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Research Article

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Prediction of Heat Energy for Electricity Estimation on Municipal Solid Waste Using Artificial Neural Network

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Abstract This study is aimed at prediction of the heat energy from municipal solid waste properties and its potential for electricity generation using artificial neural network statistical tool. Random truck sampling was used according to American Society for Testing and Materials (ASTM) in the collection of waste to the disposal site and characterized into four (4) parameters; food waste, plastic waste, wood waste, and cotton waste. A sample of the waste was measured for experimental analysis to determine the range of input parameters. Statistical design of experiment (DOE) using central composite design (CCD) matrix version (13.0.5.0) was employed to predict the heating value of each input parameters that will minimize the rate of solid waste disposal and generate heat energy responses using Artificial Neural Network model. Reliability was produced to test the networks adequacy. The central composite design (CCD) matrix predicted heat energy value of 26,102.6kJ/kg. A regression plot showing the correlation between the input and output was produced with R^2 values of 97% for the training, 87% for the validation, 98% for testing and 97% for the overall. A reliability plot of 81.7% was obtained for artificial neural network (ANN). The study established the heating values for electricity potential of the municipal solid waste components in the area. The results showed that recovery heat energy for electricity estimation is a feasible option as part of an integrated municipal solid waste management plan in Nigeria.

Keywords Municipal Solid waste, Energy, Artificial Neural Network, Electricity, and Experimentation

1. Introduction

In Nigeria, wastes are generated in the homes, commercial places, industrial sites, hospitals, schools, on streets and even religious activities (Adewumi *et al*., 2019). In the early age, the amount of waste generated by human population was very insignificant. This was due to the size of the population and the spread of population around the world. The common wastes generated during the early ages were mainly ashes and human wastes; these were released back into the ground, which did not cause any harm to the environment (Adewumi *et al*., 2019).

Solid waste can be defined as garbage, refuse and other discarded materials including waste resulting from industrial, commercial and agriculture operations and from community activities or waste that are normally solid and that are discarded as useless or unwanted (Barrett and Lawler, 2021). The solid content is technically known as refuse while the liquid substances are called effluent. The energy problem and environmental degradation are currently two vital issues for global sustainable development.

Rapid industrialization and population explosion in Nigeria has led to the migration of people from villages to cities, which generate thousands tons of municipal solid waste daily, which is one of the important contributors for environmental degradation at the national level (Vergara and Tchobanoglous, 2019). Municipal solid waste management is one of the major environmental problems of Nigeria cities. Improper management of municipal solid waste causes hazards to inhabitants. Massive volume of solid waste is generated every day in the municipal areas and unfortunately solid waste management is deteriorating day by day (Vergara and Tchobanoglous, 2019). According to Egwurube, (2018) stated that the uncontrolled urbanization has left many Nigerian cities devoid of many infrastructural services such as water supply, sewage and municipal solid waste management. Most of urban centers in Nigeria are overwhelmed by severe problems related to solid waste due to lack of low efforts by town/city authorities, garbage and its management. Great increase in the amount of municipal solid waste has been reported in the cities due to an improved lifestyle and social status. Egwurube, (2018) stated that quickening urbanization accompanied with increasing per capita incomes have also led to rapid increases in MSW generation that have dramatically expanded the burden on local governments in Nigeria for collection, processing, and disposal of MSW in efficient ways. Municipal corporations in Nigeria are unable to handle increasing quantities of waste, which results in uncollected waste on roads and in other public places. Nigeria has serious problem on municipal waste management and electricity, load shedding is now impractical as living standards now become a great barrier in socio-economic growth in the Nigeria (Aliu and Ogbeide, 2021). Hence there is need for an alternative source of energy to boost electric energy supply. Recovering energy from municipal solid waste to predict heat energy for electricity estimation is feasible by means of modeling of energy generation processes such as artificial neural network model. The aim of this research study is to predict the energy values from municipal solid waste properties for electricity generation in Nigeria using Artificial Neural Network model

2. Methodology

The generated municipal solid waste in Nigeria was classified into four (4) groups due to their energy behaviors; food waste, wood waste, plastic waste, and cotton waste (Aliu and Ogbeide, 2021). The central composite design (CCD) was used for the statistical analysis on heat energy prediction from the responses. The statistical model help to reduce the volume of municipal solid waste generated as well as estimated and predicted the heat energy responses from various municipal solid wastes in Nigeria.

3. Results and Discussion

In the process of this research work, a sample was measured for Laboratory experiment to determine the range (kg) of input parameters from the various characterized waste in the metropolis under investigation using analytical balance and muffle furnace. The results are depicted in Table 1. Statistical design of experiment (DOE) using the central composite design method (CCD) was done .Central composite design (CCD) is unarguably the most acceptable design for Artificial Neural Network (ANN). The design and optimization was done using statistical software, and for this particular problem, Design Expert 13.0.5.0 was employed as presented in Table 1.

Table 1: The range of process Input parameters

Categories	Factors	Units	Minimum	Maximum
A	Food waste	Kg	11	14
B	Wood waste	Kg	18	26
C	Plastic waste	Kg	140	170
D	Cotton waste	Kg	130	170

Table 2: Build information for the CCD design having a quadratic behavior

File Version	**13.0.5.0**		
Study Type	Response Surface	Subtype	Randomized
Design Type	Central Composite	Runs	30
Design Model	Quadratic	Blocks	No Blocks
Build Time (ms)	2		

The Central Composite Design and Design of Experiment for the range of process input parameters of the municipal waste components with coded responses to determine the optimum value of each input variable namely: food waste, wood waste, plastic waste, and cotton waste that will minimize the rate of solid waste disposal and generate heat energy from the municipal waste in Nigeria resulting to about 30 experimental runs was generated. The real values are presented in Table 3.

Table 3: Central Composite Design and Design of Experiment for the municipal waste

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
Run	**A:Food waste**	**B:Wood waste**	**C:Plastic waste**	**D:cotton waste**
	Kg	**Kg**	**Kg**	**Kg**
1	13	22	160	150
2	13	22	160	150
3	13	22	160	150
4	13	22	160	150
5	13	22	160	150
6	13	22	160	150
7	13	26	160	150
8	11	22	160	150
9	13	22	140	150
10	13	22	160	170
11	13	22	160	130
12	13	22	160	150
13	13	18	160	150
14	13	22	160	150
15	12	20	170	140
16	12	24	150	160
17	12	20	170	160
18	14	24	170	140
19	14	24	150	140
20	12	24	170	140
21	14	24	170	160
22	12	24	150	140
23	12	24	170	160
24	12	20	150	160
25	14	20	150	140
26	14	20	170	140
27	12	20	150	140
28	14	20	150	160
29	14	24	150	160
30	14	20	170	160

Using these parameters, an optimum neural network architecture was generated to predict the four response variables, namely; (food waste, wood waste, plastic waste, and cotton waste) since the same input variables were used. The network training diagram for the prediction of heat energy responses using back propagation neural network is generated.

From the network training diagram, it was observed that the network performance was significantly good with a performace error of 6.97e+06 which is far lesser than the set target error of 0.01. The maximum number of iteration needed for the network to reach this performance was observed to be 20 iterations which is also less than the initial 1000 epochs. The gradient function was calculated to be 1.81e+03 with a training gain (Mu) of 1.00. Validation check of six (6) was recorded which is expected since the issue of weight biased had been addressed via normalization of the raw data. A performance evaluation plot which shows the progress of training, validation and testing is presented in Figure 1

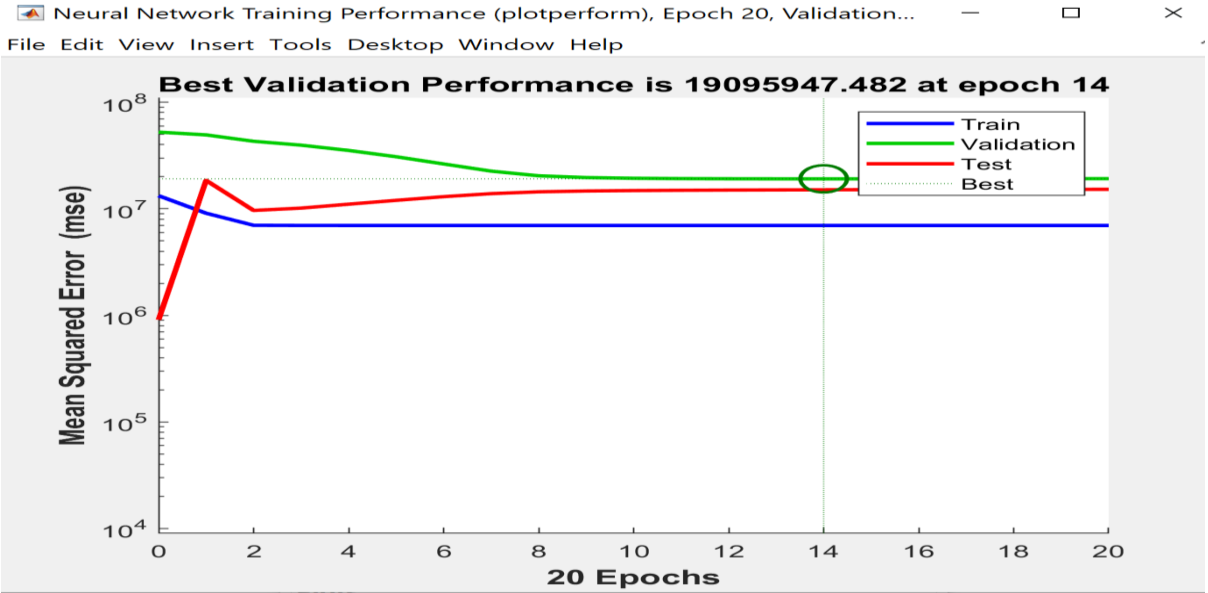

Figure 1: Performance curve for trained network to predicting heat energy responses

From the performance plot of Figure 1, no evidence of over fitting was observed. In addition similar trend was observed in the behavior of the training, validation and testing curve which is expected since the raw data were normalized before use. Lower mean square error is a fundamental criteria used to determine the training accuracy of a network. An error value of 19095947.482 at epoch 14 is an evidence of a network with the capacity to predict the heat energy response. The training state, which shows the gradient function, the training gain (Mu) and the validation check, is presented in Figure 2

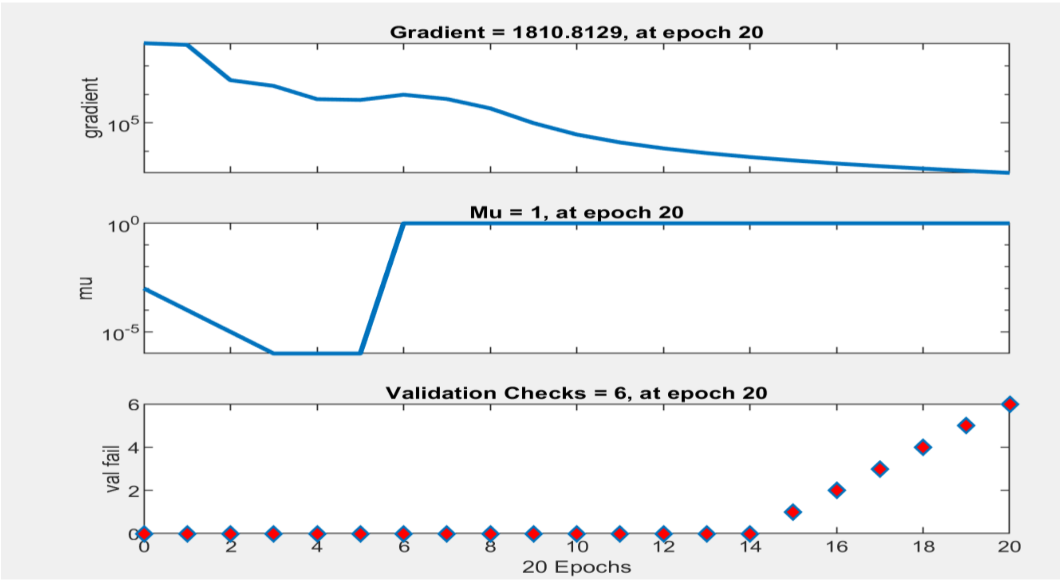

Figure 2: Neural network gradient plot for predicting heat energy responses

Back propagation is a method used in artificial neural networks to determine the error contribution of each neuron after a batch of data training. Technically, the neural network determined the gradient of the loss function to explain the error contributions of each of the selected neurons. Lower error is better. Computed gradient value of 19095947.482 as observed in Figure 2 indicates that the error contributions of each selected neurons is very minimal. Momentum gain (Mu) is the control parameter for the algorithm used to train the neural network. It is the training gains and its value must be less than unity. Momentum gain of 1.00 shows a network with high capacity to predict the heat energy. The regression plot which shows the correlation between the input variables (food waste, wood waste, plastic waste, and cotton waste) and the target variable (Heat Energy) with the progress of training, validation and testing is presented in Figure 3

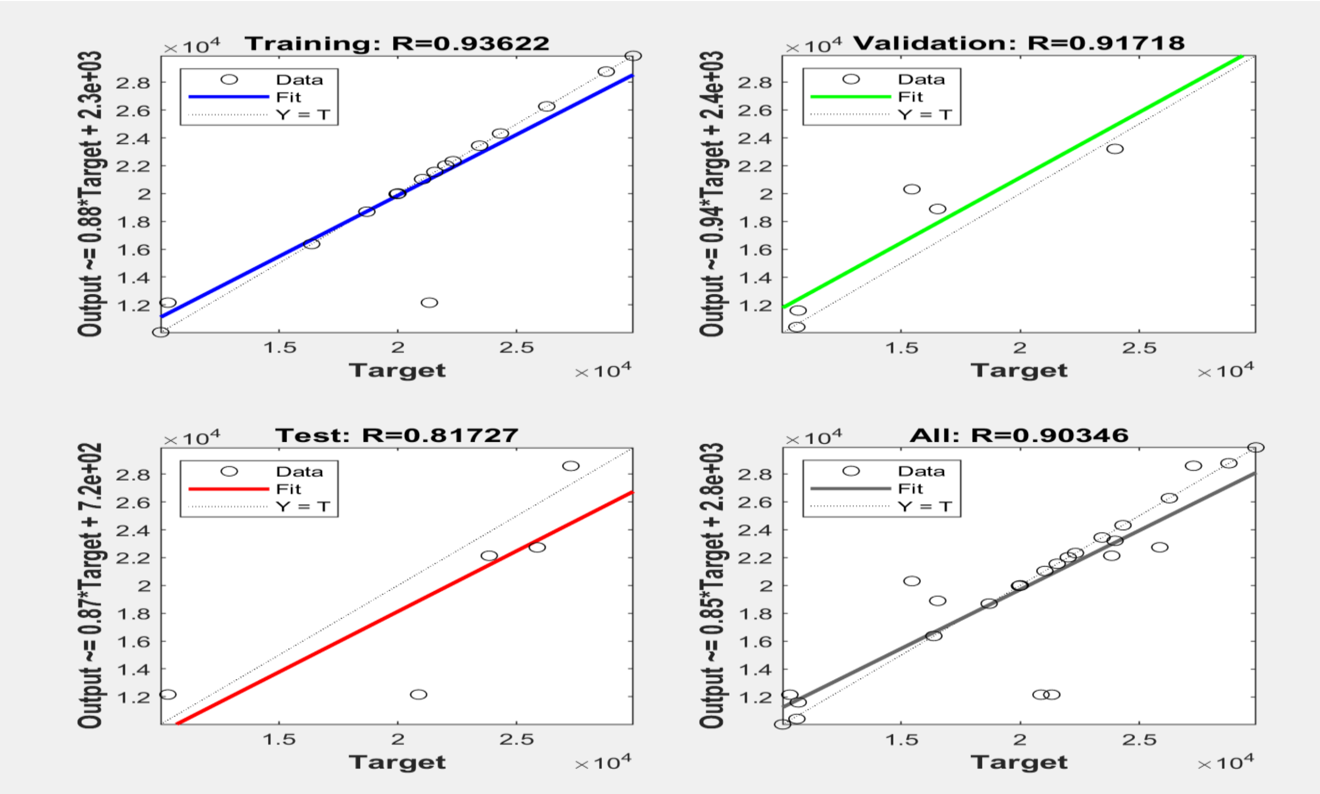

Figure 3: Regression plot of training, validation, testing for heat energy responses

Based on the computed values of the correlation coefficient (R) as observed in Figure 3, it was concluded that the network has been accurately trained and can be employed to predict the heat energy. To test the reliability of the trained network, the network was thereafter employed to predict its own values of heat energy response using the same sets of input parameters (food waste, wood waste, plastic waste, and cotton waste) generated from the central composite design. Based on the observed and the predicted values of surface tension, a regression plot of outputs was thereafter generated as presented in Figure 3 that shows the regression plot of training, validation and testing and combination of all for heat energy responses and the results is presented in Table 4 that has four input variables designated as factor 1, factor 2, factor 3, and factor 4 representing food waste, wood waste, plastic waste, and cotton waste and three response variables designated as EXP, ANN, and error representing: Heat energy (J).

Table 4: ANN prediction results for the generated heat energy from municipal waste

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**EXP**	**ANN**	**Error**
Run	**A:Food waste**	**B:Wood waste**	**C:Plastic waste**	**D:cotton waste**	**Heat energy (J)**	**Heat energy (J)**	**Heat energy (J)**
	Kg	Kg	Kg	Kg			
1	13	22	160	150	10324	12157.3348448519	-1833.33484485187
2	13	22	160	150	10326	12157.3348448519	-1831.33484485187
3	13	22	160	150	10323	12157.3348448519	-1834.33484485187
4	13	22	160	150	10324	12157.3348448519	-1833.33484485187

5	13	22	160	150	10325	12157.3348448519	-1832.33484485187
6	13	22	160	150	10323	12157.3348448519	-1834.33484485187
7	13	26	160	150	10021	10024.0501226721	-3.05012267208804
8	11	22	160	150	29899	29897.7648803372	1.23511966282604
9	13	22	140	150	22015	22014.9202852721	0.0797147278535704
10	13	22	160	170	20005	20004.8344664777	0.165533522296755
11	13	22	160	130	28765	28764.9722602965	0.0277397035206377
12	13	22	160	150	21325	12157.3348448519	9167.66515514813
13	13	18	160	150	16534	18893.5257201205	-2359.52572012050
14	13	22	160	150	20873	12157.3348448519	8715.66515514813
15	12	20	170	140	27276	28582.4284518679	-1306.42845186788
16	12	24	150	160	15454	20308.6740523843	-4854.67405238429
17	12	20	170	160	23843	22131.7110791980	1711.28892080201
18	14	24	170	140	23438	23438.2310660214	-0.231066021377046
19	14	24	150	140	21037	21036.7680169095	0.231983090503491
20	12	24	170	140	21552	21552.1169976798	-0.116997679753695
21	14	24	170	160	16371	16370.7385524895	0.261447510483777
22	12	24	150	140	19965	19965.0643942310	-0.0643942310052807
23	12	24	170	160	26262	26261.9547436768	0.0452563231519889
24	12	20	150	160	25862	22733.5954297333	3128.40457026671
25	14	20	150	140	22322	22321.9858621282	0.0141378718471969
26	14	20	170	140	24315	24314.7357006995	0.264299300528364
27	12	20	150	140	23981	23202.9418063460	778.058193653960
28	14	20	150	160	18693	18693.2152935256	-0.215293525623565
29	14	24	150	160	10677	11607.3766971278	-930.376697127780
30	14	20	170	160	10621	10422.5067441323	198.493255867697

ANN in Comparison with Experimental Response

Coefficient of determination (r^2) values of 0.90346 as observed in Figures 3 was employed to draw a conclusion that the the trained network can be used to predict the heat energy beyond the limit of experimentation. To evaluate the performance of ANN in predicting the heat energy, a comparative analysis between ANN and experimental values was performed. Prediction of heat energy using selected input variable combinations was done using ANN model. A regression plot of output between the experimental values of heat energy and the predicted values of heat energy was generated using ANN Coefficient of determination (r^2) was determined for ANN predicted heating values of heat energy as presented in figure 3. The rule of higher the better was employed to select the best model for predicting the surface tension.

4. Discussion

The ANN model was employed to predict heat energy for electricity estimation from the waste generated in Nigeria Cities. The data was normalized before generating the network. A regression plot of training, validation, and testing for heat energy responses produced with R-values of 93% for the training, 91% for the validation, 81% for testing and 90% for the overall. Reliability was produced to test the networks adequacy a reliability plot of 81.7% was obtained for ANN model employed. To validate the adequacy of the model based on its ability to predict its target response, the goodness of fit statistics was employed. The **Predicted R^2** of 0.4401 is in reasonable agreement with the **Adjusted R^2** of 0.6267; i.e. the difference is less than 0.2. **Adeq Precision** measures the signal to noise ratio. A ratio greater than 4 is desirable. Our ratio of 6.829 indicates an adequate signal.

5. Conclusion

Statistical design of experiment (DOE) using central composite design (CCD) matrix was employed to predict the heating value from the waste parameters that will minimize the rate of solid waste disposal as well as generating heat energy to boost the electric power supply in Nigeria Cites using ANN model. Reliability was produced to test the networks adequacy. A reliability plot of 80.6% using artificial neural network (ANN) model technique was achieved. The study established the heating values for energy potential of the municipal waste components in the area. The results of this study showed that waste to energy solves the problem of municipal solid waste disposal while recovering the energy from the waste materials with the significant benefits of environmental quality, increasingly accepted as a clean source of electric energy estimation in Nigeria.

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