consistency ratio is greater than 0.1, then the results of the pairwise comparison is inconsistent, and therefore cannot be accepted [34]. Actions described in Sections 2.3 and 2.4 are repeated for each of the alternatives under consideration.

Table 1. Values of random index (*RI*) [30].

Values	Number of elements in pairwise comparison							
n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI(*n*)	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.3. Ranking of Technologies

Ranking of the technologies is achieved by minimising the weaknesses and threats, and maximising strengths and opportunities. To achieve this, a decision matrix [25] is developed from the weights of SWOT groups, as illustrated in Table 2. Elements of the decision matrix are then transformed into a measure of suitability ranging from zero to one using desirability functions [25]. A desirability value of one that implies that the SWOT group factor is optimal, while a value of zero means the attribute is totally undesirable. Transformation of beneficial criteria, in this case strengths and opportunities, is done using Equation (6), while for non-beneficial criteria, i.e., weaknesses and threats, is accomplished using Equation (7):

$$d_i = \begin{cases} 0 & \text{if } w_{ij} \le w_{\min j} \\ \left(\dfrac{w_{ij} - w_{\min j}}{w_{\max j} - w_{\min j}} \right)^{\delta} & \text{if } w_{\min j} \le w_{ij} \le w_{\max j} \\ 1 & \text{if } w_{ij} \ge w_{\max j} \end{cases} \tag{6}$$

$$d_i = \begin{cases} 1 & \text{if } w_{ij} \le w_{\min j} \\ \left(\dfrac{w_{ij} - w_{\max j}}{w_{\min j} - w_{\max j}} \right)^{\delta} & \text{if } w_{\min j} \le w_{ij} \le w_{\max j} \\ 0 & \text{if } w_{ij} \ge w_{\max j} \end{cases} \tag{7}$$

In Equations (6) and (7), d_i are the individual desirability of SWOT group weights of a given alternative *i*; $w_{\min j}$ and $w_{\max j}$ are the maximum and minimum values of a given set of SWOT groups weights, respectively; derived using from Equation (3) and summarised in Table 2, and w_{ij} are SWOT group weights between $w_{\min j}$ and $w_{\max j}$. The parameter δ is a constant that determines the shape of the desirability function. When the value of δ is equal to 1, the function varies linearly between 0 and 1, in the case where δ is greater than 1, the shape is concave, while values of δ less than 1 results in a convex function.

Table 2. Multi-criteria analysis (MCA) decision matrix diagram.

Criteria	Alternative technologies			
	A_1	A_2	…	A_n
C_1	w_{11}	w_{12}		w_{1n}
C_2	w_{21}	…	…	w_{2n}
…	…	…	…	…
C_n	w_{n1}	w_{n2}	…	w_{nn}

C_i are criteria, in this case SWOT groups; A_i are technologies to be ranked; w_{ij} are weights assigned to each SWOT group (see Section 2.2).

The overall desirability of a given alternative can then be calculated using the weighted summation method [26] according to Equation (8):

$$D_i = \sum_{i=1}^{n} \omega_i d_i \tag{8}$$

where D_i is desirability of a given bioenergy technology; and ω_i are the weights assigned to SWOT groups i. The technologies can then be ranked basing on their overall desirability, and those with higher desirability values are the preferred options.

2.4. Sensitivity Analysis

The last step is to carry out sensitivity analysis to determine the stability of the ranks of alternative bioenergy systems subject to changes in weights of SWOT group factors. During this process, point data is modified to observe their effects on the ranks of technologies, therefore enabling generation of scenarios [35].

3. Application of the Methodology

3.1. Description of the Study Area

The study was carried out in Gulu municipality, located about 330 km by road to the north of the Ugandan capital, Kampala (Figure 3).

Figure 3. Map of Uganda showing the location of study area, in circle (based on United Nations (UN) map, Source: UN Cartographic section [36]). Reprinted/Reproduced with permission from UN Online Project, 2014.

The municipality is the second largest urban settlement in Uganda, with an estimated population of 150,000 inhabitants [37]. The majority of households rely on charcoal and firewood as the main sources of domestic energy, but the biomass resources in the area are being extracted faster than the rate of replenishment [38]. A study by Drigo [8] indicated that the municipality currently experiences a net deficit of fuel wood resources. Recent efforts by the government and development partners have led to an increased use of energy-saving stoves. Bioenergy technologies such as biomass briquetting, biogas and gasification are still new to the area and not widely adopted [39].

3.2. Technologies Considered in the Study

A literature survey and field visits were carried out to identify possible bioenergy technologies that could be developed for use in the study area. Emphasis was placed on identifying technologies which have been successfully employed in the country, but are not widely adopted. Where possible, samples of the technologies were acquired for demonstration during stakeholder workshop, otherwise, photographs were taken. The following is a brief description of technologies that were identified and considered for this study. More detailed explanation of these technologies is available in Okello *et al.* [5].

3.2.1. Biogas System

Biogas technology was introduced in Uganda in the 1950s, and is one of the priority bioenergy technologies being promoted in the country [40]. As per the renewable energy policy, Uganda has set a target of installing 100,000 domestic biogas digesters by the year 2017 [9]. The systems range in volume from 6 m^3 to 16 m^3 and are specifically designed to fulfil household energy needs [5,41]. Cattle manure is the most common substrate for feeding biogas plants in the country. In the proposed system, grass is cultivated to ensure reliable supply of cattle feeds, which are kept under a zero-grazing system. An acre of pasture is provided for each animal, and normally a household requires two heads of cattle to generate sufficient biogas. The bio-digester is constructed underground and the substrate is mixed with water and fed to the digester on daily basis. Simple burners are provided for combustion of the biogas, which is conveyed from the digester to the house through pipes.

3.2.2. Briquetting System

Biomass briquetting is the conversion of loose biomass material into a high density product by subjecting the material to pressure, with or without a binder [42]. The briquetting process involves material collection, drying, commutation and densification, using various types of presses [43]. The resulting product is called briquettes and is easier to handle and has better combustion properties than the original biomass material. In Uganda, the available agricultural and forest residues could be used as raw material for briquetting [44,45]. In the proposed system, the briquettes are used for cooking in gasifier stoves that are more efficient than traditional stoves [45]. Since briquetting machines are expensive, briquetting services can be provided by a private proprietor at a fee.

3.2.3. Charcoal Systems

Charcoal is the energy source most widely used by the urban population in Uganda. The production of charcoal in the country is by carbonisation in traditional earth-mound kilns. Wood used for the production is from natural forest, mainly found on privately owned land. The efficiency of the carbonisation process is less than 15%, and combustion takes place in charcoal stoves with efficiencies of about 10% [5,46]. Charcoal production activities are a major source of employment and are blamed for the high deforestation rates in Uganda. Due to diminishing forest reserves resulting from extensive deforestation, price of charcoal is currently increasing rapidly.

3.2.4. Jatropha System

Under this system, a plantation of Jatropha (*Jatropha curcas*) is established by households. Jatropha can be planted on marginal lands or intercropped in agro-forestry systems [47]. Jatropha fruits are harvested and manually de-hulled and dried in open air. Oil extraction is carried out using expellers, such as the "Sundhara" oil expellers, which are designed for use for a variety of oil seeds under rural conditions [48]. The expeller would be privately owned by a group or an individual, who provides oil extraction service at a fee. Impurities in oil are allowed to settle before being decanted using gravitational method through a piece of cotton cloth. Combustion takes place in plant oil pressure stoves, such as the Protos (BSH Bosch and Simens Hausgeräte GmbH, Munich, Germany) [49,50]. Part of the oil extracted can be used for making soap and therefore diversifying the rural economy.

3.3. Data Collection and Analysis

3.3.1. Selection and Composition of Stakeholder Panel

Data used in this study was collected during a one-day multi-stakeholder workshop held at Gulu University in February 2013. The workshop was attended by 28 participants from various interest groups. Participants were purposely selected [51] to represent a broad spectrum of stakeholders of the bioenergy sector in the municipality. To ensure representativeness of the various interest groups, stakeholders were categorised into government, non-governmental organisations (NGOs), academic and research institutions, and private individuals and businesses using biomass for cooking. At least two participants from each stakeholder group participated in the workshop. The NGOs that participated are involved in promoting improved biomass stoves and biogas technologies in Gulu district. The researchers that participated in the workshop were from different departments of Gulu University, also located in the municipality.

3.3.2. Implementation of the Workshop

The workshop was organised in three main sessions. During the first session, participants were introduced to the topic of bioenergy technologies, and the need for improved bioenergy technologies was explained. Different bioenergy technologies currently being promoted in country were explained to participants including the challenges facing their dissemination and use. This was followed by a detailed explanation of the four bioenergy technologies to be ranked in this study. The process was made as participatory as possible so that participants could freely share their knowledge and experiences with the technologies. During the third session, participants were divided into four groups, and each tasked with development of SWOT factors for one of the technologies. Results of SWOT analysis developed by individual groups were presented to the general stakeholder's forum and discussed and a final list of SWOT factors agreed upon. Finally, the SWOT factors were typed in a specially designed spreadsheet format for pairwise comparison. These were printed and given to each participant to carry out a pairwise comparison.

3.3.3. Analysis of Results

Results of SWOT analysis were processed following the AHP procedure as described in Section 2. A spreadsheet programme was developed in Microsoft Excel® and used for pairwise comparison of the factors. The spreadsheet was also used to test for consistency of the pairwise comparison. Results were aggregated using geometric mean as recommended by Forman and Peniwati [52]. Ranking of technologies and sensitivity analysis were carried out using the multi-criteria analysis (MCA) software DEFINITE [53]. It was assumed that the SWOT factors had equal weights of 0.25. The sensitivity analysis phase was used to evaluate the effect of varying the weights on the ranks of the technologies. A numerical example of calculation steps used for ranking the technologies is given in the Appendix.

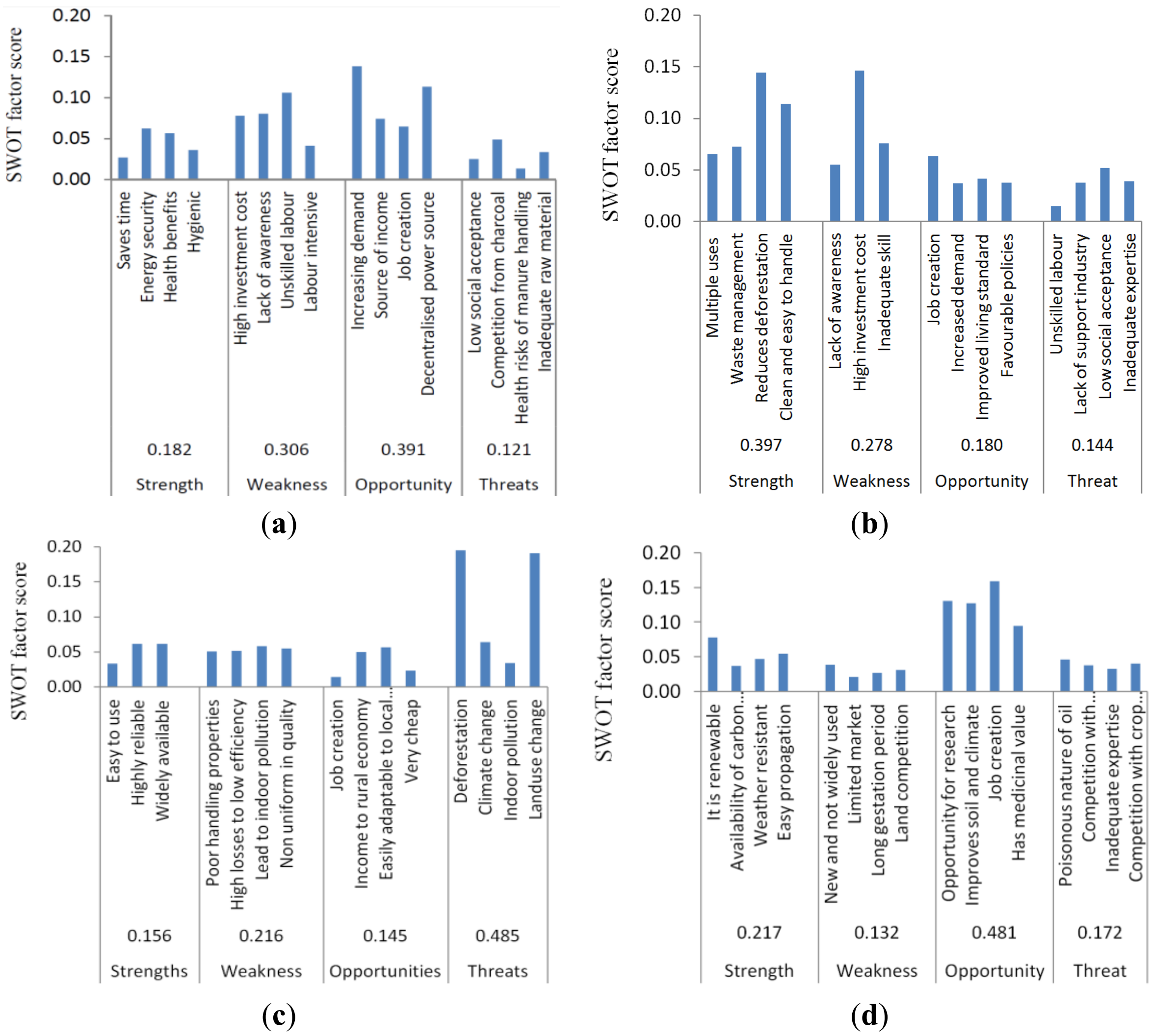
4. Results and Discussions

4.1. Results of SWOT-AHP Phase

Results of the SWOT-AHP phase is illustrated in Figure 4, and details of individual scores of the SWOT groups and factors are given in Table A1 of the Appendix. The graphs show that biogas systems had opportunities ranked highest at 0.390, mainly due to increasing demand for the systems and its ability to provide decentralised energy services to individual households (Figure 4a). Inadequacy of skilled personnel, lack of awareness about the technology and high investment costs were identified as the most detrimental factors to the adoption of biogas technology. Results of the briquette systems are given in Figure 4b, with its strengths scoring highest at 0.397. The most important strengths of briquettes identified were reduction in deforestation, cleanness and ease of handling. However, high investment costs and lack of skilled personnel were identified as most unfavourable factors to the technology. For charcoal systems, threats scored highest at 0.485 as shown in Figure 4c. This is mainly attributed to deforestation and land use change caused by charcoal production from natural forests. Meanwhile, opportunities of Jatropha system was greater than that of other SWOT group factors with a score of 0.481 (Figure 4d), mainly due to job creation, opportunities for research and development of products, diversity rural economy and the favourable climate and soils. The poisonous nature of Jatropha and competition with other fuels were the most detrimental factors identified.

Results of the SWOT-AHP phase presented here demonstrates the ability of the methodology to identify issues that stakeholders consider as critical for selecting bioenergy technologies. Some of the issues identified by the stakeholders are in agreement with available literature, for example, Mwampamba *et al.* [42] observed that briquetting has environmental benefits such as reduced deforestation, and offers opportunity for carbon credit. Threats of deforestation due to charcoal production [54], and the environmental and health benefits of biogas [55] are well documented in literatures. High investment cost was identified as major challenges to the adoption of biogas [55] and briquetting [42] technologies in developing countries. Usually, success of biogas and briquette programmes in developing countries is attributed to substantial support from government and aid agencies [54]. On the other hand, the ability of Jatropha to grow on marginal land is seen as one of its main advantages and stakeholders rated this highly. The views expressed by the stakeholders were therefore in agreement with pertinent issues concerning the bioenergy technologies studied.

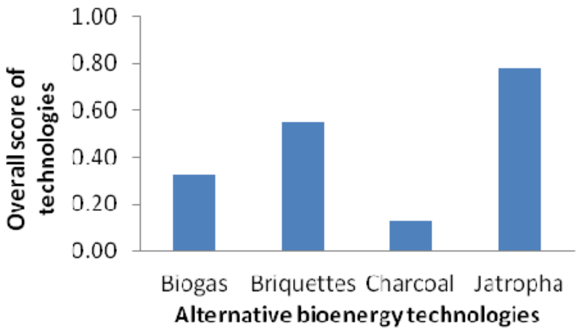
Figure 4. Stakeholder rating of SWOT factors and groups: (**a**) biogas; (**b**) briquettes; (**c**) charcoal; and (**d**) Jatropha. Only data that fulfilled consistency threshold were included in the results.



4.2. Ranks of Technologies

The ranks of the four bioenergy technologies studied are given in Figure 5. Jatropha was ranked as the best technology with an overall score value of 0.78, while charcoal ranked lowest with a score of 0.13. A numerical example illustrating how values presented in Figure 5 is given in Appendix. Available literature indicates that Jatropha oil is a suitable fuel for small scale projects in SSA, when used in multifunctional platforms [56]. It can be processed into biodiesel or used for making soap, therefore supporting diversification of rural economy [57]. However, there are debates about Jatropha production; for example, it is reported to have a negative impact on carbon stock [58]. Other challenges include low yield, limited know-how for feedstock conversion, high investment costs and inadequate private capacity to support the development of the sector [59].

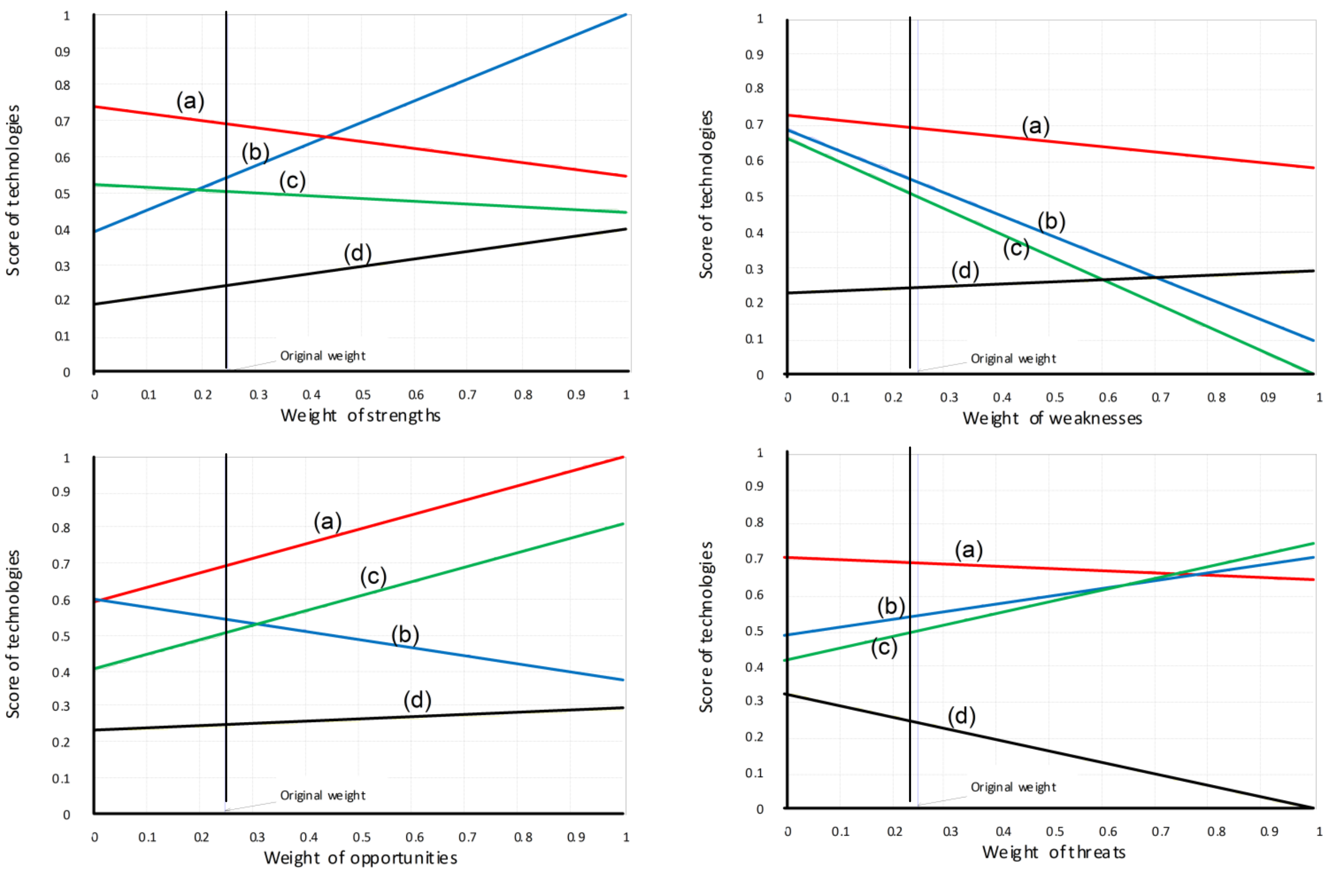
Figure 5. Scores of bioenergy technologies studied—higher scores are preferable.



4.3. Sensitivity Analysis

The effect of varying factor weights on the ranking of the technologies was analysed through sensitivity analysis, and the results are shown in Figure 6.

Figure 6. Sensitivity analysis plots: (**a**) Jatropha; (**b**) briquettes; (**c**) biogas; and (**d**) charcoal.



Biogas and briquettes were found to be highly sensitive to variation in the values of the weakness factors, with their scores dropping near to zero with high values of weaknesses. However, charcoal is more robust to variation of weakness values. Sensitivity analysis also indicates that rank reversal occurs between Jatropha and biogas systems, with biogas ranking highest when values of strengths were increased beyond 0.6. Therefore, both biogas and briquettes technologies would be acceptable by the community depending on management policies and incentives.

4.4. Discussions on the Methodology

In this study, we developed a method that incorporates desirability functions into the SWOT-AHP methodology for participatory appraisal of alternative bioenergy systems. The AHP methodology used is a very powerful MCA tool with capabilities of allowing commensurability of both quantitative and qualitative variables. Use of pairwise comparison in AHP enhances the aptitude of the decision maker in the analysis of the alternatives therefore resulting in more rational decisions. The method offers more flexibility over traditional approaches such as contingent evaluation, which requires that all variables are measured in financial terms. The multi-criteria technique employed has capability of ranking multidimensional, conflicting and uncertain systems. Furthermore, participation of stakeholders in AHP studies is based on opinion leadership and representative democracy, therefore allowing for smaller number of samples than in statistical approaches [17]. The method is useful in environments where data for decision making is not readily available. It could help in identification of hidden interests, cultural constraints and other social values of the target community.

However, the methodology is based on some assumptions and has limitations that should be taken into consideration. First, during the SWOT analysis, there is a possibility that some factors proposed by participants may not be technically suitable for consideration. Therefore, the researcher has to ensure the appropriateness of the factors by ensuring legibility and avoiding redundancy [60]. Secondly, the assumption of AHP methodology that the hierarchical factors are independent of each other may not necessarily be true, especially when complex systems are taken into consideration. This weakness could probably be reduced by integrating desirability functions in the SWOT-ANP (analytical hierarchy process) as suggested by Catron *et al.* [61]. Also, the SWOT methodology does not take uncertainties related to future development into consideration. As proposed by Kurttila *et al.* [15] scenario modelling using dynamic SWOT analysis could be a possible solution to this limitation. As a rule, the number of SWOT factors for pairwise comparisons should be limited to 10; otherwise human cognition may not be capable of objectively carrying out pairwise comparison. In cases where this rule cannot be obeyed, grouping the factors under different categories is proposed as a remedy.

Much as the SWOT-AHP method is a very useful tool, it heavily relies on qualitative judgement of the SWOT factors. It does not incorporate measurable economic, social and environmental variables of sustainability. It is therefore recommended that it should be used to supplement other more rigorous methods such as financial cash flow or cost-benefit analysis (CBA) [62], life-cycle analysis (LCA) [63] and life cycle costing (LCC) [64]. Usually, these methods require considerable amount of data and time to implement. Therefore, the proposed method may help in pre-screening of technologies that will most likely be accepted by the target community prior to more rigorous methods such as LCA, CBA and LCC. This is particularly important in developing countries where required data and logistics for their collection are often lacking. Pre-screening of technologies is advantageous since it helps to eliminate trivial options therefore enabling directing resources to a few promising alternatives. The method could also be used to identify stakeholders concerns about bioenergy technologies; thus, developing appropriate strategies for addressing them. Alternatively, the method could be used as a tool for reaching consensus in cases where there are conflicting interests among stakeholders. Generally, it could be used as a tool for soliciting stakeholder opinion during multi-criteria decision analysis of technologies, which considers social, economic and environmental aspects simultaneously [65].

The application example presented is the first of its kind and could benefit from further trials. More rigorous data collection methods could be taken into consideration to evaluate the repeatability of the results. One could also study if there would be differences in the ranking of the technologies amongst different stakeholder groups. Furthermore, the possibility of incorporating other participatory techniques such as Delphi techniques could be taken into consideration to improve the overall rigour of the participatory process.

5. Conclusions

In this study, we proposed a methodology for participatory appraisal of technologies, and applied it in a case study to rank four bioenergy systems in Uganda. The methodology is intended to identify bioenergy technologies with a higher chance of public acceptance at the early stages of project development. The case study implemented showed that the tool is effective for identifying stakeholder preference of bioenergy technologies including the underlying reasons for their choices. The results of the study suggest that Jatropha could be accepted as a fuel for household energy in Uganda. Further, stakeholders regard charcoal as not sustainable mainly because of the threats it poses to the environment. Results suggest that suitable policies aimed at increasing affordability of bioenergy technologies could help increase their adoption rates in Uganda. Also, improving the critical mass of skilled personnel could play an important role in ensuring increased dissemination of improved bioenergy technologies.

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Appendix: SWOT Factors and Their Rankings and a Numerical Example for Generating Figure 5

Table A1. SWOT factors and their rankings as identified by stakeholders.

Technology	Energy technology	Group priority	SWOT factors	Local priority	Global priority	Brief description of SWOT factors
Biogas	Strengths (S)	0.182	Saves time	0.149	0.027	Requires less time to operate compared to fuelwood collection
			Energy security	0.342	0.062	Ensures households are secure of energy supplies
			Health benefits	0.312	0.057	Reduced indoor pollution leads to better health of users
			Hygienic	0.198	0.036	Anaerobic digestion sanitises livestock waste
	Weaknesses (W)	0.306	High investment cost	0.255	0.078	Capital cost is high for average Ugandan households
			Lack of awareness	0.263	0.081	Potential users do not know about benefits of biogas
			Unskilled labour	0.347	0.106	Limited personnel to construct and maintain the technology
			Labour intensive	0.135	0.041	High labour requirements for day-to-day system management
	Opportunities (O)	0.391	Increasing demand	0.354	0.138	Demand for the technology is known to be rising
			Source of income	0.189	0.074	Possible income from sale of gas and slurry as fertilizer
			Job creation	0.166	0.065	Employment in the value chain, mainly masons
			Decentralised power source	0.291	0.114	The plants are family owned so have better control over their operational performance
	Threats (T)	0.121	Low social acceptance	0.207	0.025	Low acceptance is mainly due to lack of awareness
			Competition from charcoal	0.405	0.049	Charcoal is widely used and accepted therefore limiting adoption of the new technology
			Health risks of manure handling	0.112	0.013	Currently manure handling is done manually (by hand) and could pose risk to transmission of cattle disease to users
			Inadequate raw material	0.277	0.033	Many households do not have cattle to supply manure
Charcoal	Strengths (S)	0.156	Easy to use	0.212	0.033	Simplicity of the technology enables its ease of operation
			Highly reliable	0.394	0.061	Less prone to shutdowns due to system failure
			Widely available	0.394	0.061	Charcoal and stoves are readily available on the local market
	Weaknesses (W)	0.216	Poor handling properties	0.235	0.051	Easily crumbles into small particles during handling
			High losses to low efficiency	0.241	0.052	Wastage of charcoal occurs during use due to inefficient combustion appliances
			Leads to indoor pollution	0.271	0.058	Due to emissions of poisonous gases and particulate matter
			Non uniform in quality	0.255	0.055	Quality is not consistent due to varying source of wood used

Table A1. *Cont.*

Technology	Energy technology	Group priority	SWOT factors	Local priority	Global priority	Brief description of SWOT factors
Charcoal	Opportunities (O)	0.145	Job creation	0.101	0.015	Employment in the production and sale of charcoal and stoves
			Income to rural economy	0.344	0.050	Charcoal is a major source of income to rural households
			Easily adaptable to local conditions	0.392	0.057	Technology is simple and can easily offer opportunity to be easily adopted/improved to local conditions
			Very cheap	0.164	0.024	Potential savings by households due to low capital an operating costs
	Threats (T)	0.485	Deforestation	0.403	0.195	Currently there is rapid loss of forest vegetation in Uganda
			Climate change	0.132	0.064	Emissions from charcoal could contribute to climate change
			Indoor pollution	0.072	0.035	Indoor pollutants have negative health impacts on users
			Land use change	0.394	0.191	Undesirable change in land use due to wood harvesting leading to loss of biodiversity
Jatropha	Strengths (S)	0.217	It is renewable	0.360	0.078	It is a renewable energy source
			Availability of carbon credit	0.171	0.037	This is an incentive for using renewable energy under cleaner development mechanism (CDM)
			Weather resistant	0.218	0.047	Jatropha plant grows in adverse weather conditions
			Easy propagation	0.251	0.054	Availability and ease of propagation from seeds and cuttings
	Weaknesses (W)	0.132	New and not widely used	0.329	0.043	Being new technology, it is not known by potential users, thus limiting its adoption
			Limited market	0.177	0.023	Under developed market system for Jatropha technology
			Long gestation period	0.229	0.030	Time lag from planting to sustainable yield of 3–5 years
			Land competition	0.265	0.035	Competition for land for other productive activities
	Opportunities (O)	0.481	Opportunity for research	0.255	0.123	Opportunity to develop biodiesel, soap and medicines
			Improves soil and climate	0.249	0.119	Jatropha reduces soil erosion and improves microclimate in areas where it is grown
			Job creation	0.311	0.149	Employment in the value chain of Jatropha energy system
			Has medicinal value	0.186	0.089	Jatropha products could be used for treatment of ailments

Table A1. *Cont.*

Technology	Energy technology	Group priority	SWOT factors	Local priority	Global priority	Brief description of SWOT factors
Jatropha	Threats (T)	0.172	Poisonous nature of oil	0.296	0.051	The oil is poisonous and can be a health and safety hazard
			Competition with charcoal	0.242	0.041	Charcoal is so far very popular and could be a limiting factor to Jatropha use
			Inadequate expertise	0.207	0.036	Inadequate organisational capacity to develop the technology
			Competition with crop production	0.256	0.044	Diversion of resources to Jatropha production could lead to food insecurity
Briquettes	Strengths (S)	0.397	Multiple uses	0.166	0.066	Possibility to use in a variety of locally available cooking devices
			Waste management	0.184	0.073	It is a suitable method for managing agricultural waste
			Reduces deforestation	0.364	0.144	Due to substitution of charcoal
			Clean and easy to handle	0.287	0.114	Has better handling properties than charcoal and do not crumble easily
	Weaknesses (W)	0.278	Lack of awareness	0.200	0.055	Potential users do not know about benefits of briquettes
			High investment cost	0.527	0.147	Briquetting machines are expensive for average household
			Inadequate skill	0.274	0.076	Limited skilled personnel to maintain the technology
	Opportunities (O)	0.180	Job creation	0.352	0.063	Employment in the value chain of briquetting
			Increased demand	0.206	0.037	There is growing demand for briquettes
			Improved living standard	0.233	0.042	Use of briquettes lead to better living conditions due to reduced labour requirements for wood fuel collection
			Favourable policies	0.210	0.038	Government policies encourages use of renewable energy
	Threats (T)	0.144	Unskilled labour	0.106	0.015	Lack of skilled artisans required for briquette production
			Lack of support industry	0.263	0.038	Electricity, roads and other infrastructure required from briquetting
			Low social acceptance	0.359	0.052	Low acceptance mainly due to lack of awareness
			Inadequate expertise	0.272	0.039	Inadequate organisational capacity for the development of briquetting industry

In order to rank the technologies, first the SWOT group priority values in third column of Table A1 are transformed into a multi-criteria decision matrix, as illustrated in Table 2. The result of this process is given in Table A2.

Table A2. Multi-criteria decision matrix of the current study.

Criteria	Alternative technologies			
	Biogas	Charcoal	Jatropha	Briquettes
Strengths (S)	0.182	**0.156**	0.217	**0.397**
Weaknesses (W)	0.306	0.216	0.132	0.278
Opportunities (O)	0.391	0.145	0.481	0.180
Threats (T)	0.121	0.485	0.172	0.144

Next, the values of SWOT factors given in Table A2 are transformed into desirability values ranging between 0 and 1. Desirable attributes, i.e., strengths and opportunities should be maximised and therefore transformed using Equation (6). In Equation (6), $w_{\min j}$ is the lowest value of each criterion, given in Table A2, while $w_{\max j}$ is the highest. For the case of strengths, $w_{\min j}$ = **0.156**, and according to Equation (6), it transforms to a desirability value of 0. Also, $w_{\max j}$ = **0.397**, which transforms to a desirability value of 1 according to Equation (6). Intermediate values, w_{ij} are 0.182 and 0.217, can be transformed using Equation (6) as ((0.182 − 0.156)/(0.397 − 0.156)), and ((0.182 − 0.156)/(0.397 − 0.156)), which yield 0.108 and 0.253, respectively. Values of opportunities can be similarly transformed using Equation (6). Following a similar argument, values of weaknesses and threats can be transformed into desirability values using Equation (7). The result of this process is given in Table A3.

Table A3. Desirability values of the criteria of each technology.

Criteria *	Desirability of alternative technologies			
	Biogas	Charcoal	Jatropha	Briquettes
d_S	**0.108**	0.000	0.253	1.000
d_W	**0.000**	0.517	1.000	0.161
d_O	**0.172**	0.000	1.000	0.104
d_T	**1.000**	0.000	0.860	0.937

* d_S, d_W, d_O and d_T are desirability values of strengths, weaknesses, opportunities and threats, respectively.

Assuming equal weight of 0.25 for each of the criteria, the overall score of biogas technology can be calculated using Equation (8) as (**0.108** × 0.25) + (**0.000** × 0.25) + (**0.172** × 0.25) + (**1.000** × 0.25), which yields 0.320 as the overall score of the technology. The overall scores of charcoal (0.13), Jatropha (0.78) and briquettes (0.55) technologies can be calculated in a similar manner and the results used to plot Figure 5.

Conflicts of Interest

The authors declare no conflict of interest.

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