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Feasibility of Biomass Briquette Production from Municipal Waste Streams by Integrating the Informal Sector in the Philippines

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Abstract: A technical and socio-economic feasibility study of biomass briquette production was performed in Iloilo City, Philippines, by integrating a registered group of the informal sector. The study has shown that the simulated production of biomass briquettes obtained from the municipal waste stream could lead to a feasible on-site fuel production line after determining its usability, quality and applicability to the would-be users. The technology utilized for briquetting is not complicated when operated due to its simple, yet sturdy design with suggestive results in terms of production rate, bulk density and heating value of the briquettes produced. Quality briquettes were created from mixtures of waste paper, sawdust and carbonized rice husk, making these material flows a renewable source of cost-effective fuels. An informal sector that would venture into briquette production can be considered profitable for small business enterprising, as demonstrated in the study. The informal sector from other parts of the world, having similar conditionality with that of the Uswag Calajunan Livelihood Association, Inc. (UCLA), could play a significant role in the recovery of these reusable waste materials from the waste stream and can add value to them as alternative fuels and raw materials (AFR) for household energy supply using appropriate technologies.

Keywords: feasibility; cost recovery; biomass; AFR; briquette production; briquettes; informal sector; municipal wastes

1. Introduction

1.1. Solid Waste Management Framework

Over the last 15 years, the Philippines has endeavored to improve its management and operation of solid waste through the implementation of several national laws like the Republic Act 9003 (RA 9003), also called the "Ecological Solid Waste Management Act of 2000". This law manifests the policy of the Philippine government to "adopt a systematic, comprehensive, and ecological solid waste management (SWM) program in the country" and is based on the hierarchy of waste management, which promotes the source reduction, reuse, recycling and resource recovery (3Rs) of materials. Under this Philippine law, an SWM Framework Plan is hoped to empower the informal sector as a partner of public and private institutions, organizations and corporations in the promotion and implementation of the 3Rs with the overall objective of alleviating poverty.

Being an agricultural country, the Philippines generates a substantial amount of bio-residues (biomass) with promising potentials when properly utilized as renewable sources for industrial, commercial and household purposes. Especially, its use as alternative fuel for cooking is relevant for poorer households. This includes among others rice husk, residues from coconut use, forestry residues and urban wastes [1]. Biomass is any organic matter that is available on a renewable or recurring basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes, wood wastes, aquatic plants, animal wastes, municipal wastes and other waste materials, and is recognized as one of the major potential sources for energy production [2–4]. It is a renewable energy source that could significantly improve our environment, economy and energy security [5] and, hence, is considered as a basic energy source in many developing countries [6]. When biomass wastes are converted to energy, they can substantially replace fossil fuel, reduce the emission of greenhouse gases (GHG), while closing the carbon cycle loop and providing renewable energy to people in developing countries, like the Philippines [7]. As raw materials, biomass wastes are attractive for large-scale industries and community-level enterprises. At small-scale levels, biomass is recognized as capable of meeting both heat and electricity demand most effectively in the form of combined heat and power, contributing towards international commitments to minimize environmental damage [8].

Iloilo City, being one of the highly urbanized cities in the Philippines with a population of 424,619 and having a land area of 56 km^2, currently generates an increasing amount of solid wastes with around 300 tons per day. From that, a portion of 170 tons/day is delivered by the municipal waste collection services to the local dumpsite. The dumpsite, which is around 5 km from the city center, is a controlled facility. It is located in Barangay (Brgy.) Calajunan, Mandurriao, which hosts approximately 300 households of waste reclaimers who recover resources through collection and separation of specific wastes that can be sold to nearby junkshops [9]. A barangay is the smallest administrative division in the Philippines [10] and is the native Filipino term for a village.

1.2. Integration of Waste Reclaimers into the SWM System

When RA 9003 was signed into law in 2001, it promoted the paradigm that waste is a resource that can be recovered, emphasizing the importance of waste management techniques such as the 3Rs. This law also prohibits waste picking in segregation areas or disposal facilities, unless the operator organizes and permits it. This is the case of the waste reclaimers living in the vicinity of Iloilo City's disposal site. Since 2005, the local government unit (LGU) of Iloilo City through its General Services Office (GSO) together with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and Central Philippine University (CPU) implemented projects near the disposal site to encourage the involvement of this sector. A group was formed to involve the 140 waste reclaimers in the initial activities intended for these collaborative projects by the city and GIZ. The workers were chosen according to their willingness to participate in the proposed association for waste reclaimers. Initial activities introduced to the group included training on sewing of recycled design bags and sorting out of alternative fuels and raw materials (AFR) in cooperation with cement manufacturer Holcim. From there, several sub-groups were formed according to the activities introduced to them, and then, leaders were elected for each. In order to enable the informal workers to be active in SWM over a long period, the waste reclaimers organized themselves into a membership-based organization accountable to their members. The group then registered as a formal incorporated association in May 2009, known as Uswag Calajunan Livelihood Association, Inc. (UCLA). "Uswag" is a Hiligaynon word for progress; hence, the association conveys a message that it is for a progressive Calajunan livelihood association [11–13]. This group was given access to conduct waste recovery inside the facility. However, with the ongoing construction of a sanitary landfill (SLF) adjacent to the present controlled dumpsite, the usual activities of the informal sector, specifically the waste reclaimers, would become regulated. In order for UCLA to sustain their association, there is a real need to improve the cost-benefit balance of existing livelihoods and to search for new fields of activities that could create additional income. Given the abundance of biomass wastes in the vicinity, some options identified are waste-to-energy through briquette production [9], a processed biomass fuel that can be burned as an alternative to wood or charcoal for heat energy [14,15].

1.3. Briquetting of Wastes

Briquetting involves the compression of a material into a solid product of higher bulk density, lower moisture content and uniform size, shape and materials; properties that would allow them to be used as fuel just like wood or charcoal [15,16].

It is noted that one of the major challenges for SWM in developing countries is how to enable the informal sector to improve livelihoods, working conditions and efficiency in recycling materials found in the waste stream. Organizing and training informal recyclers into micro and small enterprises is a very effective way to upgrade their ability to add value to collected materials [17]. By circumventing intermediate dealers, their income can be significantly increased, and their activities become more legitimized and socially acceptable. Likewise, forming cooperatives and associations that involve them can aid in the improvement of their position in the hierarchy of the waste recycling chain [18,19].

The integration of the informal sector in this study means the incorporation of UCLA into the city's SWM by allowing them to test the viability of briquette production in a simulated operation with the utilization of biomass wastes found at the dumpsite using appropriate technologies. UCLA, being a key player in the diversion of these wastes from the municipal waste stream, is investigated in its capacity to perform feasible briquette production with regards to relevant technical and socio-economic considerations.

2. Materials and Methods

Under the socio-economic aspect of the study, a non-experimental posttest-only design was utilized for the structured interviews prepared in order to collect the descriptive information of the participants. Primary and secondary data collected were both used to provide the necessary information needed to establish the study.

Primary data were collected through the conduct of structured interview and casual meetings/interviews with the UCLA members. Both precise quantitative findings were generated, and the qualitative description was produced in the study. Actual visitations to the study site were also done to observe how the association works on utilizing the floor space of the center during the field production tests. Secondary data were utilized to define the framework from municipal planning documents of Iloilo City, including other data that helped clarify the situation at Brgy. Calajunan.

2.1. Study Area

The Philippines is an archipelago of 7107 islands located in Southeast Asia. It has a land area of 300,000 km^2 with a total population of 92 million based on the 2010 Census of Population and Housing [20]. The country is divided into three island groups, namely Luzon, Visayas and Mindanao, with 17 administrative subdivisions known as regions. Iloilo City, the capital of the Province of Iloilo belongs to the Western Visayas region. According to the same census, the city has a total population of 424,619. It is composed of six districts, including Mandurriao, which has 180 urban barangays. Brgy. Calajunan, where the city's controlled dumpsite facility is located, has a population of 3356.

2.2. Technologies Utilized

Briquette molders and the pulping machine were the two major equipment utilized in the simulated biomass briquette production. One unit of briquette molder can produce in one pressing 16 pieces of cylindrical briquettes with a hole. Each briquette has an approximate diameter of 5 cm with a thickness of 2 cm. The inner whole is 1 cm. In producing briquettes, a hole at the center of the fuel is believed by many to improve the combustion characteristics of the briquette [21]. It encourages rapid drying, easy ignition and highly efficient burning due to the draft and insulated combustion chamber that the hole creates; hence, the same shape was adopted in this study [22].

Figure 1 presents the briquetting machine utilized during the test. The jack-driven machine consists of four major parts, namely the briquette molders, cover, hydraulic jack and frame.

The mixed biomass materials, which were first prepared separately, were placed into each of the cylindrical molders until totally filled. The molder's cover was then closed and locked by the bolts, then compressed by the 10-ton capacity bottle-type hydraulic jack. Once the materials were compressed, the cover was opened, and the jack was thrusted again until the materials were pushed out of the molders.

Figure 1. The hydraulic jack-driven briquetting machine utilized in the briquette production test.

The pulping machine as seen in Figure 2 is necessary for making the waste papers disentangle and become homogenous. During the field test when there was no electricity supply, production continued even without the use of this machine. The quality of the briquettes was, however, not satisfactory. Therefore, for every operation, the use of this equipment was emphasized. The pulping machine is driven by a 1-Hp capacitor-start single-phase electric motor. The machine was designed to have this size in terms of electric energy consumption, so that it would not create heavy electrical load during operation. The device operates like a blender, where the shredded papers or manually stripped papers are loaded inside the cylinder of the machine. The cylinder is then filled with water, just enough to soak the paper loaded inside. The electric motor is turned on until a homogenous mixture is attained. The length of the pulping operation depended on the volume of paper loaded inside the machine. The pulped papers were then screened to remove excess water. The use, however, of wet pulped waste papers in briquette production requires the briquettes to be further sundried for at least 7 days to make it suitable as dry fuel.

Figure 2. The pulping machine utilized during briquette production showing the wet pulped paper produced.

2.3. Mixture Preparation

Iloilo City, being an urbanized metropolis, generates much waste paper. The abundance of these materials generated during the 20-day segregation test [11,12] initiated further exploration of waste paper as a potential alternative source of fuel. The cellulose in paper is known to contain proteinaceous materials that tend to have an excellent adhesive property, making it useful as partial binder material [23,24].

To maximize the potential of waste paper, the addition of commonly-produced biomass wastes in the form of carbonized rice husk (CRH) and sawdust were considered as key ingredients in the formulation of mixtures for briquette production.

In summary, three materials as shown in Figure 3 were recommended for UCLA's simulated briquette production; namely, paper, sawdust and CRH. They were produced using the following mixing proportions: Briquette 1: paper (100%); Briquette 2: paper (50%) + sawdust (50%); and Briquette 3: paper (50%) + sawdust (25%) + CRH (25%).

During production, waste papers were recovered from the disposal facility and from particular colleges of CPU, whereas, the biomass wastes were obtained from the dumpsite and nearby areas and furniture shops within Iloilo City. The CRH used in the study was another form of wastes that came from the by-products of stoves that utilized rice husk as fuel for cooking. This type of stove cannot totally convert the fuels into ash, only in carbonized form. Likewise, the sawdust utilized was directly obtained from nearby furniture shops that generates much of this waste from primary wood processing operations. The addition of biomass materials to waste papers can expand the maximization of these materials, since the literature has already indicated that the heating values of rice husk and sawdust can sustain combustion [25,26].

Figure 3. The materials used in briquette production, namely, from left to right: waste paper, sawdust and carbonized rice husk.

2.4. Briquette Production and Performance Evaluation

The feasibility of briquette production performed by the informal sector was done in 15 days (Figure 4). UCLA members who had been trained on briquette production through participation in previous studies or attendance in trainings conducted were commissioned for this test. The field production test was performed to determine the average volume of briquettes they could produce under simulated work conditions wherein each participant was compensated based on the actual number of briquettes produced.

The actual field production test was performed at UCLA Center located just 100 m across Iloilo City's disposal facility. The center has an approximate floor area of 144 m^2 and was made of light construction materials, such as plywood for its flooring and nipa shingles for its roofing.

Eight (8) units of the jack-driven briquetting machine and 1 unit of the pulping machine were utilized for this test. Two persons working as a team operated each machine. On the other hand, two additional members were assigned for the pulping of waste papers. This setup, where a team is assigned to pulping while another is to briquetting, indicates a specialized type of work. This manner is common in work places in order to attain higher production.

Production of briquettes was done in modes that represent different possible types of productivity. These included a team/worker who produced briquettes based on the following rates:

- Paid for every 4 pieces of briquettes produced per day
- Paid on a fixed rate by producing 150 pieces per day with a bonus for every 4 additional briquettes formed
- Paid on a fixed rate with no required number of briquettes produced

Figure 4. The actual field production test at the Uswag Calajunan Livelihood Association, Inc. (UCLA) Center and the briquettes produced, hanged for drying.

These three different rates were representative of three different possible productivities for workers; hence, the total production divided by the number of days and number of participants would illustrate the average production rate per person. The first mode represented an output-oriented worker who can increase his/her income if he/she can produce more. The second mode represented a worker who was willing to earn that much, but if he/she wanted to increase his/her fixed income, then he can produce more so that he/she can have a bonus. The third type represented a worker who does not really mind the volume he/she can produce as long as he/she is paid a fixed amount of money. The estimation of the fixed rate at 150 pieces per day was based on the average briquettes produced during previous briquetting tests conducted [27].

In summary, the integration of UCLA members during the actual production tests started at approximately past 7 in the morning until around 5 in the afternoon. The start and end of production have all been at their pacing. They were observed as to how they organized and put their respective responsibilities in order. The preparation of equipment and other necessary instruments used during production have also been arranged in a manner that would be safe for them and at the same time at a location that would not disrupt their work activities. Production started from the preparation of materials followed by pulping of paper. With time, they became familiar as to the volume of materials they would only prepare, just enough for the whole day's production.

Dried samples were sent to Bauhaus-Universität Weimar (BUW) in Weimar, Germany, for further physico-chemical tests. The identification and characterization of the chemical and phase composition of a given solid fuel comprised the initial and most important step during the investigation and application of such fuel [28]. The physical characteristics included the briquette's dimensions and shape, bulk density and heating value. The heating value, expressed in the study as high heating value of dry matter (HHV dm), was analyzed based on Deutsches Institut für Normung (DIN) 51900-2 (Determining the gross calorific value of solid and liquid fuels using the isoperibol or static-jacket calorimeter, and calculation of net calorific value [29]). On the other hand, the chemical characteristics included the proximate analysis, which covered the ash yield and moisture of the briquettes produced. Initial tests were done based on the international standards specified under DIN 19747:2009-07 (Investigation of solids—Pretreatment of samples, preparation and processing of samples for chemical, biological and physical tests [30]) for the procedure in the sample preparation. DIN stands for Deutsches Institut für Normung which means German Institute for Standardization. Ash yield and moisture content of briquettes were determined based on the methods of the German Federal Compost Quality Assurance Organization (Analysis Handbook of the Bundesgütegemeinschaft (BGK) Kompost e.V. [31]).

3. Results

3.1. Technical and Product Performance of Briquetting

Table 1 and Figure 5 display relevant facts and quality parameters of briquettes produced using three different input materials obtained from the municipal waste stream. They were cylindrical in shape with a hole at the center. The briquettes in the first column appeared mostly white because these briquettes were produced from waste papers as the only input material of this fuel. The briquette types shown at the center of Figure 1 were light brown in color with traces of white spots. This appearance was due to the presence of 50% waste paper and 50% sawdust. In the third column, the presence of CRH resulted in a darker color of the briquette, but waste paper components can still be recognized as white and light brown color specks.

(**a**) (**b**) (**c**)

Figure 5. Types of briquettes produced using biomass wastes, from left to right: (**a**) paper (P); (**b**) paper + sawdust (P + SD); and (**c**) paper + sawdust + carbonized rice husk (CRH) (P + SD + CRH).

The briquettes had a diameter within the 5-cm range and a thickness that varies from 1.54 to 2.34 cm, while the inner hole was about 1.20 cm. Briquettes that have several materials in their mixture (Briquettes 2 and 3) were heavier than the pure paper briquette. The values for the weight and volume per briquette were necessary data for the computation of the bulk density of the fuels. With a hydraulic jack, the bulk density of the briquettes was recorded to be highest for Briquette 1 at 0.49 g/cm^3 (485.41 kg/m^3), followed by Briquette 3 (0.46 g/cm^3; 459.01 kg/m^3) and Briquette 2 (0.39 g/cm^3; 390.06 kg/m^3).

Heating value is a major quality index for fuels [24]. Fuels such as briquettes need a heating value of about 11.66 MJ/kg (5000 Btu/lb) to be able to sustain combustion [25,32]. Results of the laboratory test presented in Table 1 show that the briquettes produced by the informal sector using the jack-driven machine can sustain combustion, with the paper and sawdust combination producing the highest numerical value at 16.68 MJ/kg (7153 Btu/lb). The briquettes produced are ideal and feasible fuels for cooking and other heat-related applications.

Table 1. Quality of biomass briquettes produced.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Diameter, cm (≈)	5.37	5.53	5.48
Thickness, cm (≈)	1.54	2.34	1.96
Weight per Briquette, g	16	21	20
Volume per Briquette, cm^3	33.15	53.30	43.97
Bulk Density, g/cm^3 (kg/m^3) [a]	0.49 (485.41)	0.39 (390.06)	0.46 (459.01)
Proximate Analysis			
Heating Value, MJ/kg [b]	15.01	16.68	13.69
Ash Yield, % dm	21.0	14.6	31.0
Moisture, %	5.6	7.1	5.8

[a] Mean of bulk density = 444.83 kg/m^3; [b] mean of heating value = 15.13 MJ/kg.

The results of the proximate analysis covered in this study included the ash yield (percentage of dry matter, % dm) and moisture. Ash yield represents the inorganic oxides that remain after complete combustion of materials [33]. Results show that the third briquette (P + SD + CRH) had the highest ash content at 31.0% followed by Briquette 1 (P) at 21.0%. Briquette 2, which is a mixture of paper and sawdust, contained the lowest amount of ash at 14.6%. The moisture of the briquettes produced ranged from 5.6% to 7.1% of its dry matter (dm) weight.

To gather data for average production capacity, a 15-day test was performed. The results of this field production test are presented in Table 2. No statistical analysis was made since the measurement of the amount of materials used was only totaled after the five-day test for each briquette type. Moreover, the purpose of the field test was to observe and record the performance of the informal sector in terms of briquette outputs when exposed to a simulated production test rather than the amount of materials used. The average working time was 6 h per day. However, this working period may be extended to 8 h/day, since this is the regular number of working hours, or could even be organized into two shifts to obtain higher production output. The data showed that when analyzed numerically, the work output for heterogeneous mixtures was higher. Briquette 2 obtained the highest production rate (1.92 kg/h) followed by Briquettes 3 and 1 at 1.79 kg/h and 1.68 kg/h, respectively. As observed during the test, less pure paper briquettes were produced due to the friction created by pure paper materials on the surface of the molders. Unlike when mixed with either sawdust or CRH, the operation as observed was really simpler for them. The materials were easier to handle on the molders when the mixtures were heterogeneous because of less moisture, since the add-on materials that were mixed had gradually absorbed the moisture of pulped papers. The higher production rate in terms of the weight of briquettes produced was due to the compactness of the mixtures when placed in the individual molders. Unlike with pure paper, the pulped materials tended to spurt out of the holes during compression; hence, the briquettes produced became thinner and lighter. The briquettes produced from heterogeneous mixtures were thicker and heavier. The actual field testing also manifested the durability of the machine. The parts that showed weak performance due to the wear and tear of use were the welded hinge of the cover and the springs that pull together the molder support and the jack flooring when the hydraulic jack was loosened.

Table 2. Results of the 15-day briquette production test by integrating the informal sector.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Average daily operating time per person, h	6	6	6
Average daily briquette production per person, pieces/day	630	822	897
Average daily dry wt. of briquettes produced per person, kg/day	10.09	11.51	10.76
Average production rate per person, pieces/h (kg/h)	105 (1.68)	137 (1.92)	149 (1.79)

3.2. Cost Analysis in Briquetting

Table 3 shows the computation for the potential earnings from the production of briquettes based on the production rate performed in the laboratory and the operating cost with all data converted on a daily basis per person from the field test [27].

The briquettes may be sold to a marked-up price of Php15.00/kg (USD0.34). This amount was determined by computing first the total cost per day, which is the sum of fixed and variable costs. Fixed cost covered depreciation, interest on investment, repair and maintenance and insurance. Variable cost, likewise, covered labor cost for one person operating the machine and the cost of electricity for the use of the pulping machine. Considering all of the costs incurred for an assumed 8-h operation per day, the cost of producing any of the three briquettes ranged from about Php0.13 to Php0.16 per piece (USD0.003 to USD0.004); marking-up to 25 Philippine cents (Php0.25 or USD0.006) for profit and easy counting and selling. The price per kilo of briquettes was set to Php15.00 (USD0.34) since a kilogram of briquettes produced contains about 60 pieces of molded fuel [27].

Table 3. Potential daily production and earnings in the briquetting of wastes.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Production rate per person [1], kg/day	26.80	32.88	36.40
Operating cost [2], Php/day (USD/day)	272.00 (6.18)	257.44 (5.85)	257.44 (5.85)
Sales per person [3], Php/day (USD/day)	402.00 (9.14)	493.20 (11.21)	546.00 (12.41)
Potential earnings per person:			
Php/day [4] (USD/day)	130.00 (2.95)	235.76 (5.36)	288.56 (6.56)
Php/year [5] (USD/year)	31,200.00 (709.09)	56,582.40 (1285.96)	69,254.40 (1573.96)

USD1 = Php44. textsuperscript1 Obtained from production rate at laboratory test multiplied by 8-h production per day (B1 = 3.35 kg/h; B2 = 4.11 kg/h; B3 = 4.55 kg/h); [2] computed operating cost in Php/h (USD/h) multiplied by 8-h operation per day (B1 = Php34/h (0.77); (B2 and B3 = Php32.18/h (0.73); [3] revenue for briquettes when sold at a marked-up price of Php15.00/kg (USD0.34/kg) or at Php0.25 (USD0.006) per briquette after mark-up); [4] sales less operating cost; [5] potential earnings in Php/day (USD/day) multiplied by 20 days of production per month for 12 months in 1 year.

When the briquettes are sold after mark-up at Php15.00/kg (USD0.34) multiplied by the production rate for each briquette [27], the sales or revenue that may be generated would range from Php402.00 (USD9.14) to Php546.00 (USD12.41) per day per person. Subtracting the earned revenue with the cost of operation would give one person potential daily earnings of Php130.00 (USD2.95) to Php288.56

(USD6.56), a value that is significantly higher when compared to majority of the waste reclaimers' surveyed daily income of Php124.00 (USD2.82) [34]. When computed on an annual basis, one person may earn Php31,200.00 (USD709.09) to Php69,254.40 (USD1573.96) just by producing briquettes. Higher earnings may be realized if members of an organization would work together for their income-generating project. The project in this case would refer to the investment in starting-up a briquette production operation, which includes the fixed and variable costs of machinery acquisition, material testing, labor and electric energy, among others.

4. Discussion

4.1. Technical Feasibility

Three different types of briquettes were produced using a jack-driven briquetting machine by integrating the informal sector during the actual field production test. This designed machine can be considered as an addition to the energy conversion technologies that had been developed and adopted under local conditions in order to utilize the abandoned biomass wastes in the Philippines [1].

It was observed during the boiling and cooking operations that the use of cylindrical briquettes with the central hole emitted less smoke compared to using the solid pillow-shaped briquettes [35]. The shape of the briquettes having a central hole helped in the uniform and efficient combustion of briquettes with significant reduction in smoke, as noted by Grover and Mishra [36].

The higher density observed in the 100% waste paper briquettes may be due to its homogenous nature, which may have enabled the material to form a stronger bond, resulting in denser and more stable briquettes [15] compared to those from the two other mixtures.

The mean bulk density of the briquettes produced at 444.83 kg/m^3 was similar to other briquetting technologies developed in other places that use the piston press, creating very high pressure during operation [36,37]. The use of the finalized design of a four by four jack-driven (JD4×4FD) briquetting machine has improved the bulk density of the fuels by approximately 400% when directly compared to that of the initially developed and used hand-press (HP) molder [35]. It can be noted that the density of the briquettes increased with increasing pressure, leading to improved quality of briquettes [38,39]. This parameter is important in briquetting because the higher the density of the fuels, the higher is its energy/volume ratio as well. Briquettes with high density are also favored due to enhanced features for transport, storage and handling [40].

Likewise, the bulk densities produced were numerically similar to the results of the studies conducted [24,41], which produced fuels made from agricultural, forest-origin biomass; and waste paper using horizontal crank-and-piston briquetting press (values ranged from 469 to 542 kg/m^3) and a Shimadzu hydraulic press (value reported to be 0.32 g/cm^3 or 320 kg/m^3). The comparisons are clearly illustrated in Figure 6 where JD4×4FD refers to the finalized design of a four by four jack-driven briquetting machine while that of HP is the hand-press molder.

The heating value of the material is influenced by the species and the moisture content [42]. The results of the physico-chemical analysis of this study, however, did not indicate that a lower moisture content may lead to higher heating value. The latter may be more influenced by the materials used, especially for sawdust, since it has a higher heating value compared to pure paper and rice husk [39,43]. The highest heating value measured from Briquette 2 compares numerically fairly well when associated with other fuels produced from other studies/research (Table 4). Cooking fuels like sawdust and bio-coal briquette, firewood and charcoal have a heating value ranging from 18.65 to 27.98 MJ/kg (8000 to 12,000 Btu/lb), while that of bituminous coal, a commonly-used fuel in industries, ranges from 24.48 to 36.14 MJ/kg (10,500 to 15,500 Btu/lb) [44]. The average value of the briquettes produced, likewise, was around 15.16 MJ/kg (6500 Btu/lb). This implies that this low-cost briquetting technology can produce or form fuel briquettes that can closely meet the standards set for products that are mostly manufactured by companies using high technologies.

The higher ash yield for Briquette 3 is due to the presence of agricultural biomass like CRH, which contains higher ash yields and, thus, much more ash-forming elements than most of the forestry biomass, like paper and sawdust [28,38]. Rice husks when burnt as fuel result in the oxidation of the carbonized ash to yield white ash that consists predominantly of silica [45]; a major inorganic component of rice husk, which is about 20 to 30 percent of its weight [46]. The inorganic materials present specifically for Briquette 3 may have produced the higher amount of percentage ash yield. This parameter is an important characteristic influencing the burning technology, the emission of solid particles and the handling and use of ash [42]. The ash yields of the briquettes produced were also found to have similar values as those of commonly-used fuels in a household or in industry (Table 4).

The use of a hydraulic jack in the compression of the briquettes and the presence of many holes on the side of the molders [10] were instrumental in squeezing out excess water to decrease the moisture content by almost 4% when compared to briquettes pressed manually [22]. The moisture of the produced briquettes also met the DIN 51731 standards [47] that require fuels to have a moisture of less than 12%. The average moisture of the briquettes produced was numerically lower than most of the other fuel materials presented in Table 4. This indicates that the use of the hydraulic jack integrated with a properly-designed briquette molder can evidently squeeze out excess moisture in the mixture. When the proximate analyses of the briquettes expressed in moisture (%) were fitted against the respective bulk densities of the materials, the trend shows that the higher the bulk density of the fuel, the lower is its moisture. This is attributed to the compressive strength created through the use of a jack forcing out most of the moisture present in the briquettes during the molding process.

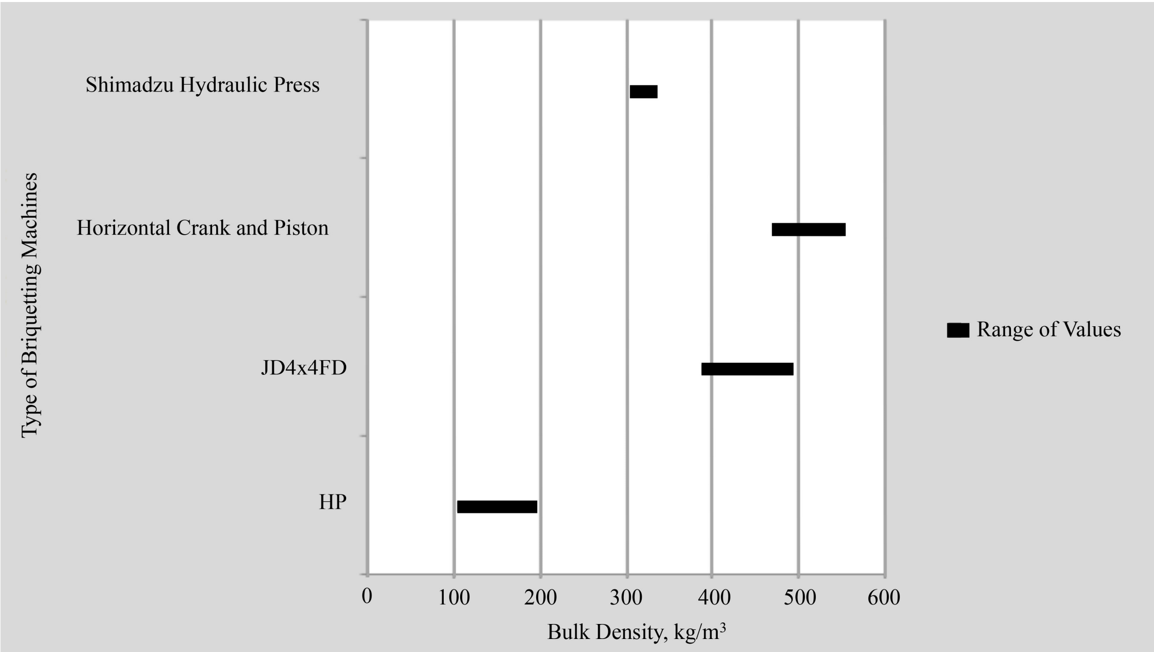

Figure 6. Ranges of the bulk densities of the different briquette molders developed.

In general, the informal sector depends on various support to link to municipal waste management works for providing: (a) secured supply with suited input materials; (b) access to a doable and affordable technology to produce briquettes; and (c) secured arrangements to work with stakeholders and the supervising municipality.

Results of the conducted field test showed that the briquettes produced can be well suited as an alternative fuel. Based on the comparison to other fuels as presented in Table 4, the results of this study indicate the potential of the produced briquettes as fuel for heat applications.

Table 4. Results of the heating value and proximate analyses of various raw materials from other findings.

Material	Parameters Measured from Other Findings					Source
	Heating Value MJ/kg	Ash Yield % dm	Moisture %	Volatile Matter % dm	Fixed Carbon % dm	
Charcoal	28.35	11.3	14.9	-	-	This study
Firewood	26.84	3.70	NR	NR	30.65	[48]
RDF	NR	26.1	4.2	73.4	0.5	[28]
Mixed waste paper	NR	8.3	8.8	84.2	7.5	[28]
Coal	20.64	18.27	7.64	43.44	NR	[49]
Bio-coal briquette	19.00	17.96	7.42	NR	64.93	[49]
Sawdust briquette	19.52	0.40	8.17	78.84	NR	[41]

RDF = Refuse-Derived Fuel; NR = Not Reported.

The results highlighted in the study emphasize that briquette production is feasible due to the availability of raw materials that are considered appropriate for briquetting. Paper waste is available in abundance in urban settings, and with its binding property, this can be mixed with any other biomass readily available in certain places. The practicality of the design and operation of the machines needed and as tried by members of UCLA with the outcome of good quality briquettes also indicates promising potentials.

The jack-driven briquetting technology utilized for fuel production by the informal sector indeed produced briquettes of higher bulk density and lower moisture content. It also molded materials having uniform size, shape and properties. The briquette molder with good compressive ability accomplished the use of paper as a reliable binding material for briquette production [24,50]. The case of UCLA in utilizing biomass wastes can also be likened to the implementation of a community-based energy briquette production in an informal settlement in Nairobi, Kenya. In this project, the materials used for briquette production in the area utilized paper as the binder, with other mixtures coming from discarded materials, like coffee hulls, rice husks, charcoal particles, sawdust and wood chips. The briquettes produced were identified as "doughnut-shaped" having a 10-cm diameter with a 1-cm central hole [23].

4.2. Socio-Economic Feasibility

The integration of UCLA waste workers in the briquette production test showed that organizing and training informal recyclers into micro and small enterprises is a very effective way to upgrade their ability to add value to collected materials [17]. Through briquette production, the utilization of waste papers found at the disposal facility and incorporating these with other materials found nearby, adds value to their wastes. They move up the hierarchy making them involved in enterprising rather than just waste picking or reclaiming [17]. The involvement of members of UCLA since 2005 to 2015 in different projects and researches conducted in the area [11–13,26,34,51–54] has provided them knowledge and information and given them capacity in many ways, especially related to various social aspects. These include, among others, conflict management, sanitation and first aid, basics on business, accounting and marketing with a focus on existing and targeted livelihood options, such as briquette production. Members have been introduced to the use of technologies, such as briquetting and pulping machines, providing them additional skills and confidence in terms of expressing their ideas for the improvement of the technologies introduced. Integrating the members to work together as one association showed that they can be relied upon and are able to perform briquette production on their own. During the field-testing, it was observed that somebody from the association would emerge as the "leader", or someone would volunteer to take charge of the operation. This is a clear manifestation that the waste workers will follow orders or instructions from a jointly-appointed, respected and accepted person whom they think has more command over them. This observation on how participants/members handled the simulated field production agrees with interpretations presented by other researches [55] and confirms that integrating the informal sector through cooperatives or associations can give them more reliability. This is necessary especially when the association would start negotiating contracts with the industries, municipal authorities or other interested entities. Integrating the informal sector in the SWM system can be realized by organizing and empowering them in good cooperation with non-government organizations (NGOs) and the local government. The presence of Iloilo City's GSO in UCLA was likewise experienced in Phnom Penh City, Cambodia. The waste pickers organized a self-help group and were supported by an NGO for acquiring knowledge and skill for manufacturing various recycling crafts by utilizing used papers and plastics [19]. Just like UCLA, they were also supported in terms of technology use, knowledge transfer and capability building by the GIZ, GSO and CPU to enable them to go into briquette production.

The actual briquette production test, which was conducted for 15 days, paved the way for the determination of the average volume of briquettes produced based on the simulated work conditions. This specific part of the study further allowed analyses of the cost of producing the briquettes, hence enabling them to mark-up the price for a value that can be afforded by people living in nearby areas. As observed throughout the simulated test, briquette production may be considered as socially feasible for similar associations given the encouraging performance the waste workers have displayed.

Involvement of the informal sector in briquette production as a livelihood is in congruence with the Philippines' SWM Framework Plan, which hopes to empower the informal sector through their promotion and implementation of the 3Rs of waste management with the overall objective of poverty alleviation. As a livelihood, it is an answer to reducing poverty in the Philippines [54,56]. Briquette production using a low-cost machine can provide alternative/additional livelihood to the urban and rural poor communities alike, giving them a more stable income. Stable income means gradual rise from poverty.

A person operating the briquette molder per day can help eliminate approximately 24 kg of waste paper, 16 kg of sawdust and 8 kg of CRH from the municipal waste stream. If computed for the six available briquetting machines at the UCLA Center, daily production of briquettes would lead to an estimated utilization of 144 kg of paper, 96 kg of sawdust and 48 kg of CRH. When converted at an annual rate, production would be 34,560 kg of paper, 23,040 kg of sawdust and 11,520 kg of CRH. The conversion of 144 kg of waste paper means 63% utilization from the current 227 kg paper waste recovered from Iloilo City's Calajunan Disposal Facility at present. If the 144 kg of paper would be sold for the common recovery price of Php1.50/kg (USD0.03), it would only earn Php216.00 (USD4.91). However, when these wastes are processed and sold as briquettes, the 144-kg waste paper may be able to generate an income of Php480.00 (USD10.91), increasing it to more than 100% of its original value. An increased use of sawdust and CRH is expected, as well, since these two materials typically have lesser selling value. In the Philippines, these biomass wastes are mostly dumped along the roads. The informal sector, therefore, could play a significant role in the recovery of these reusable waste materials from the waste stream and could benefit from additional livelihood and income through selling of AFR for household energy supply using the presented appropriate technologies.

Further benefits relate to the improvements of their working place: less exposure to waste picking at the dumpsite, weather protection during work, an acceptable and presentable working area and an organized working schedule with access to sanitation and water facilities. Waste picking undoubtedly poses health hazards to the workers. They are exposed to bad odors and diseases from dealing with mixed wastes in the dump. Women are especially more vulnerable to waste picking under unhealthy conditions at dumpsites or by sorting and washing collected materials. Working in briquette production will eliminate all of these direct effects that may be caused by long exposure to wastes. By strengthening women entrepreneurs in the informal sector, such as the case of UCLA, they would be empowered to carry out more independent activities and to establish more self-contained livelihoods. Through this, the third Millennium Development Goal (MDG), now switched to the fifth Sustainable Development Goal (SDG) that is to Promote Gender Equality and Empower Women, is addressed [57,58].

Working with the existing six units of briquetting machines would also mean working together as one team at regular hours or output-based performance, thereby providing them a sense of ownership and pride as workers. Although team work was not forced upon the workers during the field test, it was observed that the interest to earn more at the end of the day prompted them to work harmoniously and more efficiently. The scenario in enabling 18 waste reclaimers to work together at a jointly-used workplace enhanced work-related communication and skills development amongst them. When the waste workers were offered a job change to do briquetting, a compensation scheme of pay per performance with once in three days attracted the most of them compared to the option for daily payment [34].

Besides the potential gains for waste pickers, the involved municipality may benefit from the strengthening of the informal waste sector in several ways. Integrating the waste workers into the municipal waste management schemes not only secures access to additional work force, but likewise lessens the burden on social support measures for them since they may be given capacity to care better for themselves and their families. Moreover, increased waste recovery means reduced cost for waste disposal, as well as related environmental burdens due to leachate and GHG emissions [12,51]. Through energy recovery of biomass wastes coming from the municipal waste stream, the informal sector provides a significant contribution to environmental sustainability and resource efficiency by making raw materials available, here as an affordable and clean source of cooking fuels, thereby addressing the seventh MDG, which is to ensure environmental sustainability [52], now switched to the seventh SDG [58].

4.3. Applicability of Briquetting to Other Parts of the World

UCLA's familiarity with technology also allowed them to earn a net daily income higher than the majority of the waste reclaimers' surveyed daily income of Php124.00 (USD2.82) according to the conducted survey [34]. In Dhaka City, Bangladesh, the computed average daily income of the informal sector is BDT87.97 (USD1.14). With an average number of family members of five people, the income of the workers is not always enough to provide meals, but they manage it somehow by living marginally [59].

According to Medina [18], there are social benefits associated with informal recycling. The results of the study agreed that briquette production could provide employment and livelihood for impoverished, marginalized and vulnerable individuals or social groups, such as UCLA. This is proven by the potential production rate and earnings generated from this field-tested research work. The lack of education of some waste workers would not hinder their ability to participate in this endeavor since the technologies introduced were not complicated. The livelihood opportunity introduced and observed from the operations of UCLA has similarities with the case of Zabbaleen in Cairo. The Zabbaleen are a Coptic Christian minority, who have been active in collecting, sorting and recycling a substantial portion of waste in Cairo since the 1930s. A Coptic church helped to establish their association, and an environment and development program was initiated later with assistance from international funding agencies. Some opportunities introduced to them were new business prospects related to their trade and income generation project [60]. There was parallel focus on improving livelihoods by introducing technologies to add value and on education/social initiatives.

For similar briquette production initiatives introduced at Kahawa Sowento Informal Settlement in Nairobi, Kenya [23], one major problem experienced by the urban poor in cities of Sub-Saharan Africa including Kahawa Sowento Village is the inaccessibility of affordable cooking fuel. With this, the Soweto Youth in Action (SOYIA) youth group in collaboration with Green Towns developed an initiative for making fuel briquettes from urban solid waste with the aim of generating income and providing employment while contributing to environmental management. The results of the community-based energy briquette production conducted in the capital city of Kenya became valid as experienced also in UCLA. Training courses were conducted especially on the technical side of fuel briquette production; the briquettes were made from common waste materials, and quality was evaluated in a participatory manner. The "doughnut-sized" briquettes were sold at Ksh3 to Ksh5 (USD0.04 to USD0.06) per piece.

The size of the briquetting machine, roughly 300 mm × 300 mm × 650 mm in dimensions and with an approximate weight of 65 kg, makes the unit portable. This technology may be brought and introduced to places and countries where briquettes are used as fuel for cooking and biomass wastes are utilized as the main ingredient for production. This may include Bamako Mali, Lilongwe Malawi, Kenya and Haiti, which mentioned production of cylindrical briquettes with a hole using sawdust, rice husk, charcoal fines, carton board and waste paper. In Southeast Asia and nearby regions, the enormous availability of biomass wastes like rice husk and sawdust, including the commonly generated municipal solid wastes from paper, makes it valid to explore briquetting technology transfer. Based on the promising results of the introduced briquette production with UCLA from Iloilo City, Philippines, it appears feasible to explore technology transfer to Thailand, Vietnam and Nepal, since these countries are well endowed with renewable energy resources [61–63]. However, just like the Philippines, these countries are also rice producers with forestland covers.

5. Conclusions

Over the last 15 years, the Philippines has endeavored to improve its management and operation of solid waste through several national laws, which declared a policy based on the hierarchy of waste management that includes reuse, recycling and resource recovery of materials. With the prohibitions of waste picking in the disposal facilities, the existing activities of UCLA would become regulated. In order to assist the budding economic activities of this informal sector group, there is a real need to improve the cost-benefit balance of existing livelihoods and to search for new fields of activities that could create additional income. With the abundance of biomass wastes in the vicinity, some options identified are waste-to-energy through briquette production, a processed biomass fuel that can be burned as an alternative to wood or charcoal for heat energy.

Results of the study show that the integration of the informal sector in the production of biomass briquettes obtained from the municipal waste stream has led to a feasible on-site fuel production line after determining its usability, quality and applicability to the would-be users, which are comprised of the informal sector found near Iloilo City's controlled disposal facility. The technology utilized for briquetting is relatively easy to install and to operate due to its simple, yet sturdy, low-cost design. The provided equipment was able to withstand the wear and tear of operation showing suggestive results in terms of production rate and bulk density. The quality of cylindrical with hole briquettes produced in terms of bulk density, heating value and moisture closely met or has met the requirements of DIN 51731, making them a renewable source of cost-effective fuels. Based on the operating expenses, the briquettes may be marked-up to Php0.25/pc (USD0.006) or Php15.00/kg (USD0.34) for profit generation. The potential daily earnings of Php130.00 (USD2.95) to Php288.56 (USD6.56) generated in producing briquettes are higher when compared to the majority of waste reclaimers' surveyed daily income of Php124.00 (USD2.82).

An informal sector initiative that would venture into briquette production by utilizing wastes from the municipal waste stream can be considered profitable for small business enterprising, as demonstrated by UCLA, a waste reclaimers group in Iloilo City, Philippines. Provided a similar organization could be set up in other countries, this low-cost technology could play a significant role in the recovery of reusable materials from the waste stream, whereby local waste workers could further benefit from adding value to them by producing alternative fuels and raw materials (AFR) for household energy supply.

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