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Biogas Energy Potential using Linear Regression Analysis

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Abstract

A mathematical model of the relationship between biogas energy potential obtained from animal waste in Thailand by simple linear regression analysis was generated from data classified by province in 2020. The study found that the biogas energy potential was related to animal waste with a correlation coefficient of 0.9966 and could predict biogas energy potential at 99% ($p < 0.001$) with a standard error in the forecast equal to ±0.36: the forecast equation for the relation between biogas energy potential (y) and animal waste (Xi) was y = 0.0535 + 0.00002xi. The model was verified by comparing its predictions for 2021. The obtained model will be useful in future planning policies for the use of biogas renewable energy.

Keywords: Biogas energy potential, Animal waste, Linear regression analysis

1. Introduction

At a time when every country is faced with an energy crisis that is only getting more severe day by day. An effective solution uses renewable energy that is widely available in nature, to develop and apply it for maximum benefit. One form of renewable energy is biogas, which is commonly used by farmers, and entrepreneurs. It is also energy with high potential, easy to use and suitable for production in Thailand. Benefits from using biogas in factories and farms also help will help solve wastewater problems, reduce environmental pollution [1] and also reduce energy production costs. Costs can be reduced in many areas, such as reducing the import of fuel oil required for production, reducing costs from purchasing electricity and importantly, some factories can also earn income from electricity sales [2].

Biogas is clean energy, generated from waste including agricultural or forestry crops and residues, marine algae, weeds, animal manure, municipal solid waste, biodegradable industrial waste and sewage [3], through decomposition by fermentation of organic matter

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[4, 5]. When the environmental conditions are suitable, biogas will be obtained that can be used to generate electricity or heat [2, 6, 7]. Biogas is approximately 60–70% methane, 30–40% carbon dioxide, and 0–1% other gases [8]. In general, 1 m^3 of biogas provides approximately heat 22 MJ, whereas natural gas provides 35.8 MJ [9]. Biogas is therefore another option for renewable energy and is widely used today in electricity generation [10], heating/cooling [11], and use as fuel in the transportation sector [12], among others.

Regression analysis defines a relationship between two or more variables, divided into Independent and dependent variables. In this study, therefore, we computed the regression between the biogas energy potential from biogas obtained from animal waste in Thailand so that we can predict energy yields.

2. Research Methods

Predicting biogas energy potential from animal waste using a simple regression equation. The method of operation consists of the process of document research. Information used in the study tools used in research, forecasting, and testing the reliability of equations.

2.1 Data Collection

Information from the Thailand Alternative Energy Situation 2020 report (biogas section) is shown in Table 1.

Table 1 Quantity of animal waste and biogas energy potential by province in 2020 [6]

Province	Quantity (ton)	Energy Potential (ktoe)*
NORTHERN		
CHAING RAI	122,583	2.77
PHAYAO	57,573	1.22
LAMPANG	210,816	4.66
LAMPHUN	228,091	5.16
CHAING MAI	545,157	11.77
MAE HONG SON	143,896	3.05
TAK	246,512	5.43
KAMPHAENG PHET	89,992	2.22
SUKHOTHAI	115,590	2.45
PHRAE	53,100	1.18
NAN	77,985	1.70
UTTARADIT	81,718	1.74
PHITSANULOK	103,336	2.31
PHICHIT	35,015	0.79
NAKHON SAWAN	115,594	2.65
UTHAI THANI	53,639	1.16
PHETCHABUN	129,613	3.03
NORTHEASTERN		
LOEI	82,226	1.75
NONG BUA LAM PHU	58,007	1.23
UDON THANI	245,028	5.26
NONG KHAI	52,251	1.14
SAKON NAKHON	315,863	6.45
NAKHON PHANOM	191,580	4.01
MUKDAHAN	86,023	1.77
YASOTHON	180,258	3.72
AMNAT CHAROEN	109,749	2.28
UBON RATCHATHANI	419,317	8.67
SI SA KET	395,597	8.12
SURIN	571,042	12.07
BURI RAM	482,914	10.06
BUENG KAN	75,081	1.56
MAHA SARAKHAM	312,212	6.47

Province	Quantity (ton)	Energy Potential (ktoe)*
RIO ET	330,861	6.81
KARASIN	180,603	3.96
KHON KAEN	402,258	8.54
CHAIYAPHUM	173,290	3.90
NAKHON RATCHASIMA	1,162,451	24.27
CENTRAL		
SARABURI	590,670	12.30
LOP BURI	507,778	11.11
SING BURI	13,642	0.34
CHAI NAT	85,446	1.89
SUPHAN BURI	261,178	5.94
ANG THONG	32,719	0.78
AYUTTHAYA	13,835	0.30
NONTHABURI	1,743	0.04
BANGKOK	4,915	0.10
PATHUM THANI	8,539	0.18
NAKHON NAYOK	75,197	1.80
PRACHIN BURI	108,703	2.73
CHACHOENGSAO	106,303	2.69
SA KAEO	236,949	4.86
CHANTHABURI	27,244	0.65
TRAT	14,984	0.39
RAYONG	55,835	1.39
CHON BURI	202,214	5.15
SAMUT PRAKAN	4,425	0.11
SAMUT SAKHOM	309	0.01
NAKHON PATHOM	175,741	3.84
KANCHANABURI	528,409	11.67
RATCHABURI	793,718	19.58
SAMUT SONGKHRAM	1,546	0.04
PHETCHABURI	269,488	5.68
PRACHUAP KHIRI KHAN	330,181	6.94
SOUTHERN		
CHUMPHON	67,542	1.53
RANONG	12,311	0.27
SURAT THANI	118,265	2.72
PHANGNGA	42,511	1.05
PHUKET	101,332	2.61
KRABI	59,197	1.34
TRANG	129,793	3.03
NAKHON SI THAMMARAT	273,963	6.14
PHATTHALUNG	262,366	6.02
SONGKHLA	198,881	4.43
SATUN	34,159	0.73
PATTANI	61,528	1.26
YALA	61,262	1.27
NARATHIWAT	103,122	2.17

Remark: *ktoe is Final Modern Energy Consumption.

2.2 Linear Regression Analysis

A simple regression can be represented by [13, 14, 15].

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon$$

where y_i is the dependent variable and x_i is the independent variable. β_0 is the distance to intercept on the y axis or the value of y when x is zero. β_1 is the regression coefficient or slope of the regression equation. ε is the error.

2.3 Statistical Value Describing Consistency of the Regression Equation [13, 14, 15]

Regression analysis involves estimating the relationship of the independent variable in order to check that the regression equation can explain the relationship well or not. It is mainly determined by the coefficient of determination (R^2).

2.3.1 Coefficient of Determination (R^2)

The coefficient of determination or R^2 is the portion of the total variation in the dependent variable that can be explained by variation in the independent variable(s).

1. A large R^2 implies that y and x are strongly related or shows that the independent variable of the three regressions can explain most of the variation in the dependent variable: it is the ratio of SSR = sum of the differences between the predicted value and the mean of the dependent variable, and SST = sum of squared differences between the observed dependent variables and the overall mean**:**

R^2 = (variance of $\bar{y}$ due to $\bar{x}$ / variance of $\bar{y}$ total) or

$R^2 = SSR / SST$ then $0 \leq R^2 \leq 1$ because $SST > SSR$.

2. R^2 has no units.

3. if $R^2 \approx 1$, then the probability that $\bar{x}$ can explain the change in $\bar{y}$ is very large or that $\bar{x}$ and $\bar{y}$ are strongly related.

4. if $R^2 \approx 0$, then $\bar{x}$ cannot explain the change in $\bar{y}$.

2.3.2 Examining the Conditions of Linear Regression Analysis

There are four assumptions or conditions of regression analysis; these are conditions regarding errors or residuals in applying the equations. The user must verify the correctness of the generated equation. The conditions of the regression analysis must be checked with the movement values as follows:

1. Assumption of Normality – readings are distributed normally around a mean
2. Average is equal to zero – average of residuals must be zero
3. Homogeneity of Variance – variances of samples must be equal
4. Assumption of Autocorrelation - residuals must be independent of each other

2.3.3 Order of Reading Regression Analysis Results

Once preliminary agreement was checked in the regression analysis, the order of reading the analysis results is:

1. Checking the linear relationship between the independent variable and the dependent variable (F-test in the ANOVA table).
2. Checking the significance of each constant and coefficient in the equation (in the Coefficients table).
3. Writing the form of the regression equation from the obtained coefficients (from the Coefficients table).
4. Summary of the obtained regression equations (Model Summary table).

3. Results and Discussion

From the linear relationship, the dependent variable, or final energy consumption, $y_i = \beta_0 + \beta_1 x_i + \varepsilon$, where x_i, quantity of biomass in tons, was estimated using the linear regression. The parameters were calculated as follows:

SS_{xx} = 3081918500698.880

SS_{xy} = 66406979.678

SS_{yy} = 1440.606

$\bar{x}$	=	184607.325	$\bar{y}$	=	4.031
a	=	0.0535	b	=	0.00002

	y	=	0.0535	+	0.00002 x_i		
t-test			0.959		105.100		
p-value			0.341		0.000	R^2 =	0.9933
t-table	1.992					Adjust R^2 =	0.9932

Table 2 Model summary[1]

Model	R^2	*R* square	Adjusted R square	Std. error of the estimate
1	0.9966[2]	0.9933	0.9932	0.360

Remark: [1]Dependent Variable: Biogas Energy Potential (ktoe)
[2]Predictors: (Constant), Animal Waste (ton)

Table 2 sets out the correlation coefficient (R^2), prediction coefficient (*R* square) and standard error of the estimate of the regression. The decision coefficient (R^2) = 0.9933, so that the independent variable can explain 99% of the variation in the dependent variable. The variance of a simple regression equation is estimated as follows:

To estimate $y_i = \beta_0 + \beta_1 x_i + \varepsilon$ with $y = a + bx_i$

There will be an error value that is $\varepsilon = y_i - \bar{y}$

The variance of the error is $SS_{yy} - 2bSS_{xy} + bSS_{xy} = 9.715$

The variance of y is $SST = \Sigma\,(y_i - \bar{y})^2 = 1440.606$

The variance of y from the influence of x is $SSR = \Sigma\,(y_i - \bar{y})^2 = 1430.890$

One-factor ANOVA test

To test the relationship, $y_i = \beta_0 + \beta_1 x_i + \varepsilon$, the F statistic of one-way ANOVA was used based on the these assumptions;

H_o : $\beta_1 = 0$ or *y* and *x* do not have a linear relationship.

H_1 : $\beta_1 \neq 0$ or *y* and *x* have a linear relationship.

By rejecting the hypothesis when F-test > F-table $_{.05,\,1,\,n-2}$

From Table 3, the F = 11045.956 > F-table = 3.980, therefore Sig < 0.000. Therefore, reject the hypothesis, showing that *y* and *x* were strongly related and effectively lie on a straight line.

Table 3 ANOVA[1]

Model		Sum of squares	df	Mean square	F	Sig.
I	Regression	1430.890	1	1430.890	11045.956	<0.001[2]
	Residual	9.715	75	0.130		
	Total	1440.606	76			

Remark: [1]Dependent Variable: Biogas Energy Potential (ktoe).
[2]Predictors: (Constant), Animal Waste (ton).

Testing the hypothesis for the regression coefficient used the t-test statistic according to the hypothesis as follows;

To test the relationship, $y_i = \beta_0 + \beta_1 x_i + \varepsilon$ using the following assumptions;

H_o : $\beta_1 = 0$

H_1 : $\beta_1 \neq 0$

By rejecting the hypothesis when t-test > t-table $_{.025,\,n-2}$

From Table 4, check the significance of the constants and coefficients in the equation. The results of the analysis are t-test = 105.10 > t-table = 1.992 and Sig. < 0.001. Therefore, the hypothesis should be rejected and the dependent variable (y) was related to the independent variable (x).

Table 4 Coefficients[1]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. error	Beta			Lower Bound	Upper Bound
I (Constant)	0.0535	0.056		0.959	0.341	-0.058	0.165
Biogas Energy Potential	0.00002	0.000	0.997	105.10	<0.001	0.000	0.000

Remark: [1]Dependent Variable: Biogas Energy Potential (ktoe)

Testing the hypothesis for the correlation coefficient used the t-test statistic based on these hypotheses:

To test the relationship, $y_i = \beta_0 + \beta_1 x_i + \varepsilon$ according to the following assumptions;

$H_o: \rho = 0$ or the independent variable (x) has no relationship with the dependent variable (y).

$H_1: \rho \neq 0$ or the independent variable (x) is related to the dependent variable (y).

By rejecting the hypothesis when t-test > t-table $_{.025,\, n-2}$

Table 5 Correalations

	Item	y	x_i
y	Pearson Correalations Sig.(2-tailed) N	1.000 77	0.9966 0.000 77
x_i	Pearson Correalations Sig.(2-tailed) N	0.9966 0.000 77	1.000 77

From Table 5, the results of the analysis are t-test = 105.100 > t-table = 1.992 and Sig. = 0.000. Therefore, the conclusion of the test is that the independent variable (x_i) is related to the dependent variable (y) in the same direction and rejects the hypothesis. It shows that the independent variable (x_i) is related to the dependent variable (y).

Table 6 Regression to predict biogas energy potential (ktoe) from animal waste (ton)

Parameter	B	SE_b	β	t	p-value
Constant	0.0535	0.056		0.959	.000
Biogas Energy Potential	0.00002	0.000	0.9966	105.100	.000
SE_{est} = ±0.360 R = 0.9966; R^2 = 0.9933; F = 11045.956; p-value = 0.000					

From Table 6, we concluded that biogas energy potential was related to animal waste with a correlation coefficient of 0.9966 and which can predict the amount of heat obtained at 99% with statistical significance at the 0.001 level, with a standard error = ±0.36 and the forecast equation for biogas energy potential when animal waste is $y = 0.0535 + 0.00002\, x_i$

Table 7 Quantity of animal waste and biogas energy potential by province in 2021 [7]

Province	Quantity (ton)	Energy Potential (ktoe)		
		2021	Simple Regression Analysis	Different
NORTHERN				
CHAING RAI	128,325	2.80	2.82	0.02
PHAYAO	66,328	1.37	1.48	0.11
LAMPANG	236,083	5.21	5.14	0.07
LAMPHUN	200,988	4.36	4.38	0.02
CHAI MAI	633,337	13.68	13.70	0.02
MAE HONG SON	159,822	3.29	3.49	0.20
TAK	291,986	6.22	6.34	0.12
KAMPHAENG PHET	124,646	2.97	2.74	0.23
SUKHOTHAI	146,498	3.09	3.21	0.12
PHARE	69,302	1.50	1.55	0.05
NAN	99,386	2.13	2.19	0.06
UTTARADIT	117,075	2.54	2.58	0.04
PITSANULOK	154,218	3.34	3.38	0.04
PHICHIT	62,221	1.43	1.39	0.04
NAKHON SAWAN	162,982	3.76	3.56	0.20
UTHAI THANI	80,957	1.75	1.79	0.04
PHETCHABUN	165,150	3.78	3.61	0.17
NORTHEASTERN				
LOEI	109,690	2.32	2.42	0.10
NONG BUA LAM PHU	86,106	1.82	1.91	0.09
UDON THANI	307,398	6.47	6.68	0.21
NONG KHAI	80,721	1.77	1.79	0.02
SAKON NAKHON	370,137	7.53	8.02	0.49
NAKHON PHANOM	266,876	5.52	5.80	0.28
MUKDAHAN	106,598	2.19	2.35	0.16
YASOTHON	207,399	4.29	4.52	0.23
AMNAT CHAROEN	120,760	2.48	2.66	0.18
UBON RATCHATHANI	588,092	12.02	12.73	0.71
SI SA KET	535,592	10.90	11.59	0.69
SURIN	673,999	13.74	14.58	0.84
BURI RAM	636,991	13.06	13.78	0.72
BUENG KAN	82,312	1.69	1.83	0.14
MAHA SARAKHAM	363,870	7.58	7.89	0.31
RIO ET	428,406	8.84	9.28	0.44
KALASIN	169,122	3.52	3.69	0.17
KHON KAEN	516,489	10.85	11.18	0.33
CHAIYAPHUM	251,811	5.57	5.48	0.09
NAKHON RATCHASIMA	1,350,271	28.00	29.15	1.15
CENTRAL				
SARABURI	812,409	16.89	17.56	0.67
LOP BURI	652,305	14.12	14.11	0.01
SING BURI	18,550	0.45	0.45	0.00
CHAI NAT	127,348	2.89	2.79	0.10
SUPHAN BURI	409,721	9.58	8.88	0.70
ANG THONG	47,024	1.09	1.067	0.02
AYUTTHAYA	43,330	1.08	0.99	0.09
NONTHABURI	2,063	0.04	0.09	0.05
BANGKOK	5,723	0.12	0.18	0.06
PATHUM THANI	9,057	0.21	0.25	0.04
NAKHON NAYOK	163,417	4.01	3.57	0.44
PRACHIN BURI	296,165	7.06	6.43	0.63
CHACHOENGSAO	220,458	5.47	4.80	0.67

Province	Quantity (ton)	Energy Potential (ktoe)		
		2021	Simple Regression Analysis	Different
SA KAEO	268,615	5.54	5.84	0.30
CHANTHABURI	49,654	1.12	1.12	0.00
TRAT	29,941	0.78	0.69	0.09
RAYONG	106,752	2.60	2.35	0.25
CHON BURI	242,321	5.96	5.27	0.69
SAMUT PRAKAN	348	0.01	0.06	0.05
SAMUT SAKHON	954	0.02	0.07	0.05
NAKHON PATHOM	316,573	7.26	6.87	0.39
KANCHANABURI	581,008	12.57	12.57	0.00
RATCHABURI	1,047,847	24.86	22.63	2.23
SAMUT SONGKHRAM	1,947	0.04	0.09	0.05
PHETCHABURI	306,541	6.44	6.66	0.22
PRACHUAP KHIRI KHAN	378,062	7.92	8.20	0.28
SOUTHERN				
CHUMPHON	85,594	1.95	1.89	0.06
RANONG	16,435	0.37	0.41	0.04
SURAT THANI	162,569	3.71	3.55	0.16
PHANGNGA	34,876	0.84	0.81	0.03
PHUKET	6,535	0.15	0.19	0.04
KRABI	85,842	1.90	1.90	0.00
TRANG	122,365	2.66	2.69	0.03
NAKHON SI THAMMARAT	347,390	7.68	7.54	0.14
PHATTHALUNG	360,670	8.28	7.83	0.45
SONGKHLA	209,047	4.70	4.56	0.14
SATUN	41,525	0.89	0.95	0.06
PATTANI	65,870	1.34	1.47	0.13
YALA	57,299	1.18	1.29	0.11
NARATHIWAT	98,041	2.00	2.17	0.17

From Table 7 shows the results of forecasting the biogas energy potential value in 2021 using a simple regression forecast equation obtained from data in 2020. It was found that the biogas energy potential value obtained from the forecast equation gave no different values from very real values in decimal units. There are only two provinces, namely NAKHON RATCHASIMA and RATCHABURI, which have differences in the predictions in more than a single unit. Therefore, a simple regression prediction equation can be used to predict the energy potential when knowing the amount of animal waste.

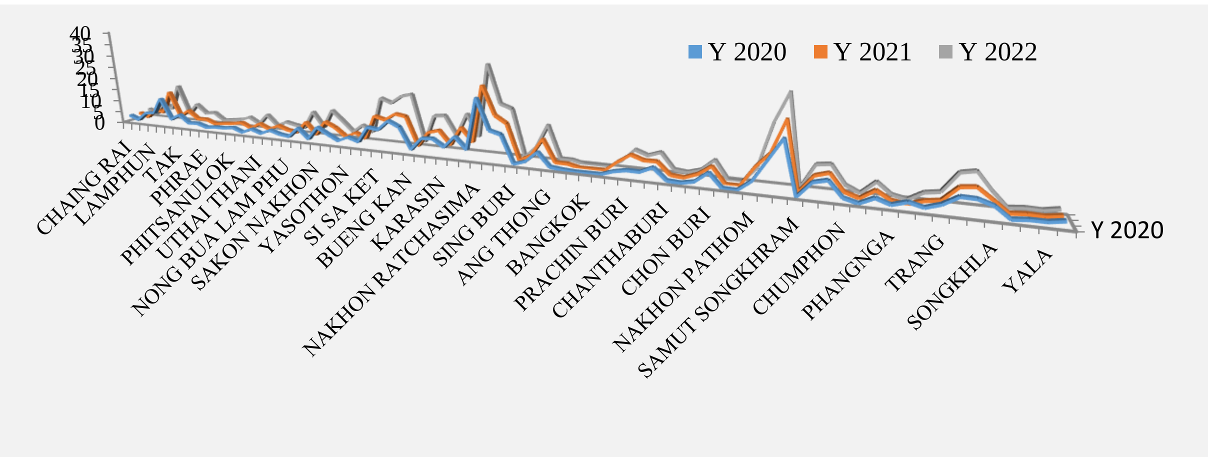

Figure 1 Energy potential from 2020 – 2022 from sources [6, 7, 16]

From Figure 1, it can be seen that the energy potential from animal waste tended to increase every year. This shows that in each Thai province, there were more livestock farmed and there was a trend for continuous development in order to have renewable products sufficient for the increasing demand of consumers. In addition, the use of bioenergy from animal waste will help eliminate the smell of animal waste. The bad smell comes from toxic gases from the fermentation of animal waste and is also a breeding ground for germs, affecting the quality of people and the environment, including being a cause of global warming due to volatile organic compounds and volatile substances containing carbon, nitrogen, and sulfur, which are formed in the form of gases that directly affect health, such as methane, carbon dioxide, ammonia, and hydrogen sulfide. Therefore, turning to biogas reduces the spread of methane gas, helping to reduce the greenhouse effect, which is the main cause of global warming. The government has therefore specified biogas in the renewable energy development plan and the renewable and alternative energy development plan to allow Thailand to use renewable energy as the country's main energy source, reduce dependence on and import of fuels and other types of energy, and create sustainable energy security for the country in the future.

4. Conclusion

The regression equation predicted the relationship between energy potential and the amount of animal waste. The discrepancy between the energy potential in 2021 and the value obtained from the forecast equation had a small error in each province. The simple regression forecast had a coefficient of determination (R^2) equal to 99% with statistical significance at the 0.001 level, and a standard error in forecasting equal to ±0.36.

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