WASTE TO ENERGY: CHARCOAL BRIQUETTES AS AN ALTERNATIVE SOURCE OF SOLID FUEL MADE FROM VEGETABLE AND FRUIT WASTES AS A RAW MATERIAL

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Abstract:

The growing problems with the solid waste management are becoming widespread throughout the country. Composting is currently the most common method of handling biodegradable wastes, however, a significant portion of biodegradable wastes derived from food and market wastes are becoming unusable or "waste-wastes". These types of wastes can be upcycled and serve as a raw material for the production of fuel and electricity. The trend in renewable energy sources and its potential to decrease the carbon footprint is now giving an impact that addresses the Sustainable Development Goal (SDG) 7 – Affordable and Clean Energy and at the same time ensuring sustainable consumption and production patterns (SDG 12). The purpose of this study is to enhance the waste management of Science City of Muñoz through the utilization of Renewable Energy Technology. The wastes of vegetable and fruit stalls were the source of the raw materials in manufacturing the charcoal briquettes. This study shows that the solid waste management system can be improved by using biodegradable waste and turning it into renewable energy. The results show that the developed charcoal briquettes are functional and dependable in terms of various tests performed. It can meet the basic requirements of the people in terms of cooking their food because of its long duration of burning time. The development of charcoal briquettes from market wastes aligns with the Circular Economy concept, which holds that any waste material found in the environment can be used to create a new beneficial product. As a result, using charcoal briquettes can also lessen the need for conventional charcoal, which otherwise would preserve the trees from cutting down and slows down the global warming.

Keywords: Solid Waste Management (SWM); Food Waste (FW); Waste-to-Energy (WTE); Renewable Energy Sources (RES); Circular Economy (CE)

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INTRODUCTION

Solid waste management is one of the most pressing issues in the Philippine setting. Even if the technology today is advance and the community is modernized, the issue in solid wastes is still unmanageable and lacks proper attention. The people overlook the magnified effects of poor solid waste management that can detriment the health of our community, and especially the environment. A proper solid waste management has been considered as one of the pillars of a healthy and successful community. Whereas, if the solid wastes are not treated properly, it can cause sickness, illnesses, and worst is complications that will lead to death. To address the issue of solid wastes, the Philippine Congress ordained the Ecological Solid Waste Management Act or RA 9003 on July 24, 2000. This Act provides "an ecological solid waste management program, creating the necessary institutional mechanisms and incentives, declaring certain acts prohibited and providing penalties, appropriating funds thereof, and for other purposes" [1].

Waste can be processed in a variety of ways, including controlled landfills and mass burning. Waste to energy conversion is a relatively new kind of waste treatment that provides a variety of advantages [2]. It can create power through a variety of methods, including incineration and anaerobic digestion [3]. WtE generation contributes to lower greenhouse gas emissions [4]. It promotes sustainable development by providing a more effective waste management system. Waste has become a challenge not just for wealthy countries, but also for developing economies, which must transform waste into opportunity in order to achieve future sustainable development [5]. GHG emissions are primarily caused by untreated waste. WTE could be a promising technology for lowering GHG emissions [6].

Renewable energy technology promotes a significant and sustainable solution to addressing our energy demands while avoiding the negative environmental and climate implications of conventional fossil fuels. It refers to a variety of technologies and sources that use naturally occurring and replenishing resources such as solar, wind, water, and geothermal heat to generate electricity and power in order to use it in some distinct functions. Concerns about climate change, energy security, and the finite nature of fossil fuels are driving the shift toward renewable energy. WTE technology is a process that converts solid waste products into usable energy, typically in the form of electricity, heat, or both.

Moreover, the Science City of Muñoz, Nueva Ecija is an urbanized city which primarily generates a high amount of municipal solid waste. The city also faces storage and disposal issues due to lack of sanitary landfills that can treat solid wastes. Biodegradable wastes coming from the market remained untreated due to lack of large composting facilities. However, this study aimed to determine the solid waste generation of the wet market and come up with a solution of treating biodegradable waste by the use of renewable energy technologies. Furthermore, this study aimed to enhance the solid waste management of the LGU of the Science City of Muñoz by introducing the Biomass briquettes as a solution for the biodegradable wastes generated by the wet market.

METHODOLOGY

This study was conducted at the wet market: vegetable and fruit stalls located in Science City of Muñoz, Nueva Ecija. The researcher included all the fruit and vegetable stalls in sample collection in order to gather data in their waste generation. The biodegradable waste generated by the fruit and vegetable stalls will be used as raw materials for the manufacturing of biomass charcoal briquettes.

Data Gathering Instrument

The data sources of the study were composed of the primary sources. The primary data was gathered through the quantification and characterization of the waste generated by the fruits and vegetable stalls in Science City of Muñoz, Wet Market.

Collection of Samples

In characterizing the solid waste generated by the fruits and vegetable stalls, the Waste Analysis and Characterization Study-A Manual by Philippine Ecology Government Project was used. The researcher provided ample garbage bags to the fruit and vegetable stall owners. The garbage bags were collected every afternoon (5:00pm) and lasted for fourteen (14) days.

Waste Analysis and Characterization

In determining the weight (kg) and volume (l), the researcher weighed an empty plastic pail using a weighing scale and tared the weight of the plastic pail. Then in terms of the volume of the pail, it was calibrated by marking the equivalent height of one liter at the inside and outside part of the container. The researcher poured one liter of water and marked the water level (height) each time one liter of water was added. Calibrating receptacles in liters allows measurement of small quantities.

After the collection, the researcher characterized the collected samples according to their types: leaves, stem, fruits, pods, flowers, roots, bulbs, tubers, and seeds [7]. The waste that was collected was delivered to the waste characterization site. In determining the waste generation, the researcher weighed the collected wastes separately and recorded the weight. Then the contents of the bag were poured and checked if the stall owners did not throw any non-biodegradable or plastics. The plastics were removed and put in the other garbage. To get the volume of the waste generated by the fruit and vegetable stalls, the segregated and characterized waste was transferred to the calibrated pail to get the volume of each type of wastes.

Manufacturing of Charcoal Briquettes

Sun Drying

The solar drying was applied after the quantification of wastes generated by the fruit and vegetable stalls. The samples that were collected was exposed to that allows the retaining water to dehydrate. The samples were sun dried for about 7 days to make sure that the moisture was evaporated properly. The sample was stored in a plastic drum after the process of sun drying.

Carbonization Process

The sundried samples were transported into DA-PhilMech to undergo in carbonization process. Carbonization is a process that typically heats biomass feedstock in a kiln or retort (pyrolysis) at temperatures around 400C (generally between 300 and 900C) in the absence of air [8]. The produced biochar is also known as charcoal, which is a porous, carbon enriched, grayish black solid [9].

Briquette Making

The carbonized or char samples was mixed with cassava starch in a ratio of 50% char, 30% water and 20% cassava starch. The cassava starch served as the binder to attain the final product. Char samples were mixed with cassava starch and water in an electric mixer. After that the mixed materials was transferred in the manual briquette press machine of the DA-PHilMech.

Assessment of the Charcoal Briquettes

Kindling Time/Igniton Time

The researcher performed several trials in determining the average time in terms of the ignition time of the charcoaled briquettes. The researcher used a butane torch in igniting the briquettes. The smartphones were used as timer to identify the ignition time of the briquettes in determining its average time before attaining the state of spontaneous combustion.

Burning Time

This was the amount of time it takes for each briquette sample to totally burn to ashes. The burning rate was calculated by subtracting the time it takes to totally burn to ashes from the ignition time [10].

Water Boiling Test/ Burning Efficiency

Water boiling test determined how many minutes was it takes for 500 ml of water to boil using 500g of charcoal briquettes in a stainless kettle. The result of this test determined the average boiling time of water using charcoal briquettes and its effectiveness as an alternative cooking fuel. Boiling is the process by which a liquid turns into a vapor when it is heated to its boiling point. The change from a liquid phase to a gaseous phase occurs when the vapor pressure of the liquid is equal to the atmospheric pressure exerted on the liquid [11].

Burning Quality Test

One of the most recognized analytical techniques in chemistry is the flame test. It is commonly used to identify and assess the presence of certain components in a salt or compound. The flame test primarily detects the presence of metal ions in a compound, and considering ions of each element have a particular characteristic based on their emission spectrum, the flame test for each element is unique [12].

Friability Test

Friability test was executed by tying two (2) briquettes together using a yarn. The tied briquettes were dropped from the height of one (1) meter above a concrete floor continuously in three trials [13].

Determination of Moisture Content

The moisture content of the developed charcoal briquettes was determined. A portion (2g) each of the samples was weighed out in a wash glass. The samples were placed in an oven for 2 hours at 105ºC [14].

Determination of Ash Content

The ash content of the developed charcoal briquettes was also determined. A Portion (2g) were placed in a pre-weighed porcelain crucible and transferred into a preheated muffle furnace set at a temperature of 600ºc for 1hour after which the crucible and its contents were transferred to a desiccator and allowed to cool. The crucible and its content were reweighed and the new weight noted [14].

Determination of Volatile Matter

The volatile matter of the developed charcoal briquettes was also determined. A portion (2g) of the sample was heated to about 300ºC for 10minutes in a partially closed crucible in a muffle furnace. The crucible and its content were retrieved and cooled in a desiccator [14].

Determination of Fix Carbon (FC)

The fixed carbon of the raw coal, rice husk and briquettes were also determined. The fixed carbon was determined using the formula [14].

RESULTS AND DISCUSSION

Waste Analysis and Characterization

Figure 1 shows the wastes generated by the vegetables and fruits stalls in the Public Market of Science City of Muñoz, Nueva Ecija. The wastes are secured in a large bundle of plastic bags and sacks. The wastes are composed of perished, and non-perish vegetables & fruits. Majority of the wastes that are being disposed are not totally perished and considered to be still consumable.

Figure 1. Wastes generated by vegetables and fruit stalls in Science City of Muñoz, Wet Market

Figure 2 presents the process of Waste Analysis and Characterization Study performed by the researcher after every collection of samples from Vegetables and Fruit stalls in the Public Market of Science City of Muñoz, Nueva Ecija. The collected samples are still in good condition and have not perished at all. Some of the disposed samples had minor damage but not rotting at all.

Figure 2. Waste Analysis and Characterization Study (WACS)

Graph of weight and volume of the wastes generated

Figure 3 displays the graph of weight per kilogram of wastes generated per day of Science City of Muñoz, Wet Market. The highest generation of waste recorded was 75.4kg per day during October 22, 2023 (Day 13), followed by 71.4kg per day on October 10, 2023 (Day 1) while the lowest waste generation recorded was 33.1kg per day on October 19, 2023, (Day 10) followed by 37.3kg per day during October 13 2023 (Day 4).

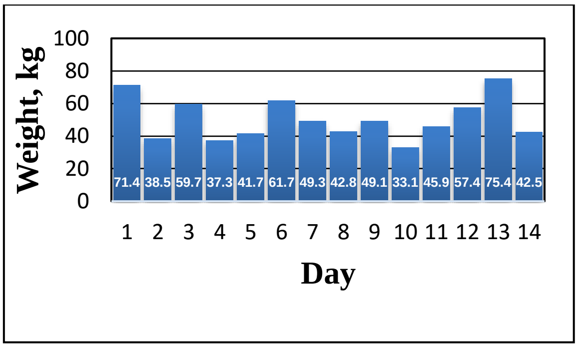

Figure 3. Weight of wastes generated per day from vegetable and fruit stalls in Science City of Muñoz, Wet Market

Figure 4 displays the graph of bulk density of waste generated per day. The highest volume of waste generated was 475 liters during October 22, 2023 (Day 13) followed by 425 liters on October 10 (Day 1) which also has the same volume of waste during October 13, 2023 (Day 3). While the lowest volume of waste generation was 186 liters on October 19, 2023 (Day 10)

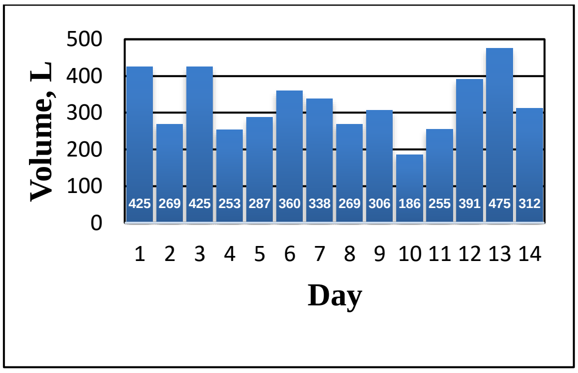

Figure 4. Bulk density of wastes generated per day from vegetable and fruit stalls in Science City of Muñoz, Wet Market

Waste Composition

The figure 5 shows the waste composition by weight percentage of Vegetable and Fruit stalls in Muñoz Wet Market. Fruits had the highest percentage of 52% in total, followed by Pods which had 21%. Meanwhile, leaves or green leafy vegetables, tubers, roots, and flowers had a weight percentage of 20%, 3%, and 3% respectively. On the other hand, the least percentage was 1% which was vegetable that is classified as flower.

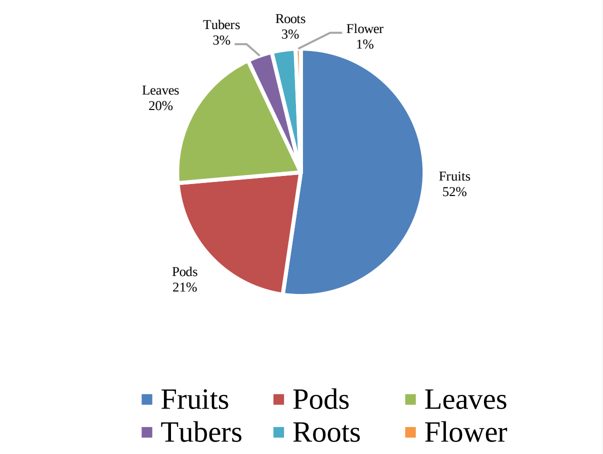

Figure 5. Percentage weight of the waste generated by the vegetable and fruit stalls in Science City of Muñoz, Wet Market.

The banana blossom, bottle gourd, bitter gourd, calamansi, cucumber, eggplant, loofah gourd, long chili, papaya, tamarind, and tomato are classified as "fruits". The bitter gourd leaves, cabbage, chayote leaves, pechay, saluyot, sweet potato leaves, and water spinach are classified as "leaves". While broccoli is the only "flower" that was classified. The carrots and radish were classified as "roots". Moreover, long beans, okra, and winged beans belong to "pods". Lastly, taro and sweet potato were classified as "tubers".

The Charcoal Briquettes

The net weight of the sundried samples was 16.13 kg, a portion of 2 kg sundried samples were used in making non-carbonized briquettes. Hence, a total of 14.13kg of sundried samples were subjected to the pyrolysis process. After the pyrolysis process, the recovered weight of carbonized samples was 8 kg in total. The missing 6.13 kg is the total weight loss that turned into ashes. Subsequently, after hammer milling the samples to attain its powdered form, the final net weight of biochar was only 7 kg. The missing 1 kg of the biochar was released through the air during the process of pulverization.

As shown in Figure 6, the carbonized waste samples turned into char, a black powdered material. The developed charcoal briquettes have a 2.5 inch in size, a diameter of 7 inches, and a cylindrical shape. The developed charcoal briquettes have a hole in the middle part allowing it to have a better combustion.

Figure 6. The developed charcoal briquettes from vegetable and fruit wastes

Step-by-Step Process of Charcoal Briquettes

The following steps are the process of turning the samples collected from Science City of Munoz, Wet Market into usable charcoal briquettes.

First step, the samples were chopped or reduced in size. Then, all of the samples were sundried in order to remove the retaining water and moisture. The samples were sundried for one week.

Second step, the sundried samples were carbonized using an improvised pyrolyzing drum. The carbonization process took one day before harvesting the product char from the samples. Then, the char and ashes separated to each by sieving it. In the sieving process, the ashes of the carbonized samples go through the sieving screen while the char remains on top of the sieving screen that is being used. Before the carbonization process, the sundried samples weighed 12 kilograms in total. After the carbonization process, the product weighed only 3.8 kilograms in total. There is 8.2 kilograms of weight loss during the carbonization process.

Third step, the carbonized samples were subjected in a hammer mill machine turning it to a refined powdered char product. Afterwards, it is mixed with the cassava starch that serves as a binder of the charcoal briquettes. The ratio of the materials used in developing the carbonized briquettes was 20% cassava starch, 30% water, and 50% char. The cassava starch was cooked in a medium heat setting on an induction stove for 5 minutes. Then, the cooked cassava starch and carbonized samples were put together into a mixing machine. The ingredients were mixed together for a maximum of 1 minute. After mixing the ingredients it was transferred into a closed container box to prevent hardening of the materials and to maintain its moisture.

Last step, the mixed ingredients were put into the top of the manual briquetting machine. It has 18 holes that are filled by the mixed ingredients. The briquette press used a hydraulic jack in compressing the ingredients. It was manually pumped by the researcher until it reached a certain threshold of pressure that gives the briquettes a compact and sturdy property.

The Properties of Charcoal Briquettes

Proximate Analysis

The data in Table 5 shows the results of proximate analysis of developed charcoal briquettes. The percent of binder used in developed charcoal briquettes was 20%. The moisture content of the briquette is 7%. The presence of high moisture content in briquette charcoal can cause it to swell and break down. Generally, fresh charcoal from an open kiln has a moisture content of less than 1%, however, over time it can absorb moisture from the air's humidity, resulting in a gain of moisture. Even in a well-burned situation, the moisture content can reach 5-10%. The moisture level of charcoal is typically limited to 5 to 15%, with a good grade charcoal having a moisture content of no more than 10% [15].

Additionally, the use of vegetable waste generated briquettes may be more beneficial for the environment, as it is a renewable resource and the briquettes produced from vegetable waste may have lower carbon emissions. The use of briquettes as a renewable fuel and energy source is highly advantageous due to their abundant raw materials. Biodegradable waste generated by nature, such as agricultural or forestry waste, can be transformed into briquettes. Furthermore, the use of biomass briquettes will have a significant impact on sustainable forest management, as it will neutralize the CO2 balance by reducing to approximately 60% and lower sulfur emissions, which are typically responsible for acid rain [16].

Table 5. Results of proximate analysis of the developed charcoal briquettes.

PROPERTY	PERCENTAGE (%)
Moisture	7
Ash content	38
Volatile matter	19.5
Fixed carbon	35.5
Total	100

Thermal Properties

The Table 6 shows the results of thermal properties tests of carbonized briquette (e.g., kindling time, ashing time, burning rate, and flame quality). The average kindling time of carbonized briquettes was fifty-five seconds. Briquette igniting duration reduces as biomass content increases. This is due to the fact that biomass has more volatile matter than coal. As a result, raising its concentration in the briquette will undoubtedly enhance its ignitability [16]. While, the average ashing time recorded was one hour, thirty-two minutes, and fourteen seconds. Hence, the kindling time was subtracted to the ashing time in order to get the burning rate of the briquette. The burning rate of the carbonized briquette was one hour, thirty-two minutes, and nineteen seconds. Chemical composition and geometry (bulk, packing, and orientation) of a material are two elements that influence its burning rate. Biomass has more volatile matter than coal and is more porous, allowing for simple oxygen entry and combustion product outflow. As a result, raising the quantity of biomass is projected to enhance the briquettes' burning rate [17]. Moreover, the flame quality test was not applicable to the carbonized briquette since it has no flame but ember upon testing.

Table 6. Results of the kindling time, ashing time, burning rate, and burning quality test.

SAMPLE	WEIGHT (g)	KINDLING TIME (sec)	ASHING TIME (sec)	BURNING RATE (sec)	BURNING QUALITY
1	63	55	1:29:05	1:28:10	EMBER
2	63	58	1:35:23	1:34:25	EMBER
3	65	52	1:32:16	1:31:24	EMBER
Average	63.6	55	1:32:14	1:31:19	EMBER

Boiling Efficiency

The Table 7 shows the results of boiling efficiency test of the developed carbonized briquettes. The average boiling time of 300mL of water using 3 pieces of briquettes was 13:33s, while the average boiling time of 400mL of water using 5 pieces of briquettes was 10:25s, and lastly the average boiling time of 500mL of water using 7 pieces of briquettes was 10:08s.

Compared to the study conducted by reference [17], in the water boiling test, the time needed to boil an equal amount of water for each group of briquettes decreases as the biomass concentration increases up to 50%. The fact that the briquetted samples with 50% biomass boil water faster than the ones with 100% biomass is an indication that somewhere beyond 50% the boiling time will start to increase. The coal briquetted sample E00 took the longest time (26min) to boil water. The S50 sample took the shortest (8.00 min) for the spear grass briquetted sample and the E50 sample for the elephant grass (6.46 min).

Table 7. Result of the boiling efficiency test.

SAMPLE	WEIGHT (g)	PIECES	VOLUME (mL)	AVERAGE BOILING TIME (sec)
1	194	3	300	13:33
2	324	5	400	10:25
3	473	7	500	10:08

Friability

The Table 8 shows the results of a friability test of developed carbonized briquettes. The two pieces of carbonized briquettes were tied using a yarn. The height of the dropping point was identified using a tape measure. The first drop of the briquettes was broken into 5 pieces having a 20% of IRI. The second drop of the briquettes was performed using the remaining big chunks of the briquettes from the first trial. The second drop was broken into 6 pieces while having a 16.6% of IRI. The last drop of the briquettes used the remaining big chunks of the briquettes from the second trial. The last drop was broken into 11 pieces having 9.09% of IRI. In total, the developed charcoal briquettes received 45.69% of IRI in drop tests.

Table 8. Result of the friability test.

TRIALS	HEIGHT	PIECES	IMPACT RESISTANCE (%)
1	100cm (1m)	5	20.0
2	100cm (1m)	6	16.6
3	100cm (1m)	11	9.09

As the peak temperature and heating rate rose, the compressive strength of the charcoal declined, and charcoal from softwoods (e.g., spruce and pine) was more brittle than charcoal from hardwoods (e.g., alder and birch). Peak temperature has a significant impact on the pore structure, surface area, and adsorption characteristics of charcoal [18].

According to reference [19], the IRI value of 50 was accepted as the minimum acceptable value for the fuel briquette developed for industrial or domestic use. The research showed that the binder used in the briquette production, cassava pulp, had a lower IRI value than 50, making it unsuitable for briquette production. The briquette produced with a 9:1 ratio for all binders also had lower IRI values than 50, thus not suitable for the production of briquettes. However, the briquette with molasses gel, concentrated slop, or binder at a higher ratio than 8:2 (7:3) or 6:4 (6:4) had a much higher IRI value than the cassava pulp binder. The soybean residue binder had a higher ratio than 7:3 or 6:4. All these briquette IRI values above 50 are therefore suitable for large scale production. These briquettes demonstrated resistance to cracking or breaking in transport and in storage.

Recommended Market Waste Plan

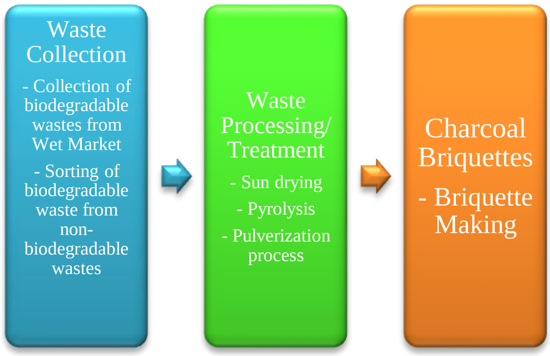

Figure 7. Process of treating market waste

The figure 13 shows the process of treating market wastes and turning them into renewable energy sources. The biodegradable waste from the wet market can serve as a raw material for making charcoal briquettes. As tested in this study, the charcoal briquettes can be an alternative source of solid fuel. Furthermore, the utilization of renewable energy technology can significantly enhance the solid waste management of LGU of the Science City of Muñoz, Nueva Ecija. Also, this will serve as a breakthrough to the Science City of Muñoz in terms of the utilization of renewable energy technology in treating the issues of solid waste.

The wastes from Science City of Muñoz, Wet Market will be collected by the city's waste management collectors. The biodegradable wastes will be sorted out from the non-biodegradable wastes as it is the only needed to make the charcoal briquettes. The sorted biodegradable wastes or vegetable and fruit wastes will be sun dried until the moisture comes off, it will take 7 days to dry the retaining water of the vegetable and fruit wastes. Then, the sundried vegetable and fruit wastes will be subjected to the pyrolysis process or carbonization process. This process will give the characteristic of the charcoal briquettes in terms of better burning combustion and less carbon dioxide emission while in use. Moreover, the carbonized product from the pyrolysis process will be pulverized before forming it into a briquette. Lastly, the pulverized materials will be mixed into a cassava starch as its binder that will help in forming the solid structure of the charcoal briquettes. The charcoal briquette production will serve as an open opportunity for the people of the Science City of Muñoz in generating income and employment once the LGU of Science City of Muñoz established a renewable energy facility that will treat and utilize the solid wastes.

CONCLUSION

The ever-growing problem of solid waste management due to unresolved and untreated wastes can affect the progress of an urbanized city, and of our country. It is one of the most pressing environmental issues in the Philippines ever since the passing of Republic Act 9003 also known as the Ecological Solid Waste Management Act of 2000. The study highlights the utilization of renewable energy technologies in enhancing solid waste management. The charcoal briquettes can serve as a mitigating tool for untreated biodegradable waste coming from the Science City of Muñoz, Wet Market. It can repurpose the biodegradable wastes into a new beneficial product that will help the LGU of Muñoz reduce funding in transportation of biodegradable wastes into Tarlac City.

Subsequently, the vegetable and fruit wastes are an effective source of raw material in making charcoal briquettes. The charcoal briquettes that are made in wet market wastes can be use alternatively as solid fuel. Also, by recycling waste and turning it into “waste materials” the increase in carbon footprint can be gradually reduced. Considering the findings of the study, the development of charcoal briquettes adheres to the Circular Economy model in which states that all of the wastes available in the environment can be a source of new products. Implementing a circular economy has the ability to address environmental issues like resource depletion and pollution while also contributing to a more sustainable and resilient economic structure.

Moreover, the introduction of renewable energy technology in enhancing the solid waste management system of the LGU of Science City of Muñoz can create an increase in job opportunities for the people. Hence, charcoal briquette is also considered as sustainable and green technology. It supports the SDG 7: Affordable and Clean Energy due to the availability of raw materials needed in manufacturing the briquettes.

Overall, the findings of the study can significantly show the effectiveness of renewable energy technology in treating the biodegradable wastes of Science City of Muñoz, Wet Market. Therefore, the charcoal briquettes can also reduce the use of traditional charcoal resulting in cutting down of trees. This allows the forest environment to remain standing as carbon sinks which prevents further climate change. By embracing renewable energy technologies, it can assist countries in transitioning to a more robust and sustainable energy in the future, addressing environmental concerns while also fostering economic and social development.

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