



Meta-Analysis of Pellet Manufacturing in Cameroon

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Abstract

Firewood and charcoal are the main sources of energy in Cameroon and are among the factors that cause deforestation. However, the accumulation of wood residues in processing industries is a source of energy that can be capitalized on to meet society's needs. The recovery of these residues into wood pellets is an activity that can replenish areas poor in biomass and thus contribute to the reduction of pressures on the natural ecosystem, desertification, and climate change. As a result, this study aims to evaluate studies recovering related waste from wood processing industries in the manufacture of compressed pellets in order to determine the remaining waste. The methodology carried out was to search articles, theses, and dissertations available in databases such as Science Direct, Research Gate, and Google Scholar that deal with wood residues and their energy recovery in the field of pellets in Cameroon. It appears that some authors claim that the manufacture of wood pellets does not require the use of a binder or glue to ensure better incorporation. This is because of lignin, which is a chemical element in wood that ensures the action of lubrication and binder once hot during densification. For example, the higher lignin content in softwood species makes the formulation of pellets less restrictive during compression. However, the production of pellets based on tropical (hardwood) woods poses a problem of internal cohesion between the particles during densification, hence the use of natural binders such as clay and starch. Each piece of wood waste has its own specificities in the manufacture of pellets, and several have not yet been tested.

Subject Areas

Forestry

Keywords

Pellets, Wood Waste, Energy, Densification

1. Introduction

In Cameroon, 22.5 million hectares of rainforests cover about 46.3% of the national territory and represent 11% of the forests of the Congo Basin [1]-[3], which is the second largest basin in the world after the Amazon basin. Due to its great forestry potential, Cameroon is a key player in the international negotiation on climate change and the development of the REDD strategy. The country has the third-largest forest area after the Democratic Republic of Congo (DRC) and Gabon. As is the case with other countries in the Congo Basin, Cameroon is grappling with the adverse effects of climate change and increasing pressure on forests. Logging in Cameroon still uses the chainsaw technique, with delimiting and cutting on site. Skidding is carried out with a tractor and a trailer equipped or not with a grapple to a road suitable for vehicles from which the wood is transported by truck to the consumption centres [3]. While the potential of the crown and branches can be inferred from the volume of logs harvested, it is often difficult to assess the potential of defective trees and shrubs damaged or felled at the same time as the main logged trees. In Cameroon, it can be estimated that there is an availability of 5 million m³ of standing timber per year. The crowns, branches, stumps, roots, and spurs abandoned in the wood yards represent about 50% of the standing volume, or 2.5 million m³ [4]. Artisanal logging from community forests in Cameroon generates a significant amount of abandoned residues at logging sites [4]. These pieces of wood are converted into marketable products in order to improve the community's income. This abundant forest biomass is known to be a reliable source of renewable energy, and its importance in achieving climate and energy objectives has so far been acknowledged. Pellet manufacturing in Cameroon is gaining traction as a sustainable energy solution, especially in rural and peri-urban areas where biomass is abundant. The country's rich agriculture and forestry sectors produce significant biomass waste, which can be converted into pellets for heating, cooking, and industrial use.

Wood pellets are among the by-products of using forest biomass for bioenergy. According to Calderon and [5], 52.74 million tons of wood pellets are consumed worldwide, and industrial wood pellet consumption has increased by 3 million tons from 2017 to 2018 [6]. Because of this global rise in pellet production and consumption, both traders and consumers now need a certification mechanism to guarantee that the pellets they deliver or receive meet all quality standards. As a result, there has been a growing body of scientific research investigating the specific parameters necessary to obtain an optimal pelletizing process that results in desired pellet quality. Hardwood pellets are pellets made

from hardwood species, such as oak or beech, which are generally denser and more resistant than softwood pellets. Softwood pellets, on the other hand, are made from softwood species, such as pine or spruce, which are generally less dense and less resistant. A natural binder is a substance used to bind wood particles together during pellet production. Natural binders may include substances such as lignin, cellulose, or proteins.

Despite the country's rich endowment of forest biomass resources, wood pellet production in Cameroon has so far been only embryonic. Learning from the advances made in improving the pelletizing process and technology will be of paramount importance to guide future developments in this sector [7]. The objective of this work is to develop a state of knowledge on wood biomass pelleting in order to document the advances made in this field, identify knowledge gaps, and shed light on key directions for future research in Cameroon.

2. Method

The synthesis of knowledge on the energetic valorization of wood residues in Cameroon, with a focus on the manufacture of pellets, was carried out by searching scientific articles, theses, and dissertations. The review covered the last 14 years. In particular, the databases (Science Direct, Google Scholar, and ResearchGate) made it possible to have access to scientific and technical journals that deal with the issue of wood residues and their energetical valorization in the field of pellets production in Cameroon (e.g., Journal of Waste and Biomass Management, MIDI Academic open access publishing, Biotechnology, Agronomy, Société environnement, Elsevier Energy reports). Literature search over the period from 2009 to 2023. We used the following search strings: Scopus: TITLE-ABS-KEY (“wood pellets” or “biomass pellets”) and (Cameroon or “Central Africa”), Web of Science: TOPIC = (“wood pellets” or “biomass pellets”) and (Cameroonian or “Central African”) * Google Scholar: (“wood pellets” or “biomass pellets”) and (Cameroon or “Central Africa”). A series of keywords was used to carry out this information search. These keywords are:

- 1) Energy recovery of wood residues in Cameroon
- 2) Pellets
- 3) Wood residues in Cameroon

2.1. Inclusion Criteria

The research work that has been selected in this meta-analysis deals with wood residues in Cameroon and valorization. These studies provide a formal methodology that makes it possible to gather and analyze the data of different studies selected on transparent criteria in order to identify the remaining to be done or better the limits in this field in Cameroon in order to seek solutions.

2.2. Exclusion Criteria

The works that have been excluded from this meta-analysis are the articles and

theses that talk about abandoning wood residues in nature, coals, or the burning of wood residues by bushfire. Biomass includes all bio-based materials that can release energy by direct combustion or following a transformation step. This implies that biomass concerns both the biodegradable fraction of industrial waste and wood directly from the forest [8]. It gives rise to three sub-families:

- 1) Wood energy
- 2) Biogas
- 3) Biofuels

Without underestimating other areas of valorization and also with a view to achieving the objectives related to this research work, we focused particularly on the literature dealing with wood pellet production and characterization.

3. Results

A total of 21 studies offered accessible results, but only 11 presented usable numerical data (Figure 1). In addition, in view of the work available on the issue of the formulation of energy pellets in general and in Cameroon in particular, there is a knowledge gap that requires special attention. Because some of these studies are only based on the formulation based on softwood species, which is less available in Cameroon, and those dealing with tropical wood are limited to a single species without any information on other species, nor on the nature and type of binder used, and also on the progress of their pelleting tests and the equipment used. The quality assessment of 11 retained studies on wood pellets in Cameroon was conducted by considering several key criteria. These criteria include sample size, experimental design, and analytical rigor. Most studies focused on specific samples of biomass, ranging from wood waste and coconut shells to agricultural residues. However, some studies, such as Kamdem *et al.* (2011), provided large-scale data, highlighting that Cameroon generates over 4.5 million tons of banana waste per year, thus adopting a more comprehensive approach. Several studies adopted an experimental approach to evaluate the combustion performance and characteristics of pellets produced from different biomasses. For instance, Vitcussia *et al.* (2020) assessed the combustion performance of pellets made from three Cameroonian biomasses in a domestic pellet stove. Other studies compared the properties of pellets based on their composition. The analytical rigor of the studies varied. Some studies focused on the technical aspects of pellet production, such as the influence of formulation on combustion performance. Others emphasized the environmental and economic implications of valorizing waste into pellets, such as reducing the energy deficit. Overall, the studies showed good quality in terms of design and analysis, but some limitations were observed, particularly regarding the representativeness of the samples and the generalizability of the results. Further and more extensive studies are needed to explore the potentialities and challenges related to wood pellet production in Cameroon.

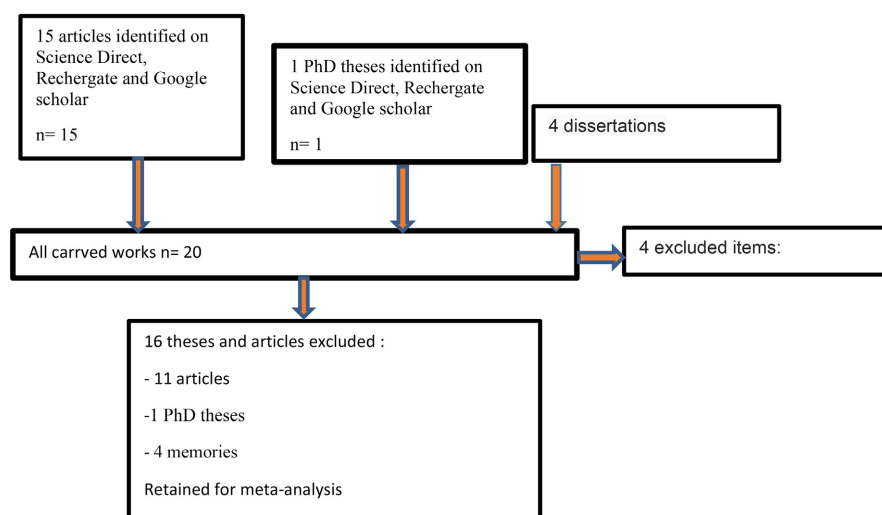


Figure 1. Flow chart of articles, theses, and dissertations in the study.

4. Wood Residues Generated by the Processing Industries

The crowns, branches, stumps, roots, and spurs abandoned in the woodyards represent about 50% of the standing volume; *i.e.*, 2.5 million m³ and that of sawmills (sawdust, slabs, chips, edgers, sapwood, core defects, etc.) represents 70% of sawmill waste, *i.e.*, 1,752,000 m³, for a total of 245 million m³ of waste. In 2006, the activity generated 245 million m³ of wood residues, or about 1.2 million tons [4]. Thus, for a wood entry into a factory of 2500000 m³, only 748,000 m³ of wood is produced, *i.e.*, a yield of 30% (70% of waste produced) (Table 1). It is noted that the timber industry in Cameroon generates large quantities of waste that is most often used as fuel or left abandoned in nature [3].

1) Residues from the first processing of wood: bark, sawdust, slabs, sapwood, edgers, heart defects, scraps, etc.

2) Residues from secondary processing: chips, sawdust, machined wood splinters, wood chips, offcuts, damaged parts (deformations and biological defects) (FCBA 2014).

Table 1. Forest and sawmill residues in Cameroon in 2006 [4] [5].

Volume of standing timber available annually	5,000,000 m ³
Residues from the forest park (about 14% of the volume of standing wood)	700,000 m ³
Factory input	2,500,000 m ³
Wood produced	748,000 m ³
Material yield	30%
Sawmill residues (sawdust, slabs, shavings, sapwood, core defects, etc.)	1,752,000 m ³ (70% sawmill waste)
Residues, forest, park, and sawmill	245 million m ³

The activity of the wood sector generated 245 million m³ of wood residues, or about 120 million tons for a density of 500 kg/m³. **Table 1** shows the volumes of forest and sawmill residues in Cameroon in 2006. Out of a mass of wood estimated at 2,500,000 m³ that entered the factory, 748,000 m³ of wood were produced. This is a material yield of 30%. The quantity of primary processing residues can therefore be estimated at 1,752,000 m³.

Uses of Residues

Depending on the technology available, part of this wood waste is recycled into charcoal [9]. A study conducted by [8]. Shows that only 0.97% of wood residues are processed into charcoal. About 1.8 million m³ of wood residues are burned in the open air each year, and barely 10% of sawn wood residues are recovered by industries [3]. A part is used for cooking in households and chicken farming. In Cameroon, 83% of the population depends on woody biomass as a source of energy, and in rural areas, it is often the only source available [8]. Firewood and charcoal are the main sources of energy and one of the driving factors in deforestation. However, the accumulation of wood residues in processing industries is a source of energy that can be valorized to meet society's needs. The interest in recovering these residues into wood pellets is an activity that can supply areas with limited availability of biomass and thus contribute to the fight against natural ecosystem degradation, desertification, and climate change. If implemented, such an initiative would also provide the population with alternative energy sources to kerosene and domestic gas, which represent 40% of the monthly expenditures of urban families [10]. The same is true of job creation and income-generating activity.

5. Densified Wood Pellets

Invented in the United States in the mid-1970s following the first oil crisis, pellets are cylindrical particles of highly densified sawdust. Depending on the heating installations (domestic, industrial, or tertiary) and the press used for densification, their dimensions vary between 5 and 10 mm for lengths, between 10 and 50 mm for width, and between 6 and 12 mm in height for lengths up to 40 mm [11].

5.1. Manufacturing Processes for Wood Pellets

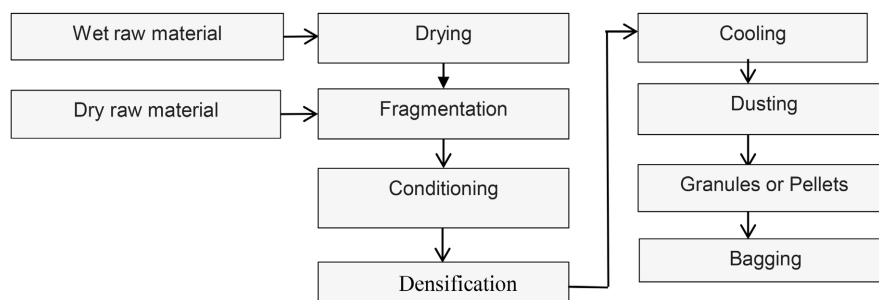


Figure 2. Manufacturing steps for energy pellets [14].

The production of energy pellets is essentially based on the use of wood as the main raw material [12]. Production is carried out in specialized factories, and the manufacturing process is very similar to that of feed pelleting. The raw material is previously dried to less than 15% moisture content [13], then fragmented to be brought to the necessary conditions of particle size before being densified or compressed through a press. The manufacturing principle follows very specific steps, as shown in **Figure 2**.

Once the shredded material has been introduced into the pellet mill, it is then compressed by forcing its passage through a die by means of a very high pressure of 1380 bar. It is sometimes necessary to add binders or steam during granulation to facilitate the extrusion process. Small cylinders exit through the holes in the die and are cut to the desired length [14]. When it passes through the press, the sawdust is subjected to strong pressure and friction, which will cause a temperature increase of more than 200°C. This high temperature pressure allows the lignin to liquefy, then plasticize and migrate partly to the outside of the pellet in formation. As it cools, the lignin then acts as a glue that will maintain the shape and density of the pellet. Pressure plays a crucial role in the compressive characteristics of the raw material, because densification makes it possible to obtain granules with a high density and a high calorific value [15] [16].

5.2. Particle Binding Mechanism during Densification

It should be noted that during the pelleting process, the wood particles are forcefully glued against each other until they undergo elastic and then plastic deformations. The particles are then welded together by molecular bonds (valence bonding or electron sharing, Van der Waals intermolecular bonds, and electrostatic and magnetic hydrogen) [17]-[21]. proposes the cohesion mechanisms occurring in a biomass powder under the action of pressure in graphic form. **Figure 3** presents a model of these mechanisms.

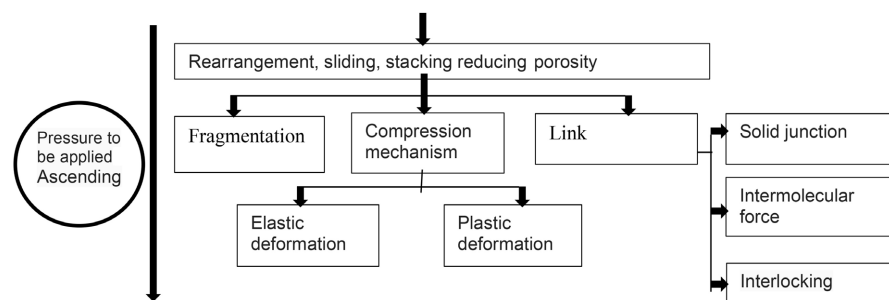


Figure 3. Cohesion mechanism under pressure [18].

5.3. Pellet Manufacturing in Cameroon

The manufacture of wood pellets in Cameroon is done formally by industries, with several local companies involved in the production of these wood pellets. An example is the Compagnie Générale de pelletés de bois. Their factory is located in Akom1, about 30 km from Kribi. They use wood residues from local and sustain-

able sources to produce wood pellets, which are a less polluting source of energy.

5.4. Bibliographic Sources on Wood Pellets in Cameroon

Evidence from the literature highlights some initiatives that allow us to better understand the current problems and issues in the pelletizing process and technology. Several authors have worked on the issue of valorization of agricultural by-products and the wood industry for the production of energy pellets; A look at the state of recent publications will allow us to mention some initiatives (**Table 2**).

Table 2. Inventory of research works on the pelletizing process and technology.

Wood species or materials used	Main findings	Implication and way forward	References
Palm nut shells, palm nut fibers, and coffee husks	Assess the combustion performance of pellets made with three Cameroonian biomass in a domestic pellet stove. Analysis of the combustion of pellets based on three Cameroonian biomasses (coffee pulp, fibers, and palm nut shells) in a domestic pellet stove	The determination of an optimal formulation of the pellets deserves further attention	[9] [22]
Movingui cokes of coconut black	Recovery of banana waste in Cameroon. Valorization of movingui wood residues for the production and characterization of pellets	The study reports good combustion efficiency and heat output of pellets in the proportions 60/30/10, but a high amount of total suspended particulate emission	[7] [9]
Production of pellets from lignocellulosic banana waste Banana waste (Common feedstocks include banana plant residues, wood chips, and agricultural waste)	Reduction of energy deficit in Cameroon	Cameroon generates over 4.5 million tons of fresh banana biomass waste annually, with the potential to produce 447,500 tons of pellets	[7]
Pellets produced from rice husks	Improve the characteristics of biomass pellets made from rice husks. The calorimetric resistance of the pellets depends on the binder/water ratio used	The optimal ratio is 1:2	[23]
State that thanks to its natural constituents, the use of softwoods does not require any binders in the formulation of hardwoods particles	In addition, they emphasize the addition of starch when using lists the main parameters that make it possible to characterize fuels (logs, coals, and pellets)		[24] [25]

To analyze **Table 2**, one can identify trends and patterns in the use of materials, blinders, and objectives across the studies. Several studies focus on using waste

materials like palm shells, coconut coir, and banana waste to produce pellets. **Table 2** also highlights the importance of optimizing pellet formulations and improving densification techniques. Overall, **Table 2** provides valuable insights into the current state of research in pelletizing processes and technology. The studies show that using waste materials for pellet production can be a good way to valorize these materials and reduce waste. However, further studies are needed to fully understand the implications of these findings and identify the best practices for pellet production. Pellets made from Cameroonian biomass show combustion efficiencies between 68.5% and 80.2%, comparable to EN+ certified pellets. Emissions (CO and particulate matter) vary depending on biomass type but are generally higher than European standards, indicating room for improvement in processing and stove technology (Kamdem *et al.*, 2011; Vitoussia *et al.*, 2020). Here is a synthesis **Table 2** that compares the main quantitative results across the studies: Study, Moisture Content (%), Density (kg/m³), Higher Heating Value (MJ/kg), Durability (%) (**Table 3**).

Table 3. Synthesis.

Study	Moisture Content (%)	Density (kg/m ³)	Higher Heating Value (MJ/kg)	Durability (%)
Study 1	10.2 ± 1.5	650 ± 50	18.5 ± 1.2	95.6 ± 2.1
Study 2	8.5 ± 1.2	700 ± 60	19.2 ± 1.5	92.1 ± 2.5
Study 3	12.1 ± 2.1	600 ± 40	17.8 ± 1.1	98.2 ± 1.8
Study 4	10.1 ± 1.1	600 ± 40	17.8 ± 1.1	98.2 ± 1.8
Study 5	11.1 ± 2.2	600 ± 40	17.8 ± 1.1	98.2 ± 1.8
Study 6	10.2 ± 1.5	650 ± 50	18.5 ± 1.2	95.6 ± 2.1
Study 7	10.1 ± 2.1	600 ± 40	17.8 ± 1.1	98.2 ± 1.8
Study 8	8.5 ± 1.2	700 ± 60	19.2 ± 1.6	92.1 ± 2.5
Study 9	12.1 ± 2.1	680 ± 40	16.8 ± 1.1	98.2 ± 1.8
Study 10	10.2 ± 1.5	650 ± 50	18.5 ± 1.2	95.6 ± 2.1
Study 11	9.5 ± 1.8	680 ± 55	680 ± 55	94.5 ± 2.3

5.5. Wood Pellets Processing Technology and Technological Properties

Studies have investigated the characterization of the materials used and the product obtained from the pelleting process.

Generally speaking, this state of the art allows us to understand that the production of biofuels is not new. But, despite this production, some binders (canola seed and vinyl glue) used by other authors are extremely dangerous for users. The combustion of pellets formulated with these binders releases highly toxic gases that can lead to death if ventilation is not properly provided [24] [25]. In Cameroon, wood industry residues are still less valued in the field of pellet production because of the lack of internal cohesion between wood particles during pelleting.

Hence the use of natural binders to reinforce the lower lignin level in hardwoods. Our contribution is to develop and characterize wood pellets from industrial processing residues using natural binders. This will give a second life to these wastes of wood that go up in smoke every day in wood processing places in Cameroon.

The chemical composition of lignocellulosic biomass can be considered at two levels: the main organic constituents (cellulose, hemicelluloses, lignin, extractables), which contain, on average, 50% carbon, 42% oxygen, 6% hydrogen, 1% nitrogen, and 1% inorganic elements commonly known as ash or mineral salts. Cellulose and hemicelluloses are associated with each other thanks to numerous hydrogen bonds. Hemicelluloses are more strongly bound to lignin by covalent bonds. The chemical composition of softwoods and hardwoods is more or less the same. Lignin, which is used as a lubricant and binder during pellet densification when hot, is increased in softwoods than in hardwoods [24] [25]. This may be the reason for the use of a natural binder in some cases of pellet formulation with hardwoods to facilitate better cohesion. Hardwoods to facilitate better cohesion. The wood pellet market in Cameroon is projected to grow steadily through 2030, driven by demand for residential heating, power generation, and animal bedding. This study has some limitations, including a limited evidence base and heterogeneous testing methods across studies. These limitations may bias our conclusions, as results may vary depending on the methods used and data quality. However, we attempted to minimize these biases by selecting only studies that presented reliable data and using statistical methods to synthesize the results. Despite these limitations, our study provides a useful overview of the properties of wood pellets in Cameroon and can serve as a basis for future research.

6. Conclusion

This study was conducted to develop a state of knowledge on wood biomass pelleting in Cameroon. It appears that in Cameroon, the majority of households use firewood and charcoal as their main source of domestic energy. One of the consequences of this practice is the gradual destruction of forest resources. However, the wood processing industries generate a large quantity of residues that can be transformed into energy pellets to meet the needs of society. As a result, several authors have worked on the issue of valorization of agricultural by-products and the industrial wood waste for the production of energy pellets. But it is important to mention that there are many articles dealing with the understanding of densification mechanisms. On the other hand, some dealing with the compression of wood pellets are mainly interested in softwoods which have an easy and quality pellet formulation. Articles detailing hardwood densification are often limited to qualitative comparisons without always succinctly giving information on the progress of their pelleting tests and the equipment used.

Conflicts of Interest

The authors declare no conflicts of interest.

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