Convolutional Neural Networks for Solid Waste Segregation and Prospects of Waste-to-Energy in Ghana

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Abstract

Waste management and practices is a pervasive world problem. This is mainly due to the continuous rise in urbanization which comes along with a rise in waste generation. Even though proper waste management has a vital role to play in the ecological environment by greening through the recovery of energy from waste, its management is a menace.
Reports in Ghana indicate that about 5 million tons of Municipal Solid Waste (MSW) is generated annually and about 60% is organic. Out of this, the non-recyclable components constitutes about 20%, which indicates that 80% can be recovered and recycled, technically. Further, about 25% of the organic waste received at the material recovery and compost facility remains as compost for use in agricultural and other purposes.
Considering the population of Ghana pegged at 30 million in 2019, and daily solid waste production of about 0.45 kg per person (Amoah, 2006). Proper management and greening of MSW is very much essential with increasing demand of energy and that is what this paper seeks to tackle.

This paper mainly emphases on analyzing and classifying (segregating) solid waste using Convolutional Neural Networks (CNN) to productively process solid waste materials to enhance the separation process of converting waste to energy. Also, the potentials and prospects of organic waste to energy is exploited to reveal the technologies, socio-economic benefits as well as the challenges of implementing waste to energy plants in Ghana. Raspberry Pi Board, a camera, LEDs, an LCD screen and a buzzer are major components used.

Results indicate that, the system can effectively segregate solid waste that is recyclable and can be converted to energy. Feasibility studies of waste to energy also indicates that, combustion and anaerobic process of conversion ia mostly applied in Ghana, which has improved the greening and advocacy for clean environment. Again, the prospects of waste to energy was analysed using SmartPLS 3.0 and results indicate that, jobs, socio-economic, tourism , environmental cleanliness and reduction of communicable diseases are the benefits of installation of waste to energy plants in Ghana.

Keywords
Anaerobic, Segregation, Greening, Waste, Recycle

1.0 Introduction

The desire for sustainable waste management and environmentalism has become a world problem due to increasing industrial activities, global population, poverty and urbanization (Zhang L, 2018). This has caused a rise in energy demand and consequently a rampant environmental deterioration due to anthropogenic pollutions (Ferronato and Torretta, 2019; Gupta *et al*. 2015; Vitorino de Souza Melaré, *et al.* 2017; Zhang L, 2018). Thus, the application of MSW to generate electricity is becoming a widely accepted concept and a silver bullet for sustainability and meeting the millennium development goal 7.1, which seeks to provide reliable, affordable and clean energy for all by 2030. Properly managed waste system draws a maximization in the provision of clean energy or fuel which could be used for electricity and steam generation.

Energy from waste refers to the conversion of non-recyclable waste materials into usable ones in the form of electricity, heat and fuel by employing different processes such as, incineration, anaerobic digestion, gasification, pyrolization, and landfill gas recovery often referred to as waste to energy.
As Ghana sets out a target to increase the share of renewable energy in the country's electricity generation mix by 10% in 2020, an idea of conversion of MSW system is targeted at maximizing energy recovery from recyclable materials with a minimized environmental and societal cost impacts through an overall treatment and waste collection steps (Barnor *et al*. 2018; Ofori-Boateng *et al.* 2013). The introduction of a sustainable MSW with an added advantage of waste sorting to properly prepare solid for further waste to energy processing is very much anticipated.

According to World Bank reports in 2016, waste generation has been on the ascendancy, with an estimate generation of 2.01 billion tons of solid waste by world cities. Further, there has been a projection of the figure expectant increment to 3.40 billion tons per year by 2050, which is attributed to the increasing rise in urbanization by a growth of 70%. Consequently, sustainable management of these wastes generated is an unabated challenge in most developing countries in recent years. In Ghana, Increase in solid waste generation is perceived to be directly proportional to the path of population growth, urbanization as well as other affluence related to the challenges of proper waste management in urban areas of most developing countries. This is due to the high income level in those areas and increasing urbanization (Amo-Asamoah; Ghana Energy Commission, 2018). Despite all these, sub-Saharan African countries like Ghana greatly focuses on improving waste collection processes instead of enhancing waste management practices in various sectors of the country. Congruently, waste management and practices, in order words zero waste management includes all activities and actions in the waste management value-chain needed to manage waste from inception to the final disposal.

In Ghana, as documented by the Ghana Statistical Service (GSS), based on the 2010 National Population and Housing Census (Torres-García, 2015), the most popular means of disposal of solid wastes is by householders through using the public dump; either dumping in a container (23.8%) or dumping into open dumpsite (37.7%). Further, about 9.1% of households dump wastes indiscriminately into open fields, gutters, and drains, while another 10.7% of households burn their solid wastes. Only 14.4% (one in seven) households hire firms or individuals to collect their solid wastes from their homes to recognized and approved waste collection centers or landfills (GSS, 2013, p.392). Only dumping into public containers and collection of wastes from households can be considered improved methods (38.1%). Recently, it has become a public policy in urban areas to charge householders who dump their solid wastes into public containers at a fee.

Given the current population of Ghana of about 30 million as of August 2019, and daily solid waste production of about 0.45 kg per person (Amoah, 2006), the daily aggregate production of solid wastes is about 11,700 tons. The estimates of the proportions of solid wastes not properly collected in Ghana are high; these include 61.9% by GSS (2013, p.392) and 60% to 75% by Anomanyo (2004). Based on these estimates, improperly collected solid wastes are currently between 7,020 to 8,775 tones daily.

The activities and actions in proper waste management include waste collection, waste transport, processing, treatment and disposal of non-hazardous waste as well as monitoring and regulation of the disposed waste by recycling (Tchobanoglous, McGraw-Hill; 1993). However, lack of availability of landfill sites in most urban areas due to unplanned human settlements, poor planning of waste management programmes and education, inadequate infrastructure, lack of funds for sensitization, lack of proper enforcement of bye laws and policies are the challenges facing solid waste management in Ghana.

According to Ofori (2016), the generation of energy from waste improves on sustainable waste management due to the fact that, the emission of methane which is typical with landfilling is greatly avoided. In simple terms, waste to energy is described as a concept or process of generating energy from waste such as industrial and commercial waste, MSW, agricultural by-products as well as animal manure which are not recyclable (Ofori, 2016). This process provides alternative means of reducing greenhouse emission by improving the greening of the environment through the need to reduce, reuse, recover, recycle and continuous management of disposed waste. Consequently, Peralla (2011) researched that, close to 80% of products are discarded within six months of leaving the production companies, which could have been recycled or converted from waste to energy to solve the ever increasing energy demand bottlenecks in Ghana.

1.1 Towards an improved Environmentalism: The Need for Greening and Waste to Energy Generation

The benefits of environmentalism gained by most western countries has generated considerable academic interest and an urgent need to work on the hazards of improper environmental conditions in developing countries ((Torres-García, 2015). However, there are apparent gaps in the knowledge, understanding and academic coverage to emulate some of the practices in the developing worlds, particularly in Africa. Lack of education, inadequate infrastructure, lack of funds, non-enforcement of bye laws, improper human settlements etc. are attributed factors to the low level of employment of these practices(Ampofo, 2016).

Generally, a lot of value has been placed on waste because it can be recycled and reused (Abdel-Shafy H.I, 2018). Thus, waste is considered a resource to alleviate poverty in developing countries by the principles of circular economy concept (Ezeudu, 2019, Wright, 2019). Congruently, no waste goes waste by discarding simply because it is not needed. But rather, the circular economy converts this waste to new products for reuse.

In Ghana, the level of employment of waste to energy plants in the management of waste is overwhelming. According to the Renewable Energy Policy Review, Identification of gaps and solutions for Ghana report, the regulatory framework for the promotion of renewable energy is anchored on the Renewable Energy Act (2011), which seeks to support and provide for the development, utilization, management of a sustainable and adequate supply of renewable energy for the production of power and heat. Thus, increasing the share of renewable energy in the national energy supply mix as well continuously managing the mitigation of climate change (Government of Ghana, 2011). Even though, lack of infrastructure, inappropriate technical knowledge, unsponsored research and development, lack of continuous funds of waste management projects are some of the challenges faced by the renewable energy sector. Thus, a lot of work has been conducted in this sector in Ghana. Nevertheless, gaps in the sector still need to be tackled in order to increase the share of renewable energy in the energy generation to the targeted 10% in 2020. Currently, the total share of RE is pegged 0.3% of the total supply, which is far too less compared with other developing countries. Informed research and development findings and report in the RE sector of Ghana has a wide prospect in attaining more attention to this area and the need to embrace these prospects for a sustainable development in Ghana.

1.2 Research Problem and Motivation

Post-collection segregation costs more and can wind up harming the environment in cases where recyclable waste is conveyed to landfill sites. The percentage of non-biodegradable waste produced today is unprecedented. Thus, there is an increasing trend of packaging of plastics and electronics with values such as durability and products' life no longer being prioritized. Waste segregation is needed in appropriately and sustainably management waste generated in Ghana. But the process of segregating solid waste when conducted manually becomes less efficient, time-consuming and not completely feasible in cases of large volumes of MSW generation.

Congruently, improper disposal of wastes in Ghana is rising with increasing population and rapid economic growth. Also, what could be waste for one could be a resource for another, which makes waste a relative concept. Thus, the need to apply principles to gain the prospects of this commodity whilst exploiting its conversion to usable products to help alleviate poverty in Ghana.

1.3 Objectives of the Research

The objective of this project is to design and construct an intelligent system for waste segregation using the CNN on the MATLAB platform and also analyze the prospects of waste to energy in Ghana.

1.4 Review of Waste Segregation Methods and Potentials of Waste to Energy in Ghana

Waste management has a vital role to play in the ecological environment. Proper waste disposal at dumping sites has an essential part in sorting at the base level, and this leads to an increase in time and manpower in the sorting of the waste. Poor sorting of waste leads to improper waste disposal, which tends to deplete the ecology of the environment. The problem of improperly collected solid waste in Ghana is more pronounced in urban areas since much of the fast-economic growth can be noticed in urban areas. Poor solid waste disposal in low-income urban areas is generally high (Anaman and Nyadzi, 2015). This context comprises an overview of related works that were attempted by other theoretical facts on waste management. It is imperative to know that solid waste has been an overwhelming challenge for governments for about 6000 years now (Bilitewski, 1994). Since the concept of waste is relative in two main respects; which has to do with the fact that, what is considered waste to one person is another's raw material input. Again, waste in its self is relative to the location of its generation and the technological state of the art, which makes it dynamic.

Sandhya Devi R.S, *et al.* 2018, researched on "Waste Segregation using Deep Learning Algorithm." The aim of the study was to deploy a Smart garbage management system in India. This research estimated that collection of waste from homes and industries were being dumped into yards. Secondly, manual techniques were used to sort the waste out, which happened to be less efficient, time-consuming, and not completely feasible due to the large amount of waste generated. The study proposed an automated waste segregation system that used CNN algorithm, a Deep Learning based image classification model to classify materials into biodegradable and non-biodegradable based on the object recognition accuracy in real-time. Actually, the algorithm was suitable for a large amount of waste classification process. A python index package of Spyder was applied to identify and classify the waste material through the provided webcam in the design model. Open-source libraries like Tensor Flow and Spyder were implemented for the process. Even though a small percentage of error was recorded in the process of segregation, the system proved to be effective and efficient compared to manual process of waste segregation.

In Ghana, several methods and procedures for proper management of waste have already been researched and carried out by Barnor, *et al*. (2018; Amo-Asamoah, *et al.* (2020); Anaman, *et al.* (2015). Also, many prototypes have also been designed with various algorithms to carry on the segregation process efficiently. In most cases, images of objects are scanned using the device to classify them accordingly.

But a major shortcoming of such a system is that, all devices work with maximum accuracy only on images containing single objects to be recognized and classified. CNN are considered to play an especially important role in the process of object recognition and classification and can be said to be the major step towards the development of image recognition. Improved methods and steps that consider the shape and size of objects for their recognition and classification have also been developed, but these can only be applied on objects that can stay in a specific shape or size, making it difficult when applied for the segregation of waste and scraps.

The major drawbacks of these existing systems are that, some models for solid waste segregation are huge. Therefore, require large spaces for construction. In situations where getting enough working space is a challenge, the project is not feasible. Also, the concept of feeding back the accuracy data into the system to improve its efficiency involves a lots of work. In the other models too, the categories in which waste are classified are less.

Therefore, an efficient method to segregate waste into the number of material types and implementing the internet as a back end to play the role of a database is warranted. This would assist the CNN data set in making intelligent decisions in order to have a wide range of datasets on several kinds of material types, reducing the stress involved in training the system and also constructing a prototype that will not require many spaces to be constructed as compared to some existing reviews. This can eventually make it possible for waste to be segregated more efficiently with enough speed.

2.0 Extent of Solid Waste Management Practice in Ghana

Solid waste management in the early days in urban centers in Ghana was conducted by incineration technology. But due to lack of funds to support the technology, the process could not be sustained. Due to this happenings, solid waste was dumped on any available free located referred to as BOLA (Okyere, *et al.* 2019; Oduro Kwarteng, 2010). Afterwards, the German Agency for Technical Co-Operation (GTZ) organized a department for solid waste management referred to as Waste Management Department., set up in urban centers. This project help to improve the deteriorating state of waste management practices in the country by setting up house to house waste collection team which was conducted with donkeys. Later this agency exited and took Ghana back to a more disastrous state of solid waste management. Communal service waste management by both private and public companies was also introduced whereby, waste is emptied in a large container located in a community to decentralize the disposal of waste in the country (Okyere *et al.* 2019).

Generally, the methods employed for solid waste disposal in Ghana are uncontrollable and unsupervised dumping of waste, composting, incineration, sanitary landfill and controlled dumping (Danso, 2016). Insufficient covering and mismanaged material at the landfill site, unpleasant odor, flies, infections and smoke caused by open fire at these sites are some of the challenges of uncontrolled dumping of refuse in Ghana. Thus, there is high demand for improved waste disposal and management systems to effectively control waste through competent institutions and efficient managerial systems.

Oteng-Ababio (2014), researched on conventional solid waste management philosophy as a potential barrier to an efficient and sustainable management, reported that waste generation can be reduced in order to adopt an integrated systemic approach that could control the waste generation process which includes waste reuse and collection. In this study, the potential of converting household waste generated to a reusable product is conducted in Accra. Thus, the composition of the waste collected is analyzed to show its ability to be recycled. Result indicated that the waste generated in Accra metropolis of Ghana is recyclable and hence a well supervised waste to reusable programme could ensure a reduction in waste generation as well as prolonging the life of the landsite available, whilst creating jobs and controlling poverty. Similarly, the renewable energy policy review, identification of gaps and solutions in Ghana re-entreated the findings of Oteng-Ababio research work.

In 2018, Mawuli Abalo researched on "A review of triple gains of waste and the way forward for Ghana". Here, a complete review of the prospects of solid waste in Ghana is provided. Thus, the research work conducted conclusively reaffirms the fact that with the insertion of appropriate and cost effective technologies in place to manage waste, gaining the full potential of generating waste to energy is possible. Moreover, other resources and income could be drawn from the greening of the environment and properly management waste in Ghana. Additionally, the recommendation made by the researcher is that the economic potential of waste could be explored because waste disposal is the last resort option in waste management practices in Ghana, and not the first as perceived. Table 1 illustrates forecasted estimates of waste generation proportions in Ghana by 2030.

Table 1: Estimated Waste Generation in the Capital City Of Ghana(ACCRA) from 2000-2030

Years	Population	Waste Generation (Tons/Day)	Waste Collection (Tons/Day)	Residual (Tons/Day)
2000	1,658,939	2,127	1,702	425
2005	1,960,797	3,369	2,695	674
2010	2,317,583	2,654	2,123	531
2020	3,237,730	3,390	2,712	678
2030	4,523,203	4,419	3,535	884

(**Source:** Oteng-Ababio. 2014)

In Ghana, the statistical data for waste generation is inconsistent due to conflicting figures reported by various sources (Abiti, 2017). The existence of challenge in data is a great impediment on proper management of waste in the city, which could be enhanced by adopting Abubakar *et al.* (2019), recommendations for adoption of smart grid in Ghana. Also, it is warranted to conduct a comprehensive survey with modern technologies and duly report waste generation figures and cities in Ghana, in order to make available data for further researches and efficient waste management practices and technologies to make informed decisions in the country.

The way and manner, municipal waste is managed in Ghana needs a re-definition significantly to meet the purpose of the policies set to solid waste management to protect policies health and as well as the environment. Conventionally, the process of Solid Waste Management (SWM) includes, waste reduction, reuse, combustion, and safe disposal of waste residuals at defined landfill sites. Nevertheless, a re-definition of the already existing hierarchy for waste management will do a lot of good for the citizens of Ghana, including the alleviation of poverty and improving in the health and job security. Therefore, figure 1 illustrate a proposed MWM concept with an added need for greening and environmentalism in order to promote the prospects of waste to energy in the country.

Considering waste management from the perspective of this research paper, complete management of waste starts from the generators of the waste, which involves multiple process and institutions. This proposed concept of waste management deals with waste segregation and sorting at the point of its generation to explicit management at disposal sites for the attainment of a complete SWM in Ghana as well improving on energy to waste production. IPCC 2007 reported that introducing an optimal approach to waste management involving an interactive and integrated system that completely controls the overall process of waste generation and effective management of residuals is the key to improving lives and livelihood. This simply implies that, waste could be considered of value and has economic gains than a menace. Thus, industrial, Commercial, domestic and other sources of waste production should join in getting the full benefit of waste instead considering it, a bye-product and useless. Exploiting this area will fetch Ghana a lot of prospects.

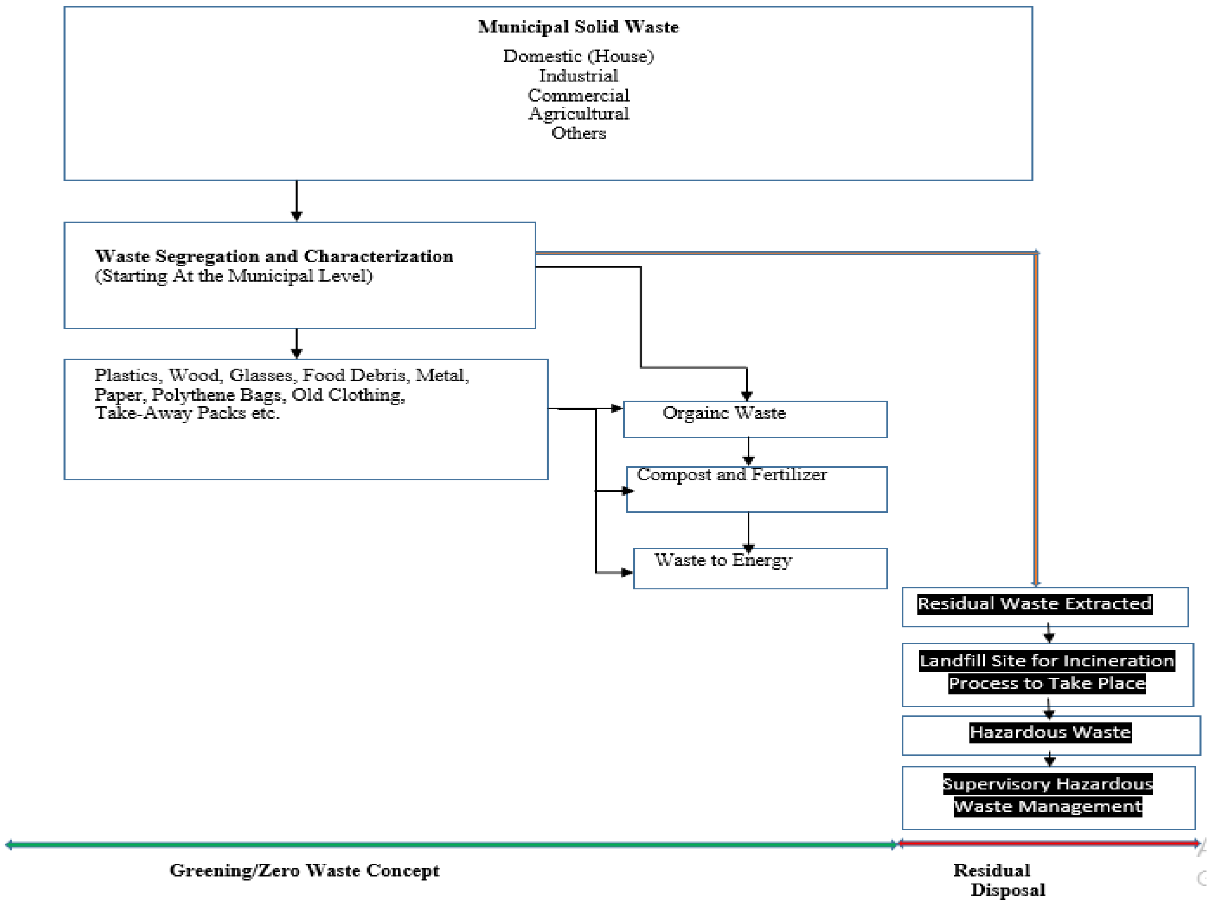

Figure 1: Proposed Municipal Waste Management Concept and Promotion of Greening in Ghana

Considering figure 1, the segregation of waste is conducted from the point of generation. This practice is essentially applied in modern waste management systems. Considerably, to achieve an effective waste to energy systems depends on lesser contamination of the waste segregated, which largely depends on how proper waste is segregated.

2.1 Block Diagram of the Municipal Solid Waste Segregation System

The system architecture or block diagram is a conceptual model that defines the structure, behavior, and views of the system. It provides the fundamental structure of the segregation system.

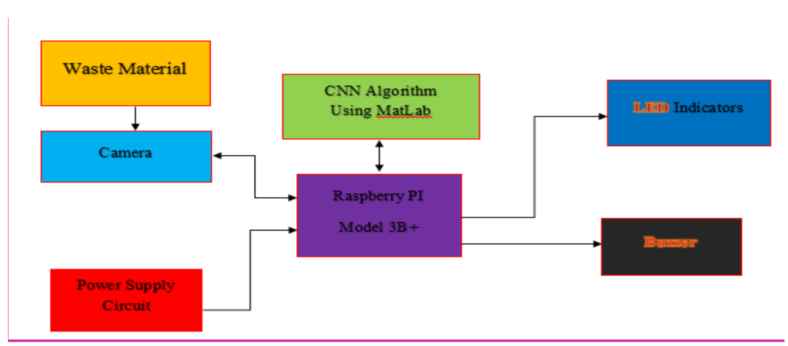

Figure 2: A Block Diagram of the Waste Classification System

Figure 2 illustrates a block diagram of the waste segregation system with all the component applied for the segregation of waste. Here, the image of the solid waste is captured by a camera powered by an external power source. Thereafter, the programmed raspberry PI model 3B processes the image to detect the type of object it is. This is done for easy separation and segregation of waste.

3.0 System Design and Methodology

The design of these systems assembly the component parts of the layout shown in the block diagram illustrated in fig. 2. The design modules, architecture of design and electronic concept adopted in the project design were duly addressed and adhered to, with an overall interest of segregating waste to enable solid waste management in the municipality. Table 2 shows a list of the components applied for the segregation of waste with their cost.

Table 2 List of Component for Solid Waste Segregation

Devices/ Components	Quantity	Prices
Raspberry Pi 3 Model b+	1	GH₵ 270.00
Camera Model V2 – 8mp Camera Sensor	1	GH₵ 175.00
Raspberry Pi Screen and Display	1	GH₵ 100 .00
Metallic Sink and Coolant	1	GH₵ 60.00
Plywood Frame	1	GH₵ 60.00
Plastic Casing	1	GH₵ 20.00
Raspberry Pi Universal Power Adaptor	1	GH₵ 20.00
Breadboard	1	GH₵ 20.00
Jump Wires	50	GH₵ 2.00
LEDs	30	GH₵ 0.50p

3.1 Design Specifications

The specifications of components for this project is shown in table 2, quantity and price for the various devices used in the setup is provided as well. Connecting the component is careful explained by the circuit diagram in figure 3.

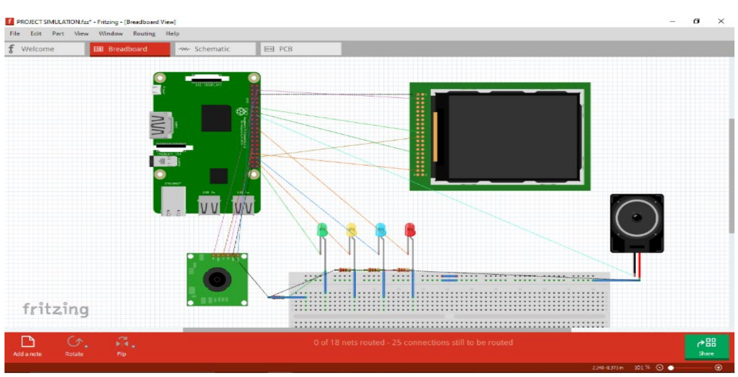

Figure 3: Breadboard Diagram of Schematics.

The simulation of our project was done using a simulation software. It is an electronics schematic capture and simulation program used in circuits teaching solution to build expertise through practical application in designing, prototyping, and testing of electronic circuits. The tools used to simulate the design include the following:

3.2 Hardware and Software for Simulation

An HP Pavilion x360 laptop with windows 10 operating system with the hardware used for the simulation. The software part being the MATLAB R2017b Software: Fritzing Beta 0.8.7.

3.3 Workflow of Solid Waste Segregation Model

The flow chart design in figure 4 depicts the flow of data and information through the system. It caters for the logical developer design and defines actions of a given decisions and information process flow. Here, the step by step detection and segregation process is outlined due to the instruction set in the algorithm loaded on the Raspberry Pi 3 model b+ model for detection.

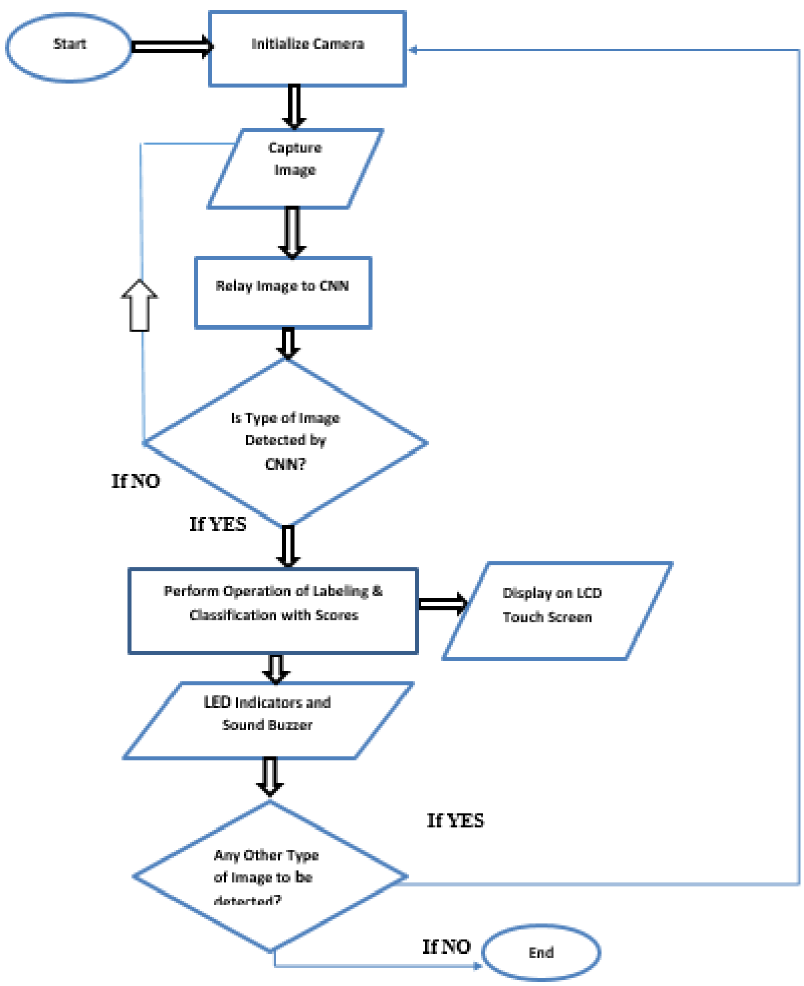

Figure 4: Flow Chart of the Solid Waste Segregation Model

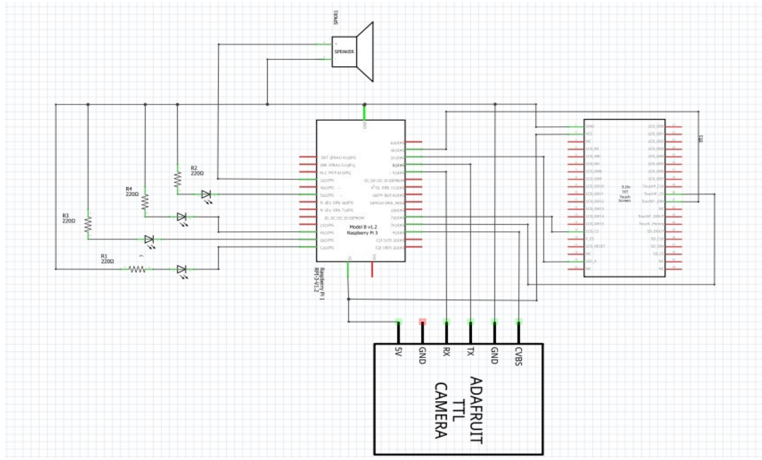

Figure 5: Zoomed-in Project Schematic Diagram

This intelligent system will be a productive way to process waste materials by analyzing and classifying waste using CNN on MATLAB software. Figure 5 illustrates the schematic diagram of the prototype design.
A waste classification system has been designed using Deep Learning Image Processing classification model for classifying objects into 4 material categories, namely: Glass, Metal, Paper and Plastic based on the object recognition accuracy in real-time as well as a CNN algorithm. This algorithm is suitable for a large amount of waste segregation process. The convolutional layer is expressed as:

$$(f * g)(t) \overset{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau)\ g(t-\tau) d\tau \qquad \textbf{Eqn. 1}$$

Where, **f (t)** represent the input image passed into the CNN and **g (t)** is a feature detector. The CNN performs a convolutional operation between the input image and the feature detector using the formula in eqn. 1 and the output image is termed the feature map which is a representation of the features extracted from the input image. This principle of CNN operation is illustrated in Figure 7 and Figure 8. The primary function of the convolutional operation as applied in CNNs is to gather features from the input image using the feature detector and place it into a feature map, which still preserves the spatial relationships between pixels.

3.4 Testing and Evaluation

The testing and evaluation stage are an integral component for a design and construction setup. Based on the implementation of the CNN in the design setup, the simulations and test results are critically analyzed and recorded to ensure that it conforms to the specified requirements. After the test of the project, various sections obtained include:

- **Training Stage**
  i. Gathering the Image Dataset
  ii. Configuring the Training options
  iii. Training (Transfer Learning)

- **Real time Validation & Test Results**
  i. Detecting and classifying each waste material
  ii. Displaying test results on an LCD screen with LED indications

4.0 Results and Analysis from Construction

After a prototype of the system was designed using the Fritzing software to produce the accurate schematic sketch, it as well served as a guideline for the actual connections on the board on which the device sits. Figure 6 shows the completed waste segregation system.

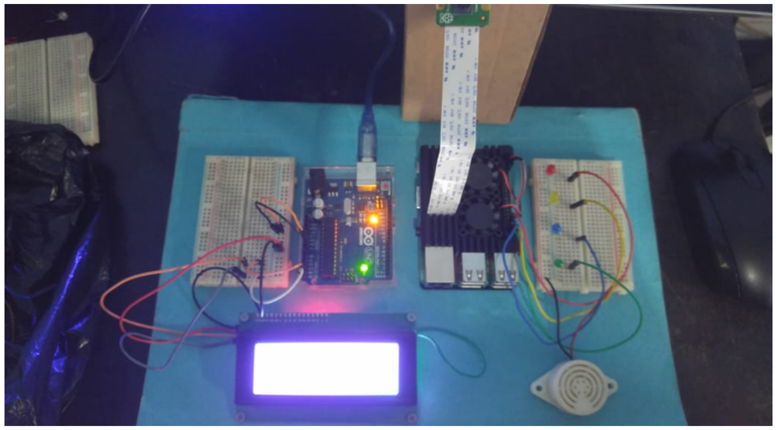

Figure 6: Waste Segregation System

4.1 Gathering the Image Dataset

In setting up a desired object detection and classification system or model, the pre-trained CNN algorithm implemented needed to be trained to obtain accuracy in achieving the desired outcome. This was accomplished by using the Transfer Learning concept whereby the last three layers of the pre-trained CNN algorithm or model were configured and trained with a given image dataset created by the user.
However, the CNN model implemented in this design setup was Alex Net. A total number of 611 images including some repeated images of the waste material for every category were sampled. This was compiled to achieve an extensive dataset of about 2,444 images in total. The dataset comprised of images augmented into different angles to increase diversity to suit real time testing conditions.

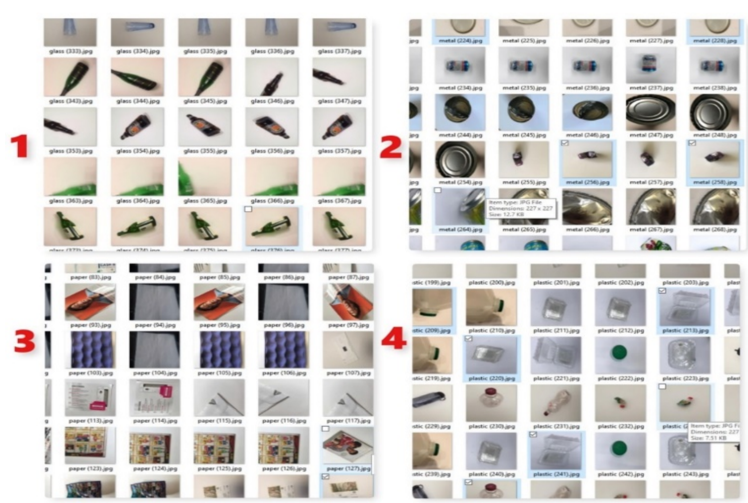

Figure 7: User Image Dataset

The image dataset in Figure 7 indicates the respective classes of the design specification with regards to our project, namely: glass, metal, paper, and plastic.

4.1.1 Configuring the Training Options

A higher percentage of the images from each category were allocated to the training data sets which were augmented into various angles or perspectives to make the AlexNet CNN algorithm very smart and effective in real time detection as explained earlier. The transfer learning concept kept the early layers of the CNN and modified the last three layers (the fully connected layer, SoftMax layer and Classification output layer) during the training process.

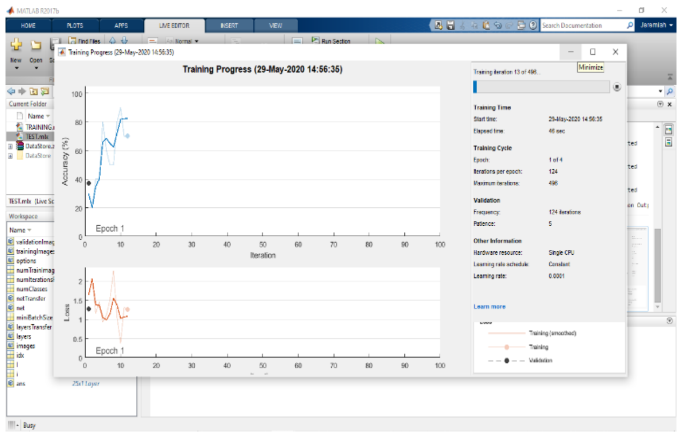

Figure 8: Training Commences

The training involved the use of a single Graphics Processing Unit (GPU). During the process, the software validated the network at every iteration, and automatically stopped when validation loss stopped improving.

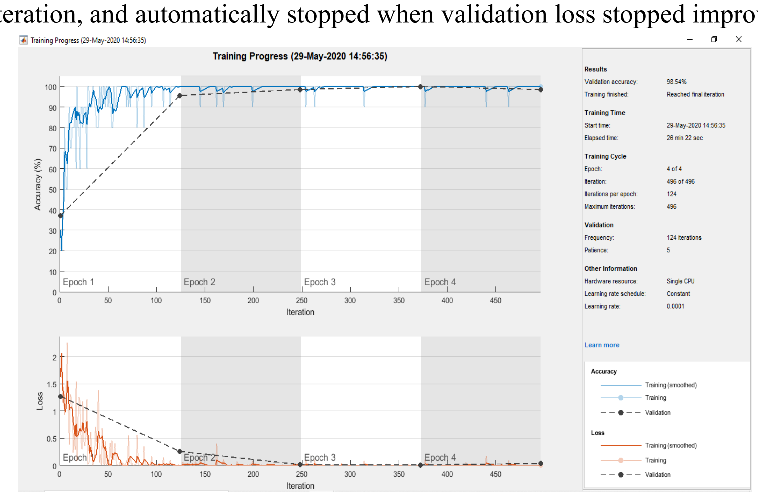

Figure 9: End of Training Display

The training completed with an accuracy of 98.54% as shown in the figure 9.

4.2 Real Time Validations and Test Results

The trained Alex Net CNN was then loaded, and real time testing was achieved with the help of the Raspberry pi camera. The categories of waste materials considered were plastic, paper, metal, and glass. We assigned specific colors of LEDs to each category of waste material thus:

1. Red LED – Plastic
2. Blue LED – Paper
3. Yellow LED – Metal
4. Green LED – Glass

The LCD screen also displayed the test results of each material during the validation process. The input image from the raspberry pi camera was resized in a 227 x 227 x 3-pixel dimension suitable for the CNN to work on for detection and classification purposes. Figure 10 shows the LCD display.

Figure 10: The 16x2 LCD Screen Display

The detection and classification were done right after the images were captured by the camera module
The item or object was immediately classified right after detection by the CNN algorithm. It obtained a 100% acuuracy level in detection.
The LCD screen displayed the category of the material after the capture by the camera module and CNN detection and classification of the waste materials. The green, red, blue, and yellow LEDs were indications for glass, plastic, paper, and metal detections, respectively.

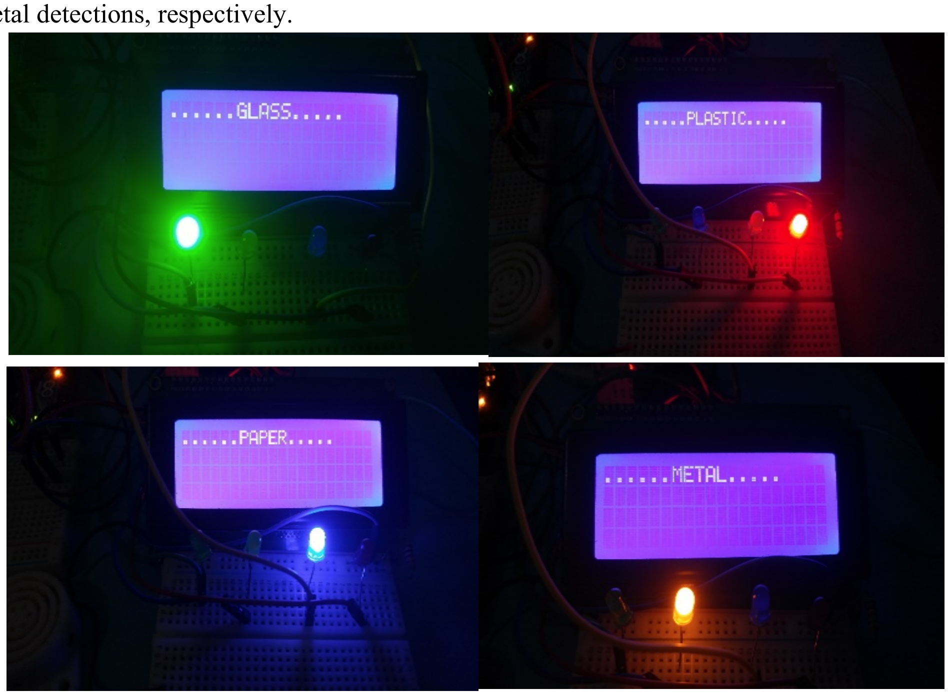

Figure 11: Display of Test Results on LCD as well as LED Indications

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Each captured image was detected and classified correctly with an approximation of the probability 1, indicating a 100% accuracy level in detection by the CNN. The rate of accuracy in detection and classification by the CNN during the validation process was efficient and effective. Figure 11, illustrates various LED indicator display on detection.

4.3 Results and Analysis of the Prospects and Barriers of Waste to Energy in Ghana

The structural model was built using SmartPLS 3.0 to present the variables perceived to have an effect on the prospects of waste to energy in Ghana. The formation of the model is purposely base on researcher's layout of questionnaire for the factor analysis of the proposed effect of each variable on the other and the overall effect on the prospects of waste to energy. Essentially, most of the variables selected for the test had five indicators pointing at questions about their effects on the prospects of waste to energy, accept the variables; prospects of waste to energy and effects of tourism on the prospects. The careful choice of indicators for each variable greatly helped in the constructing of an efficient model. Here, the indicators represent the exogenous variables, whilst the variables were endogenous variables with regards to the proposed model construct. Moreover, the field data was collated in Microsoft excel and saved in CSV (Comma Delimited) before importing in the SmartPLS software. After building the model construct, blue colored variables gives an indication of well correlated variables in the model. Thus, the structural model test and validation of can be conducted.

According to Hair, *et al.* (2013), formative measurement deal with uncorrelated measurements, where composite reliability, outer loadings and square root of Average Variance Extracted (AVE) are meaningless, the reflective measurements also deal with indicators that are highly correlated and the causality is directing from the blue-color latent variables to the yellow colored indicators is illustrated in figure 12. Thus, their reliability and validity shall be thoroughly examined (Wong, 2013).

Considering the output of structural model constructs from the SmartPLS, the two numbers seen in the model represent how much the variances of latent variable is explained by the other variables in the conceptual framework. In this case, the numbers in the blue circle represent how much the variance of the latent variables is explained by the other variables in the same construct. Also, numbers on the arrow lines refer to the path coefficients. Thus, shows the strength of the effect of one variable on the other in the framework. This also helps in ranking the statistical importance of the variables. Apparently, data set of about 1,000 sample size should have a standardized path coefficient of 0.20, so as to be able to demonstrate statistical significance (Wong, 2013).

Table 3: Lists of Abbreviations and Meaning in Model Construct

Abbreviation	Variable Relations
WTEEC	Waste to Energy Affects Environmental Cleanliness
WTESE	Waste to Energy Affects Socio-Economy
WTET	Waste to Energy Technology Employed
PWTE	Prospects of Waste To Energy
TPWE	Waste To Energy Affects Tourism

Also, values in the blue circle in the path model show how much the variances of latent variable is explained by the other variables forming it. For instance, the 0.475 in the blue circle in figure 12 representing prospects of waste to energy, indicates that 47.5% of all the reflective variables on the circle explained their effect on the variable. Table 3 is the list of abbreviation in the model construct for the interactive model construct.

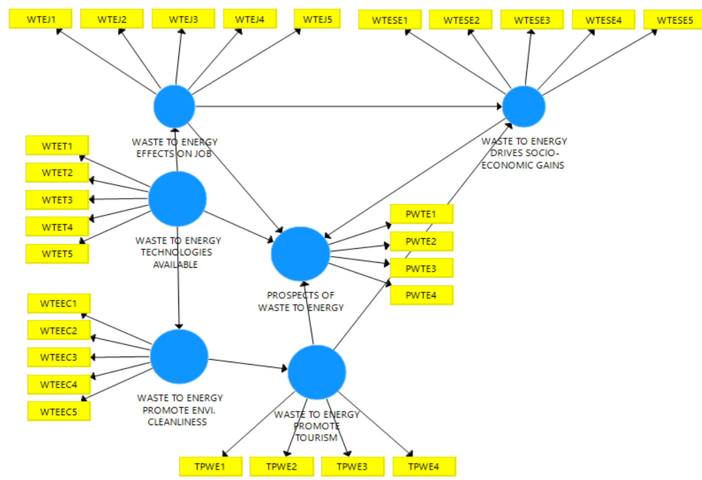

Figure 12: Prospects of Waste to Energy in Ghana Model Construct

Referring to the abbreviations used in the proposed model constructs, which is defined in table 3 to show the indicators for the causal relation between two variables in the model construct for the factor analysis of prospects of waste to energy in Ghana.

i. Model Fit for Correlation Test

Here, the bootstrapping analysis for the model is used to determine the fitness of the model. The saturated and estimated values of the analysis conducted is used for the model fit test. Whilst the saturation value should be at least 0.08 or below as proposed by Hu and Bentler, (1999). Considering the values in table 4, both the estimated and saturated values are adequate for the model construct with model implied correlations.

Table 4 Model Fit Results

	Saturated Model	Estimated Model
SRMR	0.07	0.11
d_ULS	2.25	4.90
d_G1	0.639	0.75
Chi-Square	1050.86	1145.55
NFI	0.67	0.65

Source: SmartPLS Results

The SRMR is 0.07 and NFL value is 0.11, which indicated a degree of correlation among all the variable. Furthermore, overall confirmatory factor analysis will rely on the T-values from the path coefficients and R-Square values of the model. Also, results for the path coefficient was deduced by applying the two-tailed T-test are morethan 1.96 at 5% significant level with all values of the causal relation being more than 0.2 and considered significant as shown in table 5.

Table 5: Path Coefficient Results for Model Construct

Paths	T Statistics (|O/STDEV|)	P Values
WASTE TO ENERGY DRIVES SOCIO-ECONOMIC GAINS -> PROSPECTS OF WASTE TO ENERGY	3.96	**0.00**
WASTE TO ENERGY EFFECTS ON JOB -> PROSPECTS OF WASTE TO ENERGY	0.61	**0.04**
WASTE TO ENERGY EFFECTS ON JOB -> WASTE TO ENERGY DRIVES SOCIO-ECONOMIC GAINS	5.42	**0.00**
WASTE TO ENERGY PROMOTE TOURISM -> PROSPECTS OF WASTE TO ENERGY	2.85	**0.00**
WASTE TO ENERGY PROMOTE TOURISM -> WASTE TO ENERGY DRIVES SOCIO-ECONOMIC GAINS	8.40	**0.00**
WASTE TO ENERGY TECHNOLOGIES AVAILABLE -> PROSPECTS OF WASTE TO ENERGY	5.95	**0.00**
WASTE TO ENERGY TECHNOLOGIES AVAILABLE -> WASTE TO ENERGY EFFECTS ON JOB	3.64	**0.00**
WASTE TO ENERGY TECHNOLOGIES AVAILABLE -> WASTE TO ENERGY PROMOTE ENVI. CLEANLINESS	**17.50**	**0.00**

In assessing the reliability and validity of the proposed model in order to evaluate the performance of the model construct, Convergent validity, discriminant reliability, composite reliability etc. as shown in table 7 are used for the analysis.

In measuring the average value, a satisfactory value of AVE(Average Variance Extracted) being 0.50 and higher indicates a sufficient degree of convergent validity, which means that more than half of the indicators' variance and the latent variable are errorless as suggested by Hair, (2013). Also, the composite reliability values are considered strong if values are >= 0.7.

Table 6: Measurements of Quality of Model

Variables	R Square	R Square Adjusted
PROSPECTS OF WASTE TO ENERGY	0.48	0.47
WASTE TO ENERGY DRIVES SOCIO-ECONOMIC GAINS	0.36	0.36
WASTE TO ENERGY EFFECTS ON JOB	0.04	0.04

Subsequently, the R-Square and Adjusted R-Square values as indicated in Table 6 were applied for the quality test and goodness of fit. Results indicated viability for the proposed model construct. This is because values obtained are not more 1.

Additionally, confirmatory analysis is conducted considering values of Fornell–Larcker criterion as illustrated in Table 8.

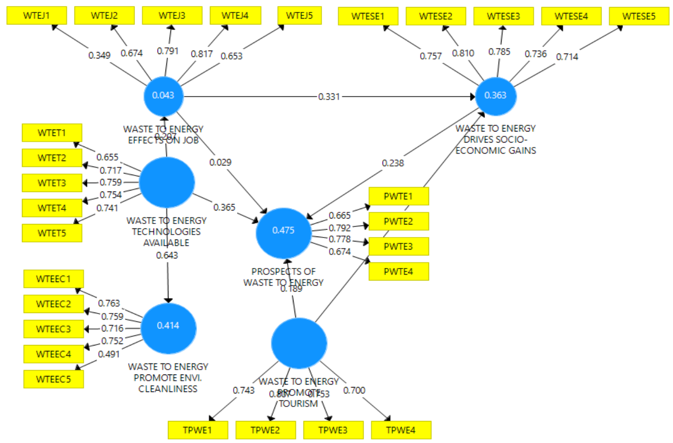

Figure 13: Bootstrapping Results of Model

Table 8 illustrate the values for Discriminant Validity test. This is considered positive when the preferred values obtained for each latent variable construct is higher than other latent variables construct (Bagozzi, 1998). The discriminant validity was measured by using the Fornell–Larcker criterion and the results demonstrated a positive validity as shown in Tables 8.

Table 7: Construct Reliability and Validity

Variables	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted
ROSPECTS OF WASTE TO ENERGY	0.704	0.709	0.819	0.533
WASTE TO ENERGY DRIVES SOCIO-ECONOMIC GAINS	0.818	0.819	0.873	0.579
WASTE TO ENERGY EFFECTS ON JOB	0.723	0.747	0.799	0.459
WASTE TO ENERGY PROMOTE ENVI. CLEANLINESS	0.743	0.774	0.825	0.493
WASTE TO ENERGY PROMOTE TOURISM	0.743	0.748	0.838	0.565
WASTE TO ENERGY TECHNOLOGIES AVAILABLE	0.775	0.776	0.847	0.527
ROSPECTS OF WASTE TO ENERGY	0.704	0.709	0.819	0.533

Table 8: Test for Discriminant Validity using Fornell Larcker Criterion

Variables	Prospects Of Waste To Energy	Waste To Energy Drives Socio-Eco'mic Gains	Waste To Energy Effects On Job	Waste To Energy Promote Envi. Cleanliness	Waste To Energy Promote Tourism	Waste To Energy Techn'gies Available
Prospects Of Waste To Energy	**0.73**					
Waste To Energy Drives Socio-Economic Gains	0.57	**0.76**				
Waste To Energy Effects On Job	0.25	0.43	**0.68**			
Waste To Energy Promote Envi. Cleanliness	0.54	0.66	0.34	**0.70**		
Waste To Energy Promote Tourism	0.53	0.51	0.23	0.50	**0.75**	
Waste To Energy Technologies Available	0.63	0.62	0.21	0.65	0.59	**0.73**

Considerably, table 7 illustrates the reliability and validity of the model construct by considering the Cronbach's Alpha with values for all construct to be < 0.7, which is a significant value. Also, values of composite reliability are significant as shown in table 7.

5.0 Conclusion and Recommendation

In this paper, an emphases on segregation of solid waste, right at the point where it is generated using convolutional neural networks due to its ability of minimal pre-processing time to enhance the waste separation process of converting waste to energy is conducted. Results indicate that, the waste segregation systems developed has the ability to efficiently separate waste with an accuracy rate of 98%. In order to attain a good detection, a total number of 611 images including some repeated images of the waste material all four category considered were sampled. This was compiled to achieve an extensive dataset of about 2,444 images in total. The dataset comprised of images augmented into different angles to increase diversity to suit real time testing conditions. On the other hand, the prospects and barriers of waste to energy researched on, indicated that socio-economic gains, jobs, tourism, technological advancements, environmental cleanliness and reduction of communicable diseases are the prospects of generating energy from waste plants in Ghana. Also, insufficient Infrastructure, lack of technical education on modern approach and methods of proper waste management, improper implementation of policies and politics are the challenges of waste to energy generation in Ghana.

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