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Economic Viability Investigation of Mixed Biomass Briquettes Made from Agricultural Residues for Household Cooking Use

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Abstract: This paper presents a theoretical evaluation of the prices of mixed briquettes produced from coconut shells (CCS), banana peels (BNP), rattan waste (RWT), and sugarcane bagasse (SGC), and, on the other hand, an analysis of the economic viability of their use as a replacement for conventional household fuels (Liquefied Petroleum Gas, fuelwood, and wood charcoal) in households in Cameroon. The investigation was carried out using the Life Cycle Cost method on a typical household over a ten-year period with annual cooking energy requirements of 950 kWh_{th}. The SGC-CCS and SGC-RWT mixed briquettes with a ratio higher than 7.75% and 11.1%, respectively, have prices lower than 0.063 €/kWh_{th}. The Present Value of the Net Benefit is positive for the use of SGC-CCS and SGC-RWT mixed briquettes. The results show that by making the right mixes of residues, it is possible to obtain biomass briquettes that are less expensive than conventional fuels.

Keywords: cost evaluation; mixed briquettes; conventional fuels; life cycle cost; household use

1. Introduction

Global energy accessibility is required to improve human survival and ensure economic, social, and environmental growth [1,2]. Most sub-Saharan African countries have faced significant growth in energy consumption because demand often outstrips supply and energy constraints [3,4]. More over two thirds of the energy consumed around the world is produced from non-renewable energy resources, as gas, oil, and coal [5]. One way of using energy is for household cooking, which accounts for a sizable portion of overall household expenses. Wood is the main energy source in a lot of low-income areas, it provides more than 80% of all the energy used in Africa [6]. These energy sources have finite supplies and a negative impact on the environment; according to forecasts, more than 60% of the wood removed from forests and non-forests is used for energy purposes [5], [7]. With a growing worldwide population, it is becoming increasingly important to have alternative, clean and sustainable energy sources to solve environmental challenges such as climate change.

Biomass is a promising renewable energy source suitable for several uses. Hazardous gases and other toxic compounds for humans are released during the direct burning of biomass fuels. According to Lambe et al. (2015), in 2012, the usage of biomass in Africa caused close to 600,000 premature deaths [8]. Numerous researches have suggested that utilising biomass in briquette form has various benefits. Briquettes have increased qualities and are suitable to move about, store, put in

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furnaces, and burn [9,10]. A biomass briquette is a solid fuel created from carbon-rich materials like agricultural waste that has been dried, carbonised, crushed, mixed with a binder, briquetted, and then dried [11]. The quality of the fuel briquettes which are produced is significantly influenced by the biomass that is selected. The choice of wastes for briquette production relies on their properties, affordability, and accessibility in a given area.

Nearly 7.5 million Cameroonians live in poverty, or on less than €1.42 per day, making Cameroon a low-income nation [12]. Increasingly expanding economies have led to increased fuel prices and shortages, which often hit households. In this economic background, fuel cooking expenditures represent a large part of overall household costs. Consumers' fuel preferences are affected by a variety of factors, including cost and financial availability, in addition to energy efficiency and environmental friendliness. Finding innovative approaches to reduce family expenses while making sure healthy meals is crucial. A careful economic investigation is necessary to evaluate the viability of briquettes for household cooking use.

This paper discusses the possibility of low-cost mixed briquettes from coconut shells, rattan waste, sugarcane bagasse and banana peels. This work is a follow-up to the work of [1,12,13] who produced, characterised and carried out an economic and energy analysis of the production and use of pure CCS, RWT, SGC and BNP briquettes. In light of the results obtained from these previous studies, the physicochemical characteristics of CCS and RWT briquettes are very satisfactory, whereas those of SGC and BNP briquettes are quite weak, even though SGC and BNP are the most widely available residues. The results of these investigations have led to the common conclusion that mixed briquettes should be produced in order to improve energy characteristics and, above all, at affordable prices. In the literature, studies have been carried out on mixed briquettes; for instance rice straw and rice bran mixture [14], corncob and rice husk [15], rice husk and coal [16], sawdust and palm kernel shell [17], sawdust and palm kernel shell [17], rice husk and palm oil mill sludge [18], rice husk and coconut shell [19], rice straw and sawdust [20], groundnut shells and bagasse [21], rice and coffee husks [22], Cocoa Pod Husk and Sawdust [23], sugarcane bagasse and rice bran [24], sugarcane bagasse, corncob and rice husk [25], rice straw and banana peels [26], coffee husk and corncob [27]. The limitations of these previous studies are that the selection of residues is not systematically justified and the mixtures are not carried out according to a clearly established relationship. Some studies use mixtures with ratio steps of 10%, some of 20%, and others of 50%, and it is after several attempts, spending money, time and resources, that conclusions are drawn. In addition, the economic aspects of using these mixed briquettes are not really taken into account.

This study presents a theoretical analysis of the economic feasibility of mixture fuel briquettes made from RWT, RWT, SGC, and BNP for Cameroonian households. The specific objectives are: firstly, to evaluate the price of the mixture briquettes; secondly, to assess the Present Value of the Net Benefit of the use of the mixture briquettes in replacement of conventional household cooking fuel, such as LPG, wood charcoal, and fuel wood. The investigation is conducted using the life cycle cost method in a Cameroonian sample household with annual thermal load of 950 kWh_{th} for cooking. This study presents a thorough energy transition strategy for Cameroonian household cooking demand in an effort to close the knowledge gap. It also contributes to (i) providing a methodology for the determination of the optimal ratio of residues in briquettes making (ii) giving information to briquettes making companies on low-cost techniques for briquettes manufacturing (iii) inform households about the cost advantages of switching to biomass briquettes for cooking.

2. Materials and Methods

The current study focuses on a single, five-person household in Douala, Cameroon located in the Central African region. The economic analysis was performed to compare the planned household biomass briquettes system. The purpose of the conducted economic analysis is to compare the conventional cooking fuel system (wood charcoal, fuelwood, and LPG) with the suggested mixture of briquettes home system.

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2.1. Assumptions

In order to conduct the assessment the following considerations are assumed:

- The thermal load of the typical household is estimated at 950 kWh_{th}/year.
- Because of the physicochemical and economic properties of pure CCS, RWT, BNP, and SGC briquettes, four types of mixture briquettes are studied: BNP-CCS, SGC-CCS, BNP-RWT, and SGC-RWT.
- The property values and prices considered for pure CCS, RWT, BNP and SGC briquettes and economic parameters are those found by [1,12] and are reported in Table 1 and Table 2.
- The price of mixed briquettes is assumed to be proportional to that of pure briquettes.
- The ratio considered are percentage by weight
- Life Cycle Cost is applying as recommended by [1].

Table 1. Characteristics of conventional fuel and pure briquettes studied.

	Pure biomass briquettes				Convectional fuels		
	Coconut shells	Rattan waste	Banana peels	Sugarcane bagasse	LPG	Fuelwood	Wood charcoal
Calorific value (kWh/kg)	8.92	8.34	4.67	7.19	12.64	5.08	8.33
Price (€/kg)	0.46	0.46	0.46	0.46	0.79	0.30	0.54
Price (€/kWh)	**0.051**	**0.055**	**0.098**	**0.064**	0.063	**0.12**	**0.065**

Table 2. Economic parameters on the study.

Parameters	Values
Cook stove cost for wood charcoal (€)	10
Cook stove cost for biomass briquettes (€)	10
LPG cylinder and cook stove cost (€)	60
Maintenance cost of LPG cook stove (€)	5
Inflation rate of maintenance cost (%)	5
Inflation rate of fuel cost (%)	2.4
Discount rate (%)	7

2.2. Determination of optimized mixture briquettes price

The prices of mixed briquettes are determined consecutively by following equations 1, 2 and 3.

$$BP = 1 - CP \tag{1}$$

CP = 0 ……1 (or 0%.......100%)

$$ME = CP \times CE + BP \times BE \tag{2}$$

$$MC = CP \times CE \times CC + BP \times BE \times BC \tag{3}$$

Where CP is the percentage by weight of Coconut or rattan waste in the mixture, CE is the Energy content of the Coconut or rattan waste kWh/kg, CC is the Energy cost of the Coconut or rattan waste €/kWh, BP is the percentage by weight of Banana or sugarcane bagasse in the mixture, BE is the energy content of the Banana or sugarcane bagasse briquette kWh/kg, BC is the energy cost of the Banana or sugarcane bagasse €/kWh, ME is the energy of mixture kWh/kg , and MC is the cost of mixture €/kg.

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2.3. Life Cycle Cost

For LCC analysis, the current value Annual Cash Flow (AC_t) for each simulation year (t) was first determined. [28, 29]:

$$AC_t = E_d FC\,(1+i)^{t-1} + MC_s(1+j)^{t-1} + INV \tag{4}$$

E_d stands for yearly energy demand for cooking in a home (kWh), FC for conventional fuel or mixed biomass price evaluated in the equation 3 (€/kWh), MC for maintenance cookstove cost (€), INV for initial investment cost (€), i for fuel price inflation rate, j for the cookstove maintenance cost inflation rate.

The present value PV_t at the end of year t, was calculated via equation 5 :

$$PV_t = \frac{AC_t}{(1+d)^t} \tag{5}$$

Where d is the market discount rate.

In both instances, the LCC was calculated by adding the 10 yearly Present Values (Equation 6):

$$LCC = \sum_{t=1}^{t=10} PV_t \tag{6}$$

Finally, $PV_{of\ Net\ Benefit}$ is

$$PV_{of\ Net\ Benefit} = LCC_{conv} - LCC_{mix} \tag{7}$$

Where LCC_{conv} is the Life Cycle Cost of conventional cooking fuel and LCC_{mix} is the Life Cycle Cost of mixed biomass briquettes.

2.4. Annualized cost of heat

Equation 8 was used to determine the annualized cost of heat (ACOH) for the mixed briquette system in addition to the LCC technique. The cost per unit of heating load and the cost-effectiveness of a system can both be calculated using the ACOH (€/kWh_{th}). ACOH is a key index of determining the economic viability of a system in comparison to another [28].

$$ACOH = \frac{LCC}{\frac{1}{d}\left[1-\left(\frac{1}{1+d}\right)^{10}\right]E_d} \tag{8}$$

Where ACOH is the Annualized cost of heat (€/kWh_{th}), LCC is the Life Cycle Cost (€), d is the discount rate and E_d is the Annual Energy demand (kWh_{th}).

3. Results and Discussion

This section presents the cost of mixed briquettes is estimated and do an economic analysis in order to figure out if using mixed briquettes made from CCS, RWT, SGC, and BNP would be more cost-effective than using traditional fuels in a typical Cameroonian home with 950 kWh_{th} of annual thermal load.

3.1. Price of mixed briquettes

Figures 1 and 2 show the prices of banana peel and sugarcane bagasse briquettes mixed with coconut husks and rattan waste, respectively. Figure 1 shows the proportion of CCS and RWT that must be added to BNP to obtain a mixed briquette with a lower cost than LPG. The figure shows that a mixed SGC-CCS briquette (92.25% SGC - 7.75% CCS) or SGC-RWT briquette (88.9% SGC - 11.1% RWT) costs the same as LPG, meaning 0.063€/kWh. These figures show that a minimum percentage of 7.75% CCS and 11.1% RWT is required in mixed briquettes of SGC-CCS and SGC-RWT, respectively, for their costs to be lower than those of LPG. It can also be seen that the higher the proportion of CCS and RWT in the mixture, the lower the cost of the mixed briquette.

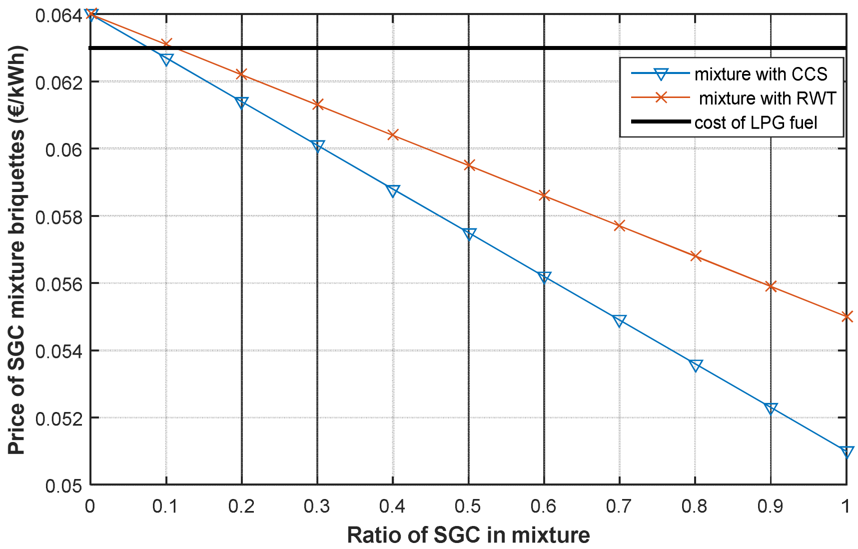

Figure 1. Price of SGC mixture biomass briquettes.

These findings suggest that briquette production companies should carefully consider the selection of residues in order to produce energy-efficient briquettes at lower costs. In Cameroon, the energy potential of sugarcane bagasse and coconut shells is 1,541.83 TJ per year and 9.3 TJ per year respectively [30,31]. Sugar cane is massively grown and exploited in the Littoral and Centre regions, while coconuts are grown and processed in the Littoral, Centre and Southern regions. However, these two crops are not harvested in the same seasons, so there are periods when one is more available than the other.

Figure 2 shows that a mixed BNP-CCS briquette (29.8% BNP - 70.2% CCS) and a mixed BNP-RWT briquette (23.3% BNP - 76.7% RWT) have the same cost as charcoal, i.e. 0.063 €/kWh. On the other hand, a mixed BNP-CCS briquette (25.5% BNP - 74.5% CCS) and a mixed BNP-RWT briquette (18.6% BNP - 81.4% RWT) have the same cost as LPG. It also appears that a minimum proportion of 70.2% CCS and 76.7% RWT is required in BNP-CCS and BNP-RWT mixed briquettes, respectively, for their costs to be lower than those of charcoal.

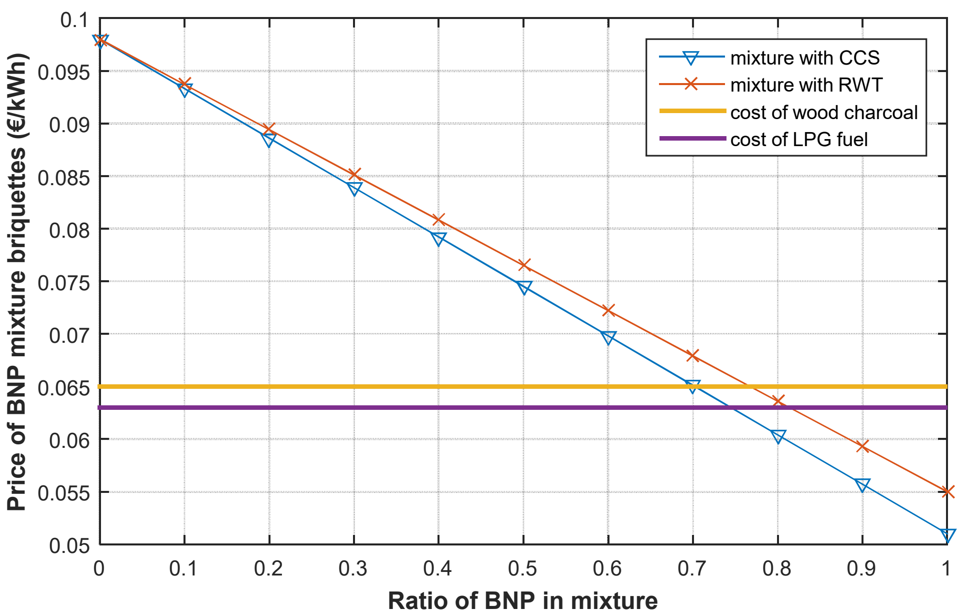

Figure 2. Price of BNP mixture biomass briquettes.

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Given the positive PVNBs for all blending ratios, economically viable blended briquettes could be produced throughout the year for household use. BNP's energy potential is one of the highest in Cameroon, with 250.84 kt of banana peels produced each year, representing a potential of 4,215.69 TJ. Bananas are grown and processed almost everywhere in the country, so banana residues are an easily accessible raw material for any briquette production company. That said, previous studies have reported that the production and use of pure BNP briquettes are economically expensive for both companies and households.

More than half of the work on briquette production focuses on the mixed residues. [14-27]. The approach proposed in this paper makes easy to select the mixing ratios and prepare the optimum briquettes in a short space of time and at a low cost. It could also be investigated other types of residue whose pure briquettes have already been characterized and whose economic analysis has already been the subject of research. Given their characteristics as reported in the literature, it would also be interesting to mix banana leaves, banana stem, cotton stalk, sugarcane leaves with one of the following residues: groundnut husk, maize cob, depending on the availability in an area.

3.2. Present Value of Net Benefit

Figures 3-6 present the results of the Present Value of Net Benefit assessment of the replacement of conventional household fuels with the studied mixed briquettes. Figures 3 and 4 show the PVNB of the SGC-CCS and SGC-RWT mixed briquettes and are almost similar due to the very close characteristics of the CCS and RWT briquettes. By observing these curves, it can easily be found that PVBN values are all positive, meaning that some of the biomass used to reinforce the SGC briquettes are economically viable for households. PVNB values for the replacement of LPG, Fuelwood and wood charcoal by mixed SGC-based briquettes are €150, €500 and €100, respectively. These values are in line with the prices of conventional fuels. It may also be that the higher the proportions of CCS and RWT are in the mixture the higher PVNBs are, due to the more interesting economic viability of the CCS CCS and RWT mixed with SGC briquettes. In figure 4, it can be seen that the PVNB values, for the whole range of the mixture ratio, are slightly lower than those in figure 3, due to the higher value of RTW compared to CCS.

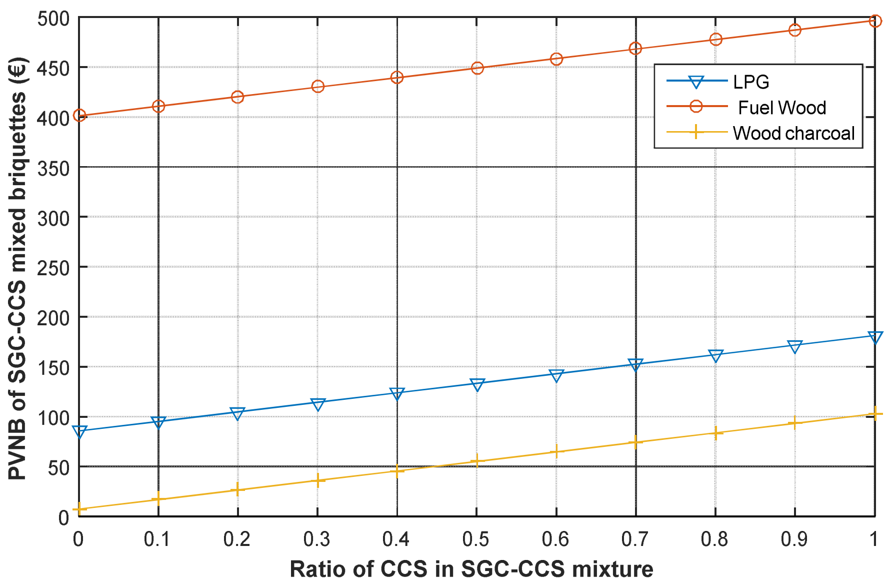

Figure 3. Present Value of Net Benefit of the replacement conventional fuel by SGC-CCS mixed briquettes.

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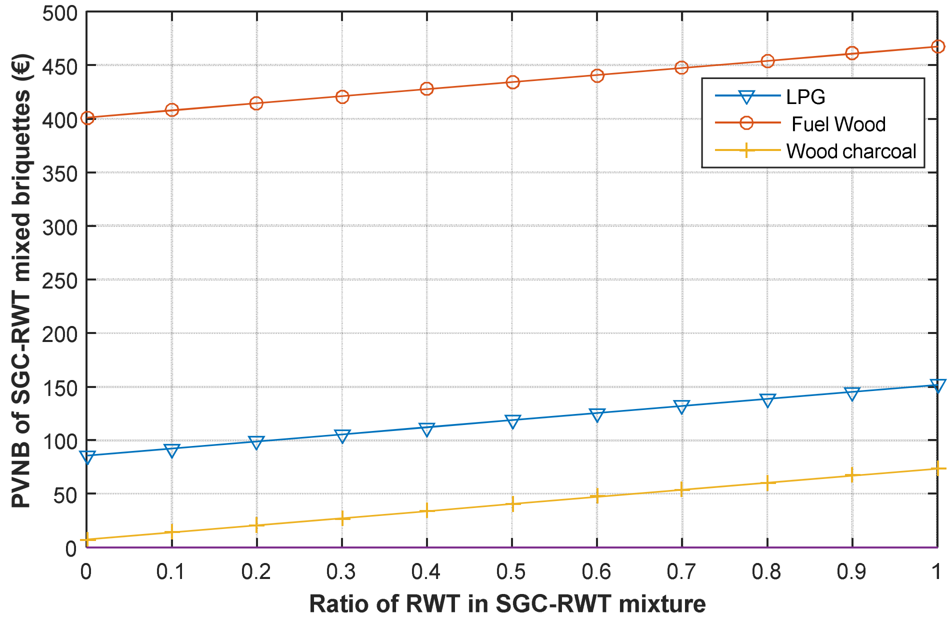

Figure 4. Present Value of Net Benefit of the replacement conventional fuel by SGC-RWT mixed briquettes.

Figure 5 illustrates the PVNBs of the replacement of fuelwood, LPG, and wood charcoal with mixed BNP-CCS biomass briquettes. It follows that the use of mixed BNP-CCS briquettes instead of fuelwood is more viable for a household due to the fact that pure CCS and BNP briquettes are more beneficial than fuelwood. The use of mixed briquettes is feasible for a ratio of at least 48% of CCS as a replacement for LPG and at least 70% of CCS as the replacement of wood charcoal.

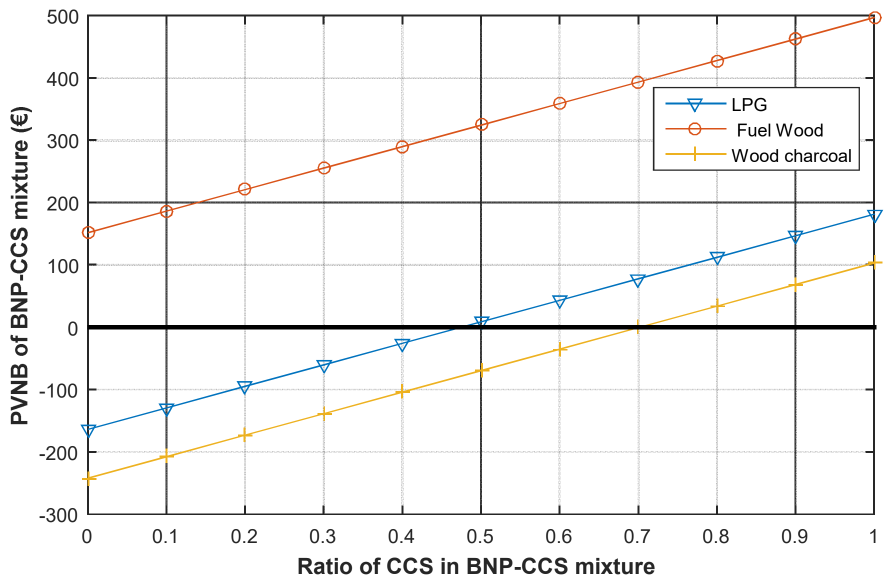

Figure 5. Present Value of Net Benefit of the replacement conventional fuel by BNP-CCS mixed briquettes.

Figure 6 shows the PVNB of the replacement of traditional fuels usually used in households in Cameroon by BNP-RWT mixed briquettes. It appears that BNP-RWT mixed briquettes are more economically viable for an average household than fuelwood. The use of these mixed briquettes is viable for an RWT ratio greater than or equal to 52% as a replacement for LPG and for an RWT ratio greater than or equal to 75% as a replacement for wood charcoal. BNP briquettes require a slightly

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higher proportion of RWT because of their less attractive physicochemical and economic characteristics.

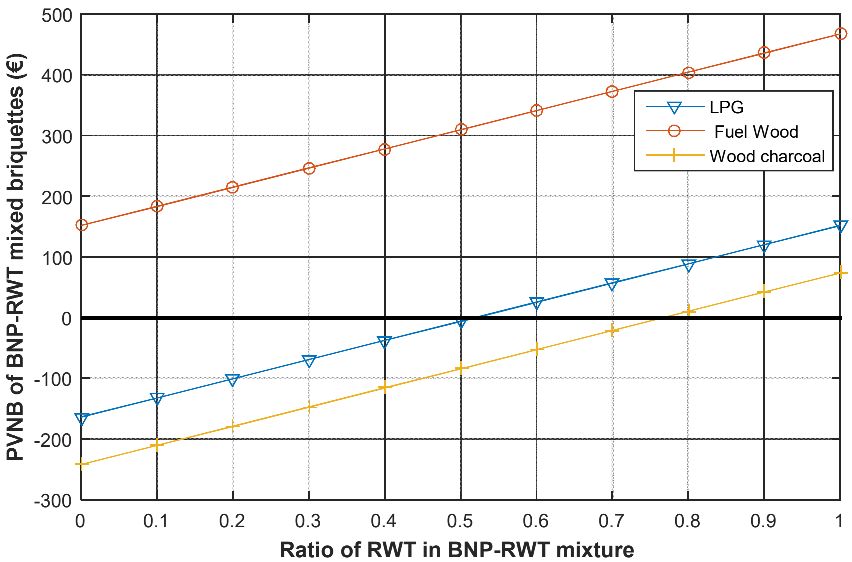

Figure 6. Present Value of Net Benefit of the replacement conventional fuel by BNP-RWT mixed briquettes.

3.3. Annualized cost of heat

The ACOH may be utilised, as was already indicated, for the systems' economic evaluation. The ACOH for proposed mixed briquettes cooking use were shown in Figure 7. According to figure (a) the use of mixed briquettes of BNP-CCS and SGC-CCS for cooking in households have an annualised heat cost varying between 0.055 and 0.105 €/kWh; and 0.055 and 0.068 €/kWh respectively. Figure (b) shows that the use of mixed briquettes of BNP-RWT and SGC-RWT for cooking in households have an annualised heat cost varying between 0.057 and 0.104 €/kWh; and 0.055 and 0.068 €/kWh respectively. It appears that the use of mixed briquettes from BNP-RWT and BNP-CCS is more expensive because of the characteristics of pure BNP briquettes. Finally, one can say that ACOH indexes confirm results of LCC analysis.

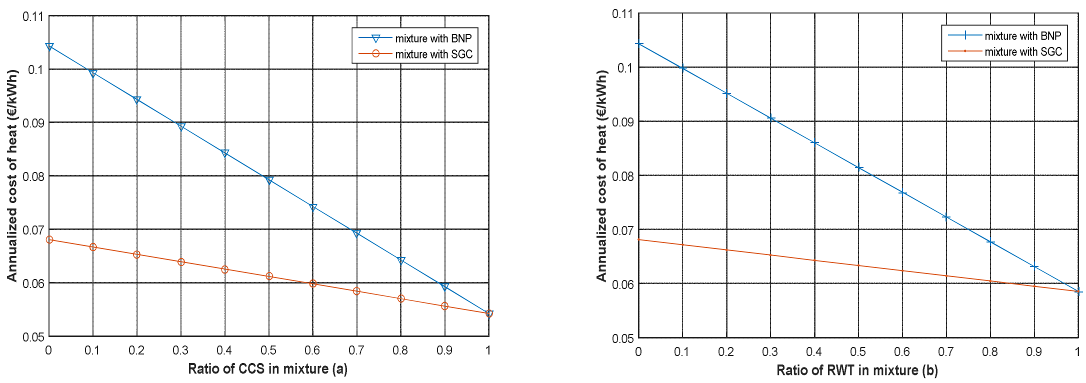

Figure 7. Annualized cost of heat of (a) CCS mixture (b) RWT mixture briquettes.

As the first study of this kind, the findings of this investigation open the way to achieving greater expertise in the proportions of mixed briquettes in Cameroon in other low-middle income countries. In Cameroon, as in most developing countries, the transition must be strongly linked to the low cost of energy source. Since 2011, there has been increasing inflation rate, with growth of 2.9%. Money spent on cooking fuel represents a significant proportion of daily household expenditure. The lower cost of fuel is therefore crucial to the growth and development of the household. By using mixed briquettes, households can make considerable financial savings and invest in other activities.

Some studies, such as Tamba, 2021 [32], have shown that in developing countries such as Cameroon, LPG use is increasing, but this also requires economic growth in the country. In light of the findings of the present study, it may be advisable to invest in briquette production rather than importing LPG. This will contribute to the development of the country's national economy. Many private investors and governments should capitalize in briquette production companies and training; these companies will produce briquettes more cheaply and households will spend less on briquettes. The acceptance of fuel briquettes in sub-Saharan Africa might be hindered by consumer ignorance or a lack of knowledge.

Expanding the usage of briquettes requires greater knowledge of them and interest in them. The Cameroonian government will profit financially if a sizable portion of the population switches to this fuel, particularly those living in urban areas. It would also be interesting for other sub-Saharan countries such as Ghana, Burkina Faso, and South Africa, which are looking for clean cooking fuel, as reported in [33–36]. The overall yearly cost of gasoline in Sub-Saharan countries was around 23 billion dollars in 2016, or roughly 112 dollars per family [37], It would be interesting to invest this money in briquettes production.

The environmental benefits of using briquettes instead of firewood have already been demonstrated. Sub-Saharan countries needed 498 million tonnes of fuelwood in 2016 (203 million tonnes for charcoal and 295 million tonnes for firewood) [37], according to a scenario established by Yvan Ayuketah et al., in 2045, the residential sector will continue to be the highest consuming sector [38]. Current consumption patterns' increased energy intensity, particularly in rural regions, will inescapably raise both energy demand and related GHG emissions, so if this substitution is not made, the consequences can be very disastrous.

4. Conclusions

The price of mixed briquettes made from banana peels, coconut shells, rattan waste, and sugarcane bagasse was theoretically evaluated in this paper. On the other hand, the economic viability of their use as an alternative to traditional household fuels (fuelwood, LPG, and wood charcoal) in Cameroonian households is investigated as well. The investigation was carried out by using the Life Cycle Cost method on a typical household over a ten-year period with annual cooking energy requirements of 950 kWh_{th}. Priced at lower than 0.063 €/kWh_{th} are the SGC-CCS and SGC-RWT mixed briquettes with ratios greater than 7.75% and 11.1%, respectively. Using mixed briquettes made of SGC-CCS and SGC-RWT has a positive Present Value of the Net Benefit. Mixture briquettes made of BNP-CCS and BNP-RWT have positive Present Value of the Net Benefit, for all values of the mixture ratio in the case of fuel wood, while for LPG and wood charcoal the positive value of Present Value of the Net Benefit is achieved from some value of the mixture ratio and higher, depending on the type of mixture. The results show that by making the right mixes of residues, we can obtain biomass briquettes that are less expensive than conventional fuels. In the future, preparation and characterization according to precise ratios could be carried out. In addition, the methodology presented here can be applied to other residues in order to make other effective mixed briquettes at a low cost.

Author Contributions: Bill Vaneck Bot: writing original draft, **Petros J. Axaopoulos**: Conceptualisation, methodology, review and editing original draft, **Evangellos I. Sakellariou**: Review and editing original draft, **Olivier T. Sosso**: Software, visualisation, **Jean G. Tamba:** Supervision and project administration.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

ACOH	Annualized Cost Of Heat, €/kWh_{th}
AC_T	Annual cash flow at the year T, €
BNP	Banana peels
BNP-CCS	Banana peels and Coconut shells mixture
BNP-RWT	Banana peels and Rattan waste mixture
CCS	Coconut shells
d	Discount rate, %
E_d	Energy demand, kWh_{th}
FC	Fuel cost, €/kwh_{th}
GHG	Greenhouse Gases
i	Fuel cost inflation rate, %
INV	Initial investment cost, €
j	Maintenance cost inflation rate,%
kWh_{th}	kilowatt-hour thermal
LCC	Life Cycle Cost, €
LCC_{bio}	Life Cycle Cost of biomass briquette, €
LCC_{conv}	Life Cycle Cost of conventional fuel, €
LPG	Liquefied Petroleum Gas
MC	Cost of mixture, €/kg
ME	Energy of mixture, kWh_{th}/kg
NM	Number of mixtures
PVNB	Present Value of Net Benefit, €
PV_t	Present Value at the year t, €
RC	Cost of replaced energy €/kWh_{th}
RWT	Rattan waste
SGC	Sugarcane bagasse
SGC-CCS	Sugarcane Bagasse and Coconut shells mixture
SGC-RWT	Sugarcane Bagasse and Rattan waste mixture
t	Year of simulation

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