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Prediction of The Biogas Production and Electricity Generation from Food Waste Using Artificial Neural Network (ANN) for the Residential Area

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Abstract: Biogas is made through the anaerobic digestion of organic substrates, and it is the end product of microbiological fermentation, containing 60 percent methane and 40 percent carbon dioxide, respectively. The main objective of this research is to identify the potential of food waste to produce power generation by converting food waste into biogas. The aim of this project is to compare the calculation value and prediction value of the biogas production and electricity generation using the Artificial Neural Network (ANN) method. The food waste data for two residential areas in Parit Raja, Johor and Sri Gading, Johor was collected from Solid Waste Management (SWM) Sdn. Bhd., Batu Pahat, Johor from February 2021 until August 2021. The findings result for seven months of biogas production and electricity production by using ANN software and by calculation have been analysed and discussed accurately. The result shows that Taman Pura Kencana, Sri Gading, Batu Pahat, Johor shows the highest total biogas production which is 90.06 m^3/month in April 2021 and followed by August 2021 with 50.77 m^3/month. As a result, the electricity production was also high during these two months which is 1840.95 MWh in April 2021 and 1037.94 MWh in August 2021. It can be concluded that biogas

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production and electricity production can be predicted by using the Artificial Neural Network (ANN) software.

Keywords: Biogas Production, Electricity Generation, Artificial Neural Network

1. Introduction

The 'Renewable energy' refers to energy from a wide range of sources, all of which are based on self-renewing energy sources such as sunlight, water that flows, wind, earth's internal heat and biomass [1]. Energy is required in almost every aspect of our lives, including agriculture, transportation, telecommunications, and industrial activities which all have an impact on economic growth. Malaysia's electricity sector is heavily dependent on fossil fuels and the electricity demand is rapidly increase due to the high economic rate so the conventional energy such as fossil fuel are finite and they are depleting day by day [2].

There are plenty ways to optimize the sources to sustain the energy and provide to those who needed. Biogas is made through the anaerobic digestion of organic substrates, in which a variety of anaerobic microorganisms break down the complex organic material. Thus, Biogas is the end product of microbiological fermentation, containing 60 percent methane and 40 percent carbon dioxide, respectively [3].

The worked presented by João Gonçalves et. al. [4] stated that food waste residues are primarily disposed of in landfills or incinerated. Biodegradation at landfills requires a large amount of space, and greenhouse gases such as methane are created without profiting from the energy contained in the biomass. The purpose of this experimental study is to know the biogas production from food waste. This experimental was conducted in a batch reactor at 37°C with an organic loading rate (OLR) of 5,10 and 20g VS/ (l.d). The development of an ANN model capable of estimating biogas output during the biodigestion process. Next, research papers by Palaniswamy et. al. [5] investigate the production of biogas by anaerobic digestion of solid-phase kitchen waste using an artificial neural network. The artificial neural network has been used to simulate and optimize biogas generation utilising a mixture of food waste and cow manure as a substrate. The paper presented by Nair V. et. al. [6] examined the performance of a laboratory-scale anaerobic bioreactor in order to estimate the methane (CH4) content of biogas produced from the digestion of municipal solid waste's organic part. The purpose of this study was to examine the impact of several parameters on biogas generation, including pH, moisture content (MC), total volatile solids (TVS), volatile fatty acids (VFAs), and the CH4 fraction. Then, the experimental data were then statistically optimised using an ANN model with free forward back propagation in MATLAB. The paper research presented by Manjula Das et. al. [7] stated that due to this biomass extensive availability and relatively easy energy conversion process, the biogas production by anaerobic digestion of lignocellulosic biomass with cattle dung receives much interest. This research papers demonstrates ANN modelling and optimization for specific biogas production using cattle dung as co-substrates, separately with bamboo dust, sugar-cane bagasse, and saw dust in mesophilic and thermophilic conditions. Next, the worked presented by Fares Almomani [8] mention that the agricultural activities have produced a large quantity of agricultural solid waste (ASWs) that need a good management and disposal. ANNs were proposed as the best algorithm for predicting the behaviour of various linear and nonlinear systems with high accuracy. An algorithm based on an artificial neural network (ANN) was created to model and optimise the cumulative methane production (CMP) from agriculture solid waste, cow dung, and their mixtures under mesophilic and thermophilic environments.

This study was aimed to predict the production of biogas and the electricity generation from food waste using Artificial Neural Network (ANN) according to data obtained. A set of food waste data that was produce from two residential area in Parit Raja, Johor and Sri Gading, Johor was collected from Solid Waste Management, Batu Pahat Johor in order to develop a numerical model using Artificial Neural Network (ANN) to identify the production of biogas and electricity generation determines by several parameters such as the weight of food waste in a day, daily feedstock volume, feedstock retention time, temperature, yield factor, digester volume, proportion of methane gas, gas leaking, plant operation energy, electricity efficiency and energy produced per ton of methane production.

2. Materials and Methods

This section are focuses on the process of the project where there is explanation on materials about Biogas energy, electricity production and Artificial Neural Network method. Besides, a set of food waste database is collected and desired equation being analyse in this section. The actual result from the calculation will be separated to Input and Target before the data been trained using ANN software. This study focuses on the biogas production (m^3/month) and electricity production (MWh) for 7 months from 24th February 2021 until 22nd August 2022. The collected data will be test and train using ANN model that develop in MATLAB R2021a software.

2.1 Theory of Biogas

Biogas is derived by organic waste (biomass) and there are many types of biomasses can be used to produce biogas such as agricultural residues, industrial wastes, municipal solid wastes, household wastes and organic wastes mixtures [9]. Malaysia generates almost 103 million tonnes of biomass each year, which includes agricultural waste, forest residues, and municipal waste [9]. Palm oil mill effluent (POME), livestock manure, and municipal solid waste (MSW) are the main sources of biogas in Malaysia [10]. Thus, this biomass can be a new source of energy in providing electricity by recycling it to produce biogas. Biogas is a product of an anaerobic digestion process that is rapidly gaining traction as a viable source of continuous electricity generation. As a result, biogas is the end product of microbiological fermentation, containing an average of 60% methane and 40% carbon dioxide, respectively [4].

2.2 Theory of Artificial Neural Network (ANN) Software

An artificial neural network is a stochastic modelling method that uses simple computational pieces to describe complicated linear and non-linear relations. The ANN technique is a data-driven model in which a mathematical relationship between a collection of known input and output data can be established without prior understanding of physical link between the input and output variables [7].

Independent and dependent parameters are linked in the network system by various nodes known as neurons. These neurons can store and process a huge amount of information over the entire domain during the computational approach. One or more input signals are received by each neuron. It generates an output signal based on the neuron's transfer function. The output signal of each neuron in the network is transferred at varying intensities to the succeeding layers until the network output is attained. Besides, there is third layer which called Hidden layer [7]. Figure 1 and Figure 2 show the function fitting neural network for biogas production and electricity production.

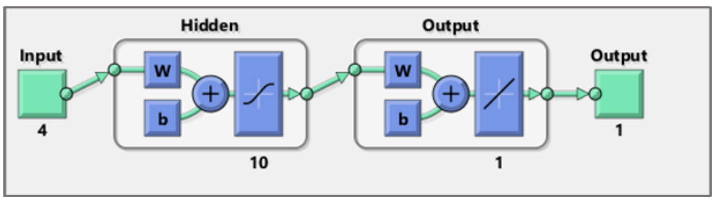


Figure 1: Function fitting neural network for biogas production

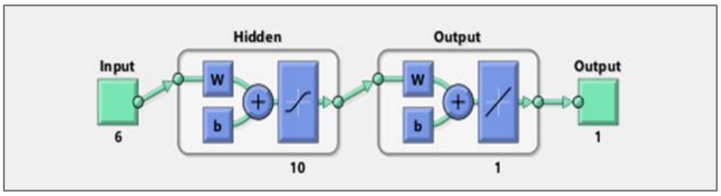


Figure 2: Function fitting neural network for electricity production

2.3 Material: Input Data of Food Waste

A set of food waste database is collected and desired equation being analyse in this section the actual result from the calculation will be separated to Input and Target before the data been trained using ANN software. This project focuses on the biogas production (m^3/month) and electricity production (MWh) in Parit Raja for 7 months from 24^{th} February 2021 until 22^{nd} August 2021.

The input data of food waste was collected from Solid Waste Management (SWM) Sdn. Bhd., Batu Pahat, Johor. The data is about food waste that was produced around residential area in Parit Raja, Johor and Sri Gading, Johor. The data are taken between 24^{th} February 2021 until 22^{nd} August 2021 from 30-unit houses in Taman Pura Kencana, Batu Pahat, Johor and 29-unit houses in Taman Universiti, Batu Pahat, Johor.

After data collection has been made, three sets of equation have been taken from paper [11]–[15] to calculate the output data of biogas production per day (m^3/day) and electricity production (MWh). The equations are for the calculation before developing the ANN model.

2.4 Method: Equation for Biogas Production, Electricity Production and Error between Calculated Result and ANN Result

To calculate the output data of biogas production per day Eq. 1 and Eq. 2 were used to measure the value of biogas production (m^3/day) as an output data for the ANN model that is proposed. Both equations are presented below:

$$G = \mathrm{C\ x\ Vd\ x\ S\ x} \left(\frac{\mathrm{k}}{1+\mathrm{kR}}\right) \qquad \mathrm{Eq.\ 1}$$

$$G = \frac{\mathrm{Y\ x\ Vd\ x\ S}}{1000} \qquad \mathrm{Eq.\ 2}$$

In previous paper, it stated that the first equation Eq. 1 has been simplified to Eq. 2 where the gas production is being calculated across a wide range of temperatures and retention times. G denotes the output data of biogas production (in m^3/day), V_d is the digester volume (in m^3) and S is the initial concentration of volatile solids in the slurry (in kg/m^3). As for Y it is yield factor based on temperature and the feedstock retention time.

There are several parameters that have been set according to the previous paper [4][11]. The first parameter is volatile solid, it has been set to 86.30%, the second parameter is digester volume, V_d. In Malaysia, the common type of digester been used is Fixed Dome plant. Therefore, the volume of the digester has been set to 3.81 m^3. Lastly, the temperature is set to 27℃ because the average temperature in Malaysia is 27.5℃. Following the calculation of biogas production using Eq. 2, the result of methane (CH4) obtained from Eq. 2 was used in Eq. 3 to obtain the value of power generation in MWh. Eq. 3 is:

$$\mathrm{Elprod} = (\mathrm{Xm_1CH_4} - \mathrm{GL}) * (1 - \mathrm{Eoperation}) * \mathrm{Eleff} * \mathrm{EnergyCH_4} \qquad \text{Eq. 3}$$

Where, $\mathrm{Xm_1CH_4}$ is the proportion of methane gas, which is 50%, and GL is the percentage of gas leaking during the biogas production process, which is 40%. Following that, Eoperation is the percentage of plant operation energy, which is 87%, Eleff is the percentage of electricity efficiency, which is 48%, and $\mathrm{EnergyCH_4}$ is the calculated energy produced per ton of methane production.

3. Results and Discussion

The findings of the study were classified using the research framework, which is the potential of food waste in Parit Raja, Johor and Sri Gading, Johor for biogas production and electricity production result from mathematical equation in subsections 2., materials and method and result from ANN software.

3.1 Potential Food Waste in Parit Raja, Johor and Sri Gading, Johor.

Table 1 and Fig. 3 shows the food waste that produced from Parit Raja, Batu Pahat, Johor from 24th February 2021 until 22nd August 2021. The data were taken from 30-unit houses in Taman Pura Kencana, Johor and 29-Unit houses Taman Universiti, Johor. The food waste produce by these two residential areas has been scheduled for collection twice a week. The next collection of food waste will take two or three days after prior date.

Table 1 is the total weight collected from Taman Pura Kencana and Taman Universiti varies by month. The highest amount of food waste collected in Taman Pura Kencana was 1138.39kg in April 2021, followed by 919.8kg in August 2021. Following that, Taman Universiti has the highest value of food waste collected (747.4kg) in August 2021 and the lowest value of food waste collected (34.06kg) in May 2021.

Table 1: Total food waste by months for Taman Pura Kencana and Taman Universiti.

Months	Taman Pura Kencana	Taman Universiti
February	198.95	None
March	794.42	542.28
April	1138.39	526.31
May	305.73	34.06
June	712.98	245.74
July	338.8	329.38
August	919.8	747.4

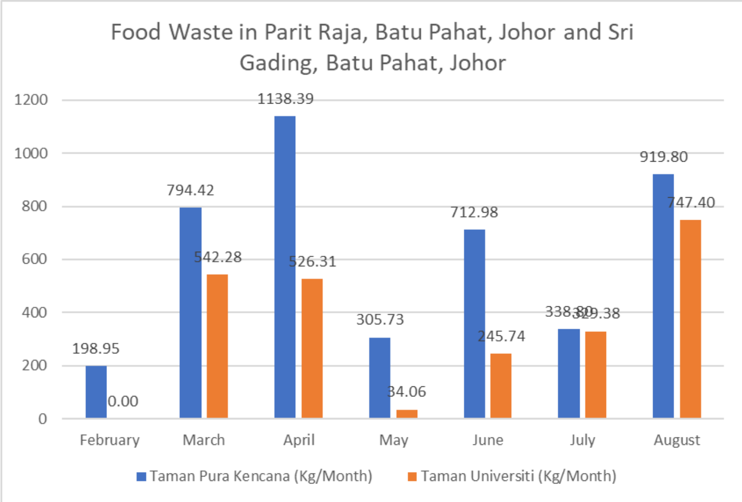


Figure 3: Food waste data in Parit Raja, Johor and Sri Gading, Johor

There are numerous factors influence the weight of food waste on specific months. As shown in the table, the highest rate of food waste produced for both Taman Pura Kencana and Taman Universiti took place in august 2021, and it has been observed that the highest rate of food waste occurs during Movement Control Order 2.0, also known as 'Pelan Pemulihan Negara' (PPN). This shows that many people spent more time at their house and prefer to cook or order takeout from restaurants and eat at home during this event. This indicates that the weight of food waste varies as a result of this factor. The weight of the food waste is one parameter that determine the rate of biogas production. As a result, the higher the weight of food waste in a month, the greater the value of biogas production in a month and the greater the value of biogas production in a month, the greater the value of the electricity generation in a month.

3.2 Result from Mathematical Equation: Biogas Production and Electricity Production

This calculation has been made before the ANN model development. The production of biogas and electricity production was determined by several parameters and the parameters have been set according to the previous paper which has been listed in subtopic 2.4.

Table 2 and Figure 5 shows the targeted data achieve from the calculation using Eq. 2 and Eq. 3, the production of biogas (m^3/month) and electricity production (MWh) for 30-unit houses at Taman Pura Kencana, Sri Gading, Batu Pahat, Johor and Table 3 and Figure 6 is the targeted data achieve for 29-unit houses at Taman Universiti, Parit Raja, Batu Pahat, Johor.

Table 2: Biogas production and electricity production at Taman Pura Kencana

Months	Biogas Production (m^3/month)	Electricity Production (MWh)
February	10.81	220.95
March	37.78	772.40
April	90.06	1840.95
May	16.69	341.21
June	37.09	758.21
July	15.30	312.84
August	50.77	1037.94

Table 3: Biogas production and electricity production at Taman Universiti.

Months	Biogas Production (m³/month)	Electricity Production (MWh)
February	None	None
March	18.11	370.30
April	23.39	478.05
May	0.29	5.84
June	6.86	140.20
July	13.53	276.56
August	28.19	576.23

From Table 2 and Figure 5, the calculated data at Taman Pura Kencana, Sri Gading, Johor shows

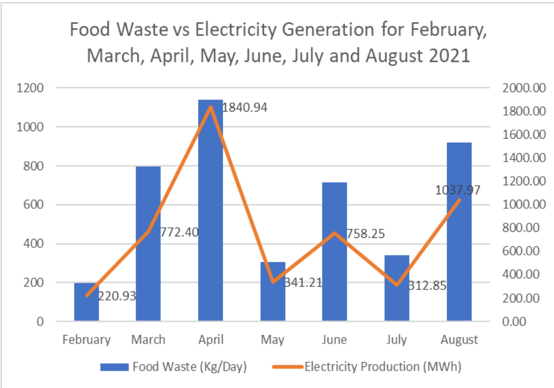


Figure 5: Biogas production vs electricity production at Taman Pura Kencana.

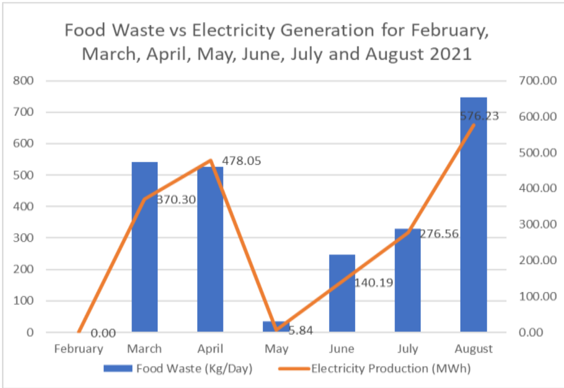


Figure 6: Biogas production vs electricity production at Taman Universiti.

the highest biogas production was in April 2021 with 90.06 m³/month following by 50.77 m³/month in August 2021 and third highest is 37.78 m³/month in March 2021. As previously stated, the higher the value of biogas production, the higher the value of electricity production. Therefore, the highest value of the electricity generated from food waste was in April 2021 with 1840.95 MWh followed by 1037.94 MWh in August 2021 and March 2021 with 772.40 MWh.

Then, the calculated data shows that the highest rate of biogas production was 28.19 m³/month in August 2021, as shown in Table 3 and Figure 6. The second highest value of biogas production is 23.39 m³/month, and it was in April 2021 and followed by March 2021 with 18.11 m³/month. As a result, the highest rate of electricity production was 576.23 MWh in August 2021, and the second highest electricity production rate is 478.05 MWh in April 2021 followed by March 2021 with 370.30 MWh.

The parameters selected have an effect on the rate of biogas production, and the most significant parameters affecting the biogas production is the weight of food waste collected. The higher the weight of the food waste, the higher the rate of biogas production and the lower the weight of the food waste, the lower the rate of biogas production. Furthermore, the rate of the electricity production is influenced by parameters and one of the parameters influencing the electricity production is the energy produced of methane production. Thus, it can be concluded that the equation can be used to calculate the production of biogas and electricity production.

3.3 Result from the Performance of ANN Model: Model 1 and Model 2

Table 4, Table 5, Figure 7 and Figure 8 shows the result of prediction for the biogas production and electricity production from MLP ANN approach. The model performed well in this study, but at instances it was unable to predict the biogas production and electrical production values as accurately as the actual values.

Table 4: Result of the biogas production and electricity production at Taman Pura Kencana using ANN approach

Month	Biogas Production at Taman Pura Kencana (m^3/month)	Electricity Production at Taman Pura Kencana (MWh)
February	10.81	220.93
March	37.78	772.40
April	90.06	1840.94
May	16.69	341.21
June	37.09	758.25
July	15.30	312.85
August	50.77	1037.97

Table 5: Result of the biogas production and electricity production for Taman Universiti using ANN approach

Month	Biogas Production at Taman Universiti (m^3/month)	Electricity Production at Taman Universiti (MWh)
February	None	None
March	18.11	370.30
April	23.39	478.05
May	0.29	5.84
June	6.86	140.19
July	13.53	276.56
August	28.19	576.23

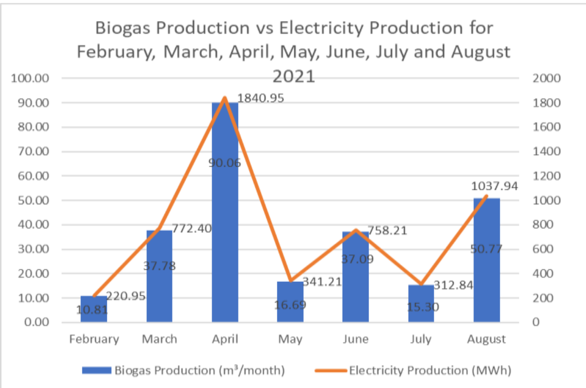


Figure 7: Biogas production vs electricity production for Taman Pura Kencana from ANN approach

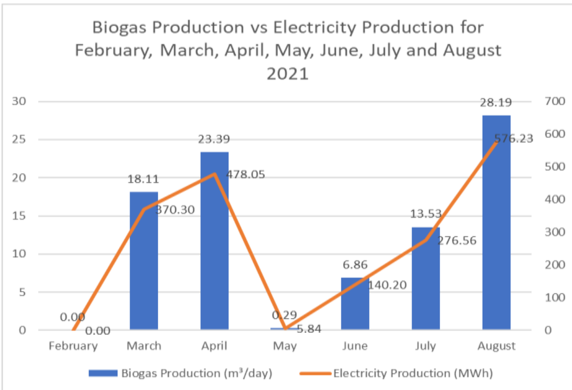


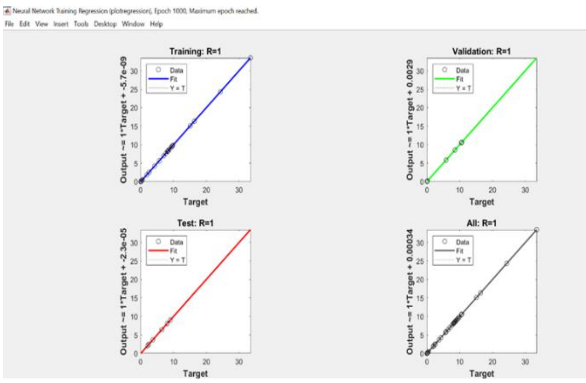
Figure 8: Biogas production vs electricity production for Taman Universiti from ANN approach.

According to Table 4 and Figure 7, the predicted data shows that biogas production for all months has the same value as the actual (calculated) value, with the highest month of the biogas production is April 2021 (90.06 m^3/month) and followed by August 2021 (50.77 m^3/month). As for the electricity production, the predicted data shows that, only on March 2021 has the same value with calculated value. For the other months it has minor error, and this shows that this ANN model software cannot predict accurately as the actual value assigned for the electricity production.

Table 5 and Figure 8 demonstrate the predicted data from ANN software for biogas production and electricity production at Taman Universiti. The predicted data shows that the biogas production for every month at this residential area has the same value as the actual (calculated) value. The highest biogas production predicted is on August 2021 with 28.19 m^3/month same as the actual value data. The tabulated data for electricity production then shows that all months have the same value as the actual data except for June 2021, which has a minor error. Despite minor error, this ANN model is regarded as successful.

3.3.1 ANN Model 1: Biogas Production

The overall model was performing very well. This performance is represented by the MSE and the regression value, which is known as the correlation coefficient. The MSE was the difference between the actual and predicted value.



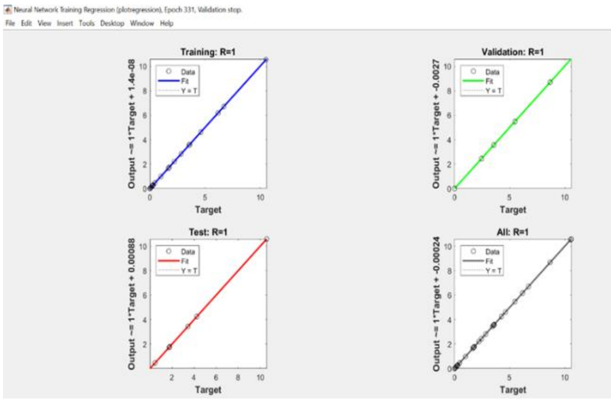


Figure 9: Plot regression of ANN configuration for Taman Pura Kencana.

Figure 10: Plot regression of ANN configuration for Taman Universiti.

Taman Pura Kencana. The ANN model has successfully predicted the biogas production with the best fit were approached to 1. The best R-value was equal to 1, while the best MSE value was equal to 0. As for Figure 10, it performs very well during training and stop before 1000 epochs. The number of training epochs reached was 331 and this means that the model's data could learn the network very well during training. It shows the best fit value and graph that represent the regression of ANN configuration for Taman Universiti. The ANN model has successfully predicted the biogas production with the best fit were approached to 1. The best R-value was equal to 1, while the best MSE value was equal to 0.

3.3.2 ANN Model 2: Electricity Production

The overall model was performing very well. This performance is represented by the MSE and the regression value, which is known as the correlation coefficient. The MSE was calculated as the difference between the actual and predicted value. The best R-value was 1, while the best MSE value was 0. Another factor to consider is that the MSE value of testing data must be greater than the MSE value of training data. When this ANN model reaches a maximum validation check, it stops to train.

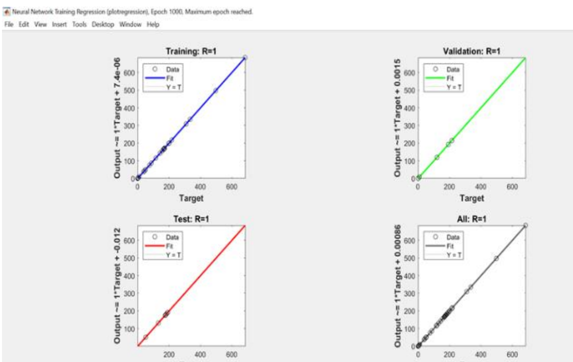


Figure 11: Plot regression of ANN configuration for Taman Pura Kencana

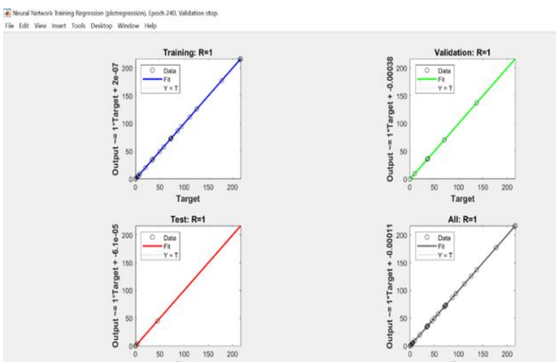


Figure 12: Plot Regression of ANN configuration for Taman Universiti.

Figure 11 shows the best fit value and graph that represent the regression of ANN configuration for Taman Pura Kencana. The ANN model has successfully predicted the electricity production with the best fit were approached to 1.

For Figure 12, the ANN model performs very well during training and stop before 1000 epochs. The number of training epochs reached was 240 and this means that the model's data could learn the network very well during training. This figure shows the best fit value and graph that represent the regression of ANN configuration for Taman Universiti. The ANN model has successfully predicted the biogas production with the best fit were approached to 1.

Consequently, from the results that have been discussed in this section, it can be said that the potential of food waste to be converted to biogas and produce electricity is good. Moreover, the high food waste produce for the certain month (April 2021 and August 2021) is because during April 2021 it is a fasting month for Muslims and the implementation of the Movement Control Order 2.0, or 'Pelan Pemulihan Negara' is on August 2021. People are tending to stay at home during this time or take away the foods from restaurants and this leads to the higher food waste production. Next, from the result obtained it can be concluded that the biogas production and electricity production can be predicted for every month and in future it can be predicted for every year.

3.4 Error between Calculated Result and ANN Software Result

This section will cover about the error between calculated result and ANN software result of biogas production and electricity production as listed in Table 6,7,8, and 9.

I. Taman Pura Kencana, Sri Gading, Batu Pahat, Johor.

Table 6: Error of Biogas Production

Month	Actual Value (m^3/month)	Predicted Value (m^3/month)
February	10.8089	10.8149
March	37.7837	37.7837
April	90.0558	90.0558
May	16.6913	16.6914
June	37.0902	37.0903
July	15.3032	15.3032
August	50.7734	50.7731

Table 7: Error of Electricity Production

Month	Actual Value (MWh)	Predicted Value (MWh)
February	220.9505	220.9339
March	772.4022	772.3998
April	1840.9548	1840.9432
May	341.2107	341.2112
June	758.2149	758.2491
July	312.8362	312.8464
August	1037.9416	1037.9707

II. Taman Universiti, Parit Raja, Batu Pahat, Johor.

Table 8: Error of Biogas Production

Month	Actual Value (m^3/month)	Predicted Value (m^3/month)

February	0	0
March	18.1147	18.1070
April	23.3864	23.3872
May	0.2856	0.2856
June	6.8589	6.8594
July	13.5293	13.5292
August	28.1881	28.1882

Table 9: Error of Electricity Production

Month	Actual Value (MWh)	Predicted Value (MWh)
February	0	0
March	370.3016	370.3004
April	478.0514	478.0512
May	5.8356	5.8359
June	140.1953	140.1947
July	276.5643	276.5630
August	576.2266	576.2251

The calculated data of an error for biogas production and electricity production in table above shows that there is an error during the simulation of ANN software that prevents it from providing an accurate output as assigned. In contrast, the ANN software accurately predicts the amount of actual value and regarded as successful.

4. Conclusion

Food waste is common waste produced by households, restaurants, hotels, and other establishments. It has been a matter of concern due to the degradation process, which necessitates a larger area for the process to take place. Meanwhile, Malaysia's electricity sector is heavily reliant on fossil fuels, and electricity demand is rapidly increasing due to the country's high economic growth rate. The findings of this study show that, the higher the amount of food waste collected in a month, the greater the number of electricity production in a month. From this result, food waste has the potential to generate power and contribute to the production of a large amount of renewable energy in the form of biogas. In addition, the Artificial Neural Network (ANN) approach can be used to predict the value of biogas production and electricity production when the results collected from this approach are as same as the calculated value with minor error recorded. It is important to design a biogas power plant by having the prediction of the biogas production and the power output from the biogas produce. Nevertheless, a better understanding about this software working principle is needed before the development of the ANN model. On the other hand, the potential of the biogas produced from food waste for Taman Pura Kencana was high on April 2021 with 90.06 m^3/month and followed by August 2021 with 50.77 m^3/month which could provide an electricity generation potential of 1840.95 MWh and 1037.94 MWh. As for Taman Universiti, the highest amount of biogas produced from food waste was high on August 2021 with 28.19 m^3/month which could provide an electricity generation potential of 576.23 MWh. As a conclusion, the biogas production and electricity production can be predicted by using the Artificial Neural Network (ANN) software and on the bright side, the food waste is an encouraging low-cost and sustainable energy source that could be used to generate biogas energy and electrical power.

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