

Article

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 ratios higher than 7.75% and 11.1%, respectively, have prices lower than EUR 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



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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 as a result of growing demand, which often outstrips supply, and energy constraints [3,4]. Moreover, two-thirds of the energy consumed around the world is produced from non-renewable energy resources, such 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 many 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; it is estimated that 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 in cooking, heating, and gasification [8–10]. In Africa, many users make use of direct combustion of biomass, but this conversion method is poorly efficient and depletes the environment [11]. In addition, hazardous gases and other compounds toxic to 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 [12]. Numerous researchers have suggested that utilizing biomass in briquette form has various benefits. Briquette manufacturing improves biomass characteristics and makes them more suitable to move about, store, place in furnaces, and burn [10,11]. A biomass briquette is a solid fuel created from carbon-rich materials like agricultural waste that has been dried, carbonized, crushed, mixed with a binder, briquetted, and then dried [13–15]. The quality of the fuel briquettes that 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.

In Cameroon, the most commonly used cooking fuels are fuelwood, charcoal, and LPG. According to data from the National Institute of Statistics of Cameroon, the energy needs of an average household are 950 kWh per year. Household food products include the fuels used to cook food [16]. Fuelwood is usually burned in a traditional three-stone fire because of its affordability. There is no need to pay for it; it is constructed of up of three similar-sized stones on which a cooking kettle is placed over a fire [17]. The common cook stoves used for charcoal burning cost an average of EUR 10 in the Cameroonian market. The LPG burned in a gas-fired cooking stove consists of pressurized gas from a gas cylinder passing through the regulator and hosepipe on its way to the command button; the package costs about EUR 60. Expenditure on cooking fuels accounts for an average of 20% of a household's daily expenses. Nearly 7.5 million Cameroonians live in poverty, or on less than EUR 1.42 per day, making Cameroon a low-income nation [18]. Increasingly expanding economies have led to increased fuel prices and shortages, which often hit households. In this economic background, fuel and 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 [19–21]. Finding innovative approaches to reduce family expenses while making sure healthy meals are cooked 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 made from coconut shells, rattan waste, sugarcane bagasse, and banana peels. This work is a follow-up to the work of Bot et al. [1,15,22] who produced, characterized, 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 mixtures [23], corncob and rice husk [24], rice husk and coal [25], sawdust and palm kernel shell [26], sawdust and palm kernel shell [27], rice husk and palm oil mill sludge [28], rice husk and coconut shell [29], rice straw and sawdust [30], groundnut shells and bagasse [31], rice and coffee husks [32], cocoa pod husk and sawdust [33], sugarcane bagasse and rice bran [34], sugarcane bagasse, corncob, and rice husk [35], rice straw and banana peels [36], and coffee husk and corncob [37]. 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 fully taken into account. The aim of this study is to define the ideal ratios for preparing mixed briquettes in a single trial without repeating the experiments.

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 as follows: firstly, to evaluate the price of the mixed briquettes; secondly,

to assess the Present Value of the Net Benefit of the use of the mixed briquettes as a replacement of conventional household cooking fuel, such as LPG, wood charcoal, and fuelwood. The average Cameroonian household size is five people [16]. Our investigation was conducted using the life cycle cost method in a Cameroonian sample household with an annual thermal load of 950 kWh_{th}. 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 briquette making; (ii) giving information to briquette-making companies on low-cost techniques for briquette manufacturing; and (iii) informing households about the cost advantages of switching to biomass briquettes for cooking. In addition to the introduction, this paper consists of a materials and methods section describing the methodology for the determination of briquette prices, the Present Value of Net Benefit, the annualized cost of heat, and a results and discussion section reporting the results of our investigation and their interpretation.

2. Materials and Methods

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

2.1. Assumptions

In order to conduct the assessment, the following considerations were assumed:

- The thermal load of the typical household was estimated at 950 kWh_{th}/year according to the National Institute of Statistics of Cameroon [16];
- Because of the physicochemical and economic properties of pure CCS, RWT, BNP, and SGC briquettes, four types of mixed briquettes were 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 were the same as those found by Bot et al. [1,15,22] and are reported in Tables 1 and 2;
- The price of mixed briquettes was assumed to be proportional to that of pure briquettes;
- The ratio considered was percentage by weight;
- The life cycle cost method was applied as recommended by Bot et al. [1].

Table 1. Characteristics of conventional fuels 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 (EUR/kg)	0.46	0.46	0.46	0.46	0.79	0.30	0.54
Price (EUR/kWh)	0.051	0.055	0.098	0.064	0.063	0.12	0.065

Table 2. Economic parameters of the study [16,22,38,39].

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

2.2. Determination of Optimized Mixed Briquette Price

The prices of mixed briquettes were determined consecutively by the following Equations (1)–(3).

$$BP = 1 - CP \quad (1)$$

$$CP = 0 \dots 1 \text{ (or } 0\% \dots 100\%)$$

$$ME = CP \times CE + BP \times BE \quad (2)$$

$$MC = CP \times CE \times CC + BP \times BE \times BC \quad (3)$$

where BP is the percentage by weight of banana or sugarcane bagasse in the mixture, CP is the percentage by weight of coconut or rattan waste in the mixture, ME is the energy of mixture in kWh/kg, CE is the energy content of the coconut or rattan waste in kWh/kg, BE is the energy content of the banana or sugarcane bagasse briquette in kWh/kg, MC is the cost of mixture in EUR/kg, CC is the energy cost of the coconut or rattan waste in EUR/kWh, and BC is the energy cost of the banana or sugarcane bagasse in EUR/kWh.

2.3. Life Cycle Cost

For LCC analysis, the current value of annual cash flow (AC_t) for each simulation year (t) was first determined [40,41]:

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

E_d stands for the yearly energy demand for cooking in a home (kWh), FC denotes the conventional fuel or mixed biomass price evaluated as in Equation (3) (EUR/kWh), MC_s denotes the maintenance cooking stove cost (EUR), INV denotes the initial investment cost (EUR), i represents the fuel price inflation rate, and j represents the cooking stove maintenance cost inflation rate.

The present value PV_t at the end of year t was calculated via Equation (5):

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

where d is the market discount rate.

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

$$LCC = \sum_{t=1}^{t=10} PV_t \quad (6)$$

Finally, $PV_{of \text{ Net Benefit}}$ is calculated as follows:

$$PV_{of \text{ Net Benefit}} = LCC_{conv} - LCC_{mix} \quad (7)$$

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 (EUR/kWh_{th}).

$ACOH$ is a key index for determining the economic viability of a system in comparison to another [40].

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

where $ACOH$ is the annualized cost of heat (EUR/kWh_{th}), LCC is the life cycle cost (EUR), d is the discount rate, and E_d is the annual energy demand (kWh_{th}).

3. Results and Discussion

In this section, the cost of mixed briquettes is estimated and economic analysis is conducted in order to figure out if using mixed briquettes made from CCS, RWT, SGC, and BNP is 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 EUR 0.063/kWh. These figures show that minimum percentages of 7.75% CCS and 11.1% RWT are 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.

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 1541.83 TJ per year and 9.3 TJ per year, respectively [30,31]. Sugar cane is immensely 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.

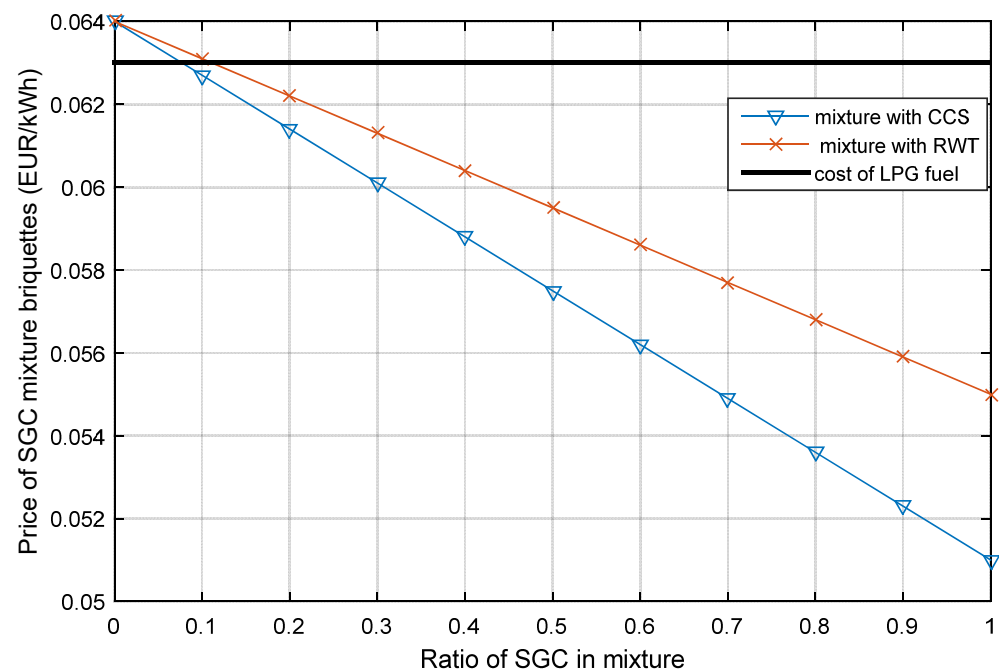


Figure 1. Price of SGC mixed-biomass briquettes.

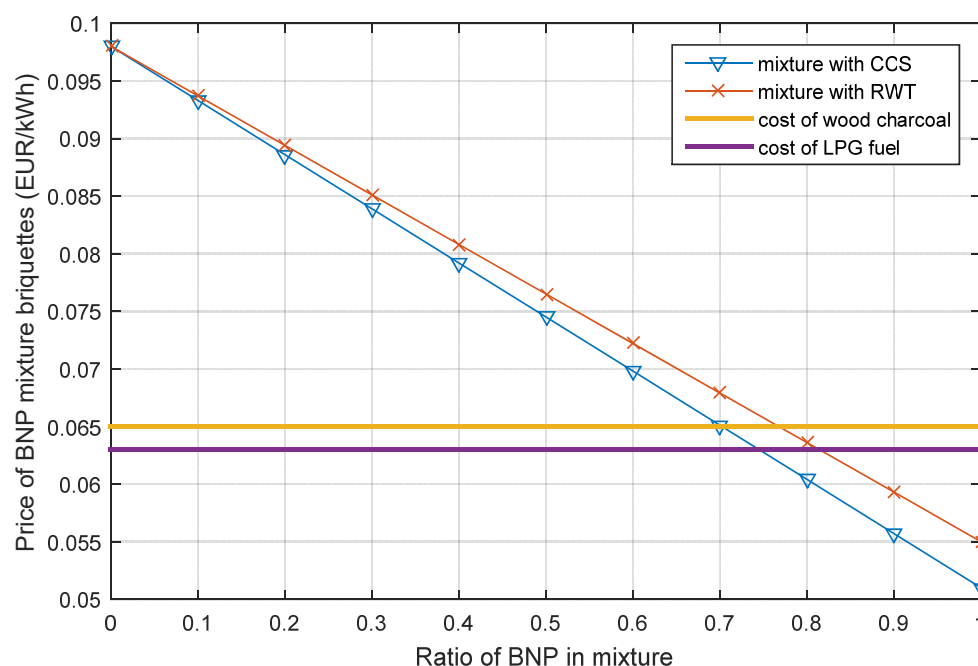


Figure 2. Price of BNP mixed-biomass briquettes.

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., EUR 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.

Given the positive PVNBs for all blending ratios, economically viable mixed 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 4215.69 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 mixed residues [24]. The approach proposed in this paper makes it easy to select the mixing ratios and prepare the optimum briquettes in a short period of time and at a low cost. Other types of residues whose pure briquettes have already been characterized and whose economic analysis has already been the subject of research could also be investigated. Given their characteristics as reported in the literature, it would also be interesting to mix banana leaves, banana stems, cotton stalks, and sugarcane leaves with one of the following residues: groundnut husk or 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 values of the SGC–CCS and SGC–RWT mixed briquettes, which are similar due to the very close characteristics of CCS and RWT briquettes. By observing these curves, it can easily be found that PVNB values are all positive, meaning that some of the biomass used to reinforce the SGC briquettes is economically viable for households. PVNB values for the replacement of LPG, fuelwood, and wood charcoal by mixed SGC-based briquettes are EUR 150, EUR 500, and EUR 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 PVNB values are. 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 RWT compared to CCS.

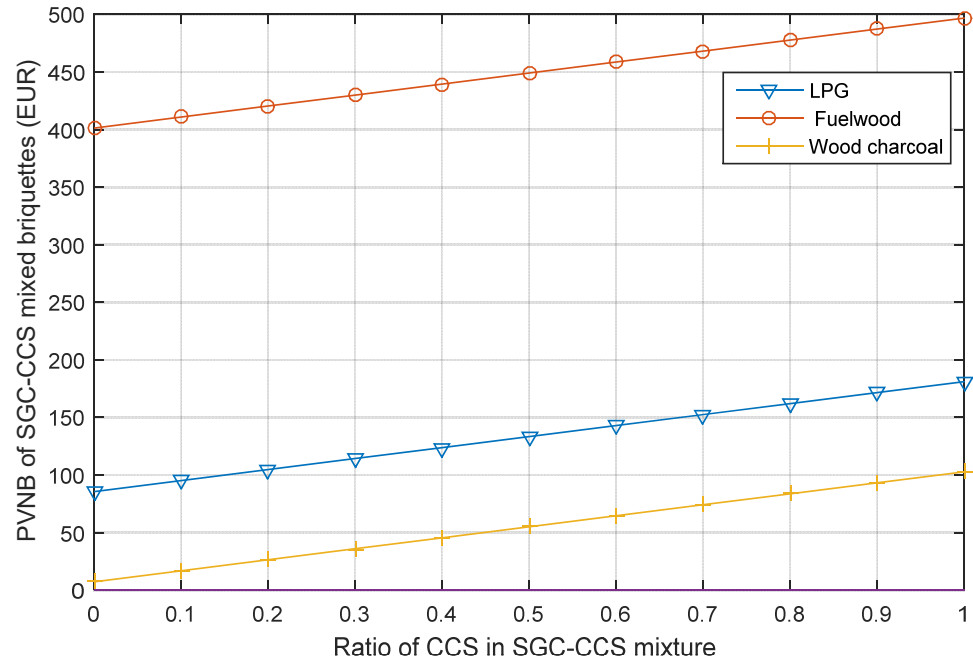


Figure 3. Present Value of Net Benefit of the replacement of conventional fuel by SGC–CCS mixed briquettes.

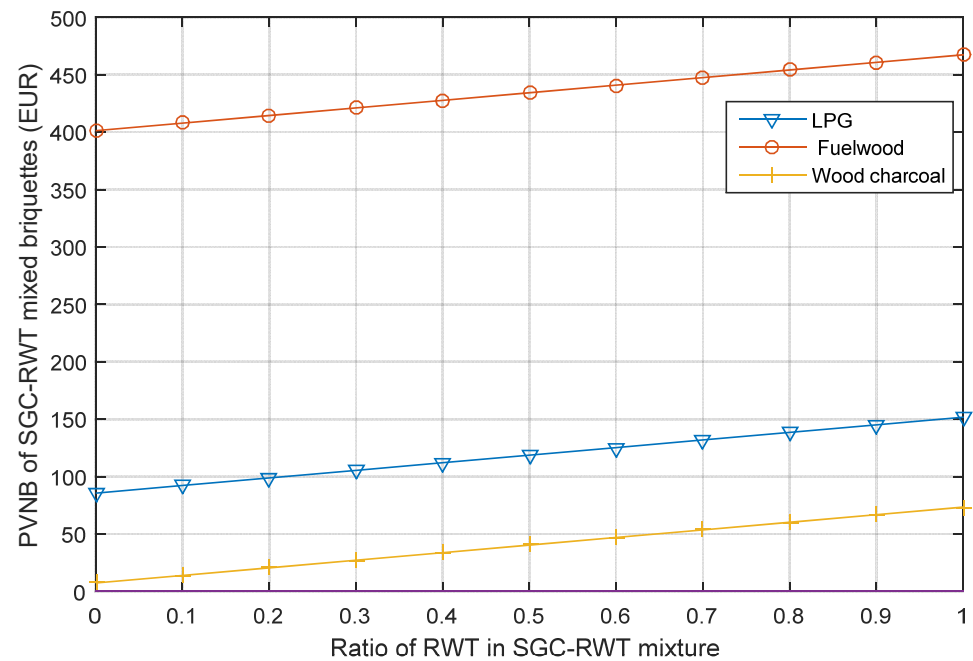


Figure 4. Present Value of Net Benefit of the replacement of conventional fuel by SGC–RWT mixed briquettes.

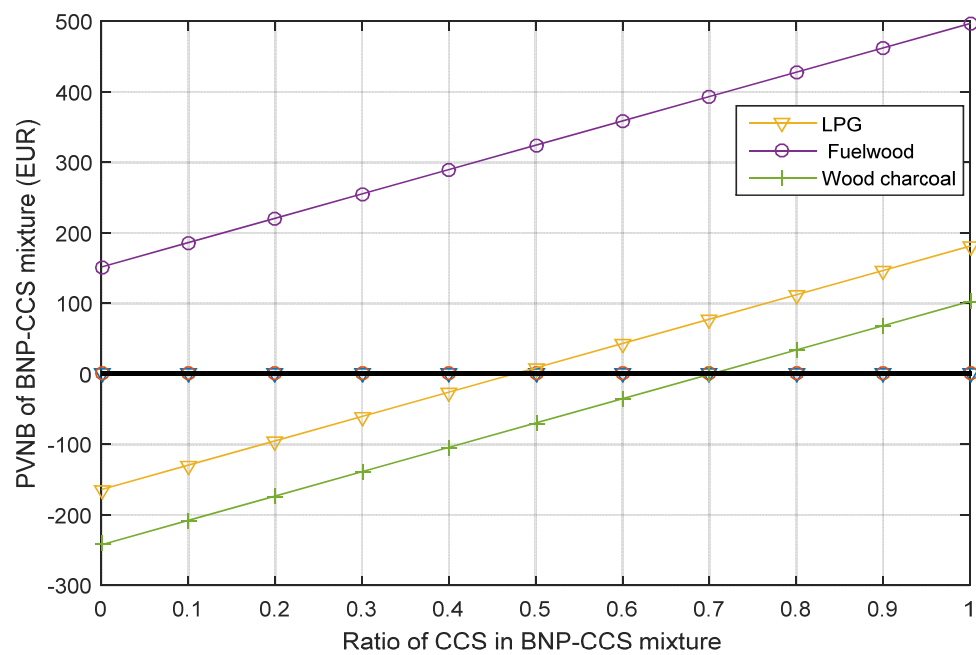


Figure 5. Present Value of Net Benefit of the replacement of conventional fuel by BNP-CCS mixed briquettes.

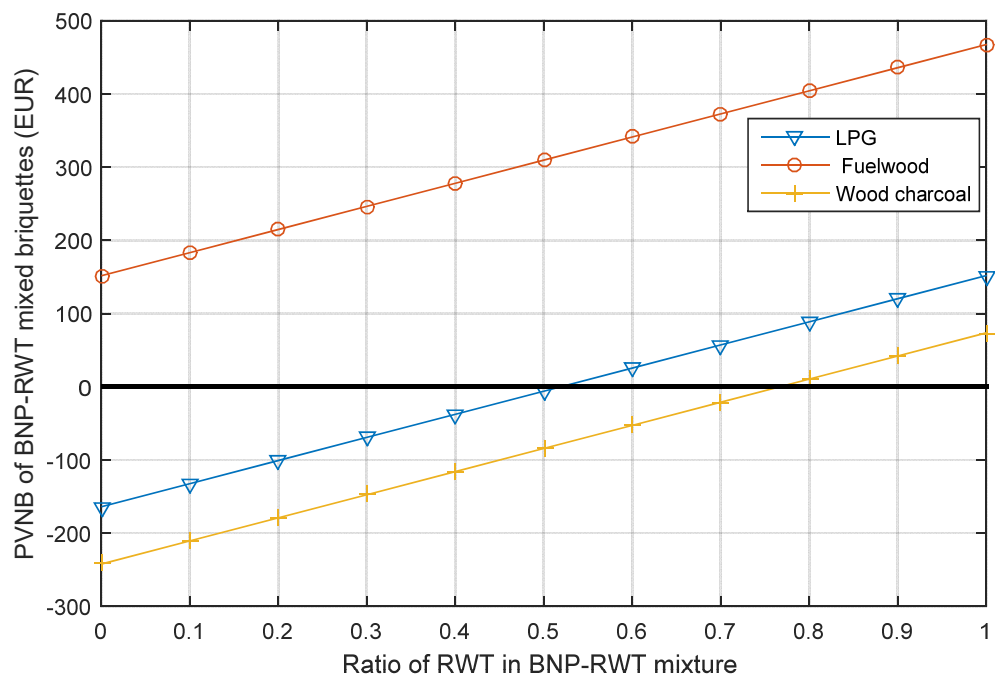


Figure 6. Present Value of Net Benefit of the replacement of conventional fuel by BNP-RWT mixed briquettes.

Figure 5 illustrates the PVNB values of the replacement of fuelwood, LPG, and wood charcoal with mixed BNP-CCS biomass briquettes. It appears that the use of mixed BNP-CCS briquettes instead of fuelwood is more cost-effective 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 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 higher proportion of RWT because of their less attractive physicochemical and economic characteristics.

3.3. Annualized Cost of Heat

The ACOH may be utilized, as was already indicated, for the systems' economic evaluation. The ACOH for the proposed mixed briquettes' use in cooking is shown in Figure 7. According to Figure 7a, using mixed briquettes of BNP-CCS and SGC-CCS for cooking in households has an annualized heat cost varying between 0.055 and 0.105 (EUR/kWh) and 0.055 and 0.068 (EUR/kWh), respectively. Figure 7b shows that the use of mixed briquettes of BNP-RWT and SGC-RWT for cooking in households has an annualized heat cost varying between 0.057 and 0.104 (EUR/kWh) and 0.055 and 0.068 (EUR/kWh), respectively. It appears that the use of mixed briquettes made 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 the results of LCC analysis.

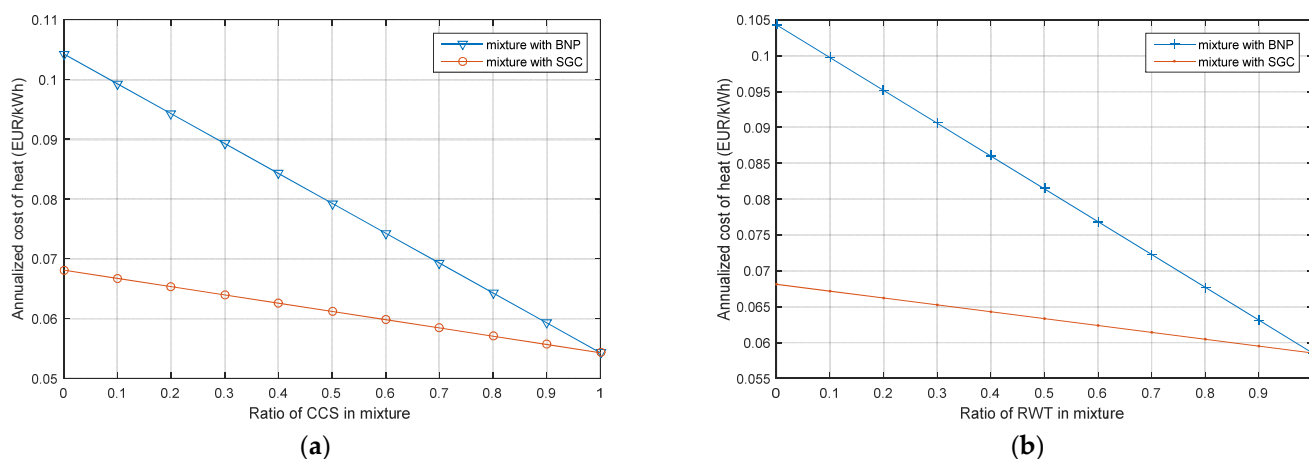


Figure 7. Annualized cost of heat of (a) CCS mixture and (b) RWT mixture briquettes.

As the first study of its kind, the findings of this investigation facilitate achieving greater expertise in the proportions of mixed briquettes in Cameroon and other low-middle-income countries. In Cameroon, as in most developing countries, the transition must be strongly linked to the low cost of energy sources. Since 2011, there has been increasing inflation rates, with 2.9% growth. 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 households. By using mixed briquettes, households can make considerable financial savings and invest in other activities.

Some studies, such as that authored by Tamba in 2021 [42], 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 on 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 fuels, as reported in [43–47]. The total annual cost of petrol in sub-Saharan countries was around USD 23 billion in 2016, i.e., around USD 112 per family [47]. It would be interesting to invest this money in briquette 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) [48], according to a scenario established by Yvan Ayuketah et al. In 2045, the residential sector will continue to be the highest consuming sector [48]. 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 could 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 EUR 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. Mixed briquettes made of BNP–CCS and BNP–RWT have positive Present Values of the Net Benefit for all mixture ratios in the case of fuelwood, while for LPG and wood charcoal, a positive 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, one can obtain mixed-biomass briquettes that are less expensive than conventional fuels. The main limitation of this study is its theoretical aspect; consequently, in the future, preparation and characterization according to precise ratios could be carried for validation. In addition, the methodology presented here can be applied to other residues in order to make other effective mixed briquettes at a low cost.

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

Nomenclature

$ACOH$	Annualized cost of heat, EUR/kWh _{th}
AC_t	Annual cash flow in the year t , EUR
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, EUR/kWh _{th}
GHG	Greenhouse Gases
i	Fuel cost inflation rate, %
INV	Initial investment cost, EUR

j	Maintenance cost inflation rate, %
kWh_{th}	Kilowatt-hour thermal
LCC	Life cycle cost, EUR
LCC_{bio}	Life cycle cost of biomass briquette, EUR
LCC_{conv}	Life cycle cost of conventional fuel, EUR
LPG	Liquefied petroleum gas
MC	Cost of mixture, EUR/kg
ME	Energy of mixture, $\text{kWh}_{\text{th}}/\text{kg}$
NM	Number of mixtures
PVNB	Present Value of Net Benefit, EUR
PV_t	Present Value at the year t , EUR
RC	Cost of replaced energy EUR/ 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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