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Effect of Geothermal Generation on Energy Costs and GDP

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Abstract: The paper is a two-step analysis; it seeks to look at the possible correlation between geothermal generation and the economy, whether there is a bi-directional causality between economic growth and electricity costs. Emphasis is being placed on specific source of energy to show that it being renewable energy and a comparative least cost source of energy, it will have a significant impact on electricity tariff reduction. By use of Vector Error Correction Model and Granger Causality Test on data—for the period ranging from 2007 to 2016, assessment is done to ascertain correlation between electricity tariff, electricity consumption/electricity generation and the various GDP contributory sectors. Results show that reduced electricity tariffs positively impact on economic growth in the manufacturing and construction sectors specifically and geothermal being the comparative least cost energy source that plays a significant role in increasing electricity consumption resulting from reduced costs and consequently economic growth through increase in manufacturing, construction and wholesale and retail industry. Noting the findings, the government should undertake expansion focusing on least cost energy sources—geothermal and other similarly related source of energy, consider price discrimination for the industries in order to boost industrialization and increase electricity access.

Key words: Geothermal, exports, industrialization, electricity cost, GDP and domestic consumption.

1. Introduction

Electricity is an essential input in production. Kenya being an emerging economy at the verge of takeoff significantly requires electricity for industrialization, therefore, less costly and stable supply of electricity is of high importance for takeoff and continued industrialization since it will encourage investors and equally if the electricity supply is stable, clean and not spasmodic due to power outages, it will play a major role in attracting investment hence increasing industrialization [1].

Various authors have conducted an empirical study on similarly related subject area. Some have reviewed the impact of electricity consumption on the economy, the impact of electricity prices on the economy and a combination of both the consumption rate and price on the economy for different countries. The studies have predominantly shown proof that electricity is a major causality for economic growth majorly through increased output from manufacturing; however the direction of causality has differed from author to author based on the time period under analysis, data set duration, the model used for the analysis and the level of the economy i.e. whether it is an emerging economy or a developed economy [2].

The first authors to conduct an analysis on the causal relation of energy consumption and the economy, Kraft and Kraft [3] using USA as the subject area of study found a unidirectional causality from Gross National Product to Energy Consumption. It can be noted that the method of analysis significantly affected the findings. Various authors undertook to expand the analysis beyond the USA. Asafu-Adjaye [4] conducted an analysis on the relationship between energy consumption, energy prices and economic growth on the Asian developing countries through co-integration and error correction model which showed varied results for the different countries. Except for India and

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Indonesia-in the short run-the results show that there is no neutrality between energy and income.

Shiu and Lam [5] expanded the analysis further to a country at the industrialization phase. The paper used a vector error correction model on data of a 30-year period to assess the causality of electricity consumption on economic growth; a unidirectional causality was established from electricity consumption to GDP. In the analysis, a point to note, distinction should be made between the electricity consumption tendencies in the developed countries and the developing economies. This will in turn affect the direction of causality to some extent. Cheng and Lai [6] undertook a study on Taiwan electricity consumption and its impact on the economy. Studies on developing countries including Kenya have equally been undertaken. Lee [7] looked at the causal relationship and the co-movement between energy consumption of 18 developing countries and their GDP including Kenya. The paper used 26-year panel data. The results indicated there is both a long run and short run relationship between energy consumption and GDP. Iyke and Odhiambo [8] looked at the causal relationship between electricity consumption and economic growth in Ghana using the Trivariate Causality model. The dataset was for a period of 41 years ranging from 1971 to 2012. It obviates the variable omission bias, and uses cross-sectional techniques. The results showed that there is a short run and long run causality relationship from economic growth to electricity consumption. The policy recommendation is for the policy makers in Ghana to consider alternate sources of electric power generation so as to reduce any future pressures or avoid exhaustion of the current sources of electricity generation.

To reiterate the difference in consumption trend between developing countries and developed countries Narayan [9] analyses the long-run relationship between energy consumption and real GDP for over ninety countries. The results were mixed, with greater evidence at the country level supporting energy consumption having a negative causal effect on real GDP. For the G6—France, Germany, Italy, Japan, the United Kingdom, and the United States, the findings indicated that energy consumption negatively Granger causes real GDP.

Consequently, this paper seeks to see not only the impact of reduced electricity cost and electricity consumption rate on the economy through increased industrialization but also how increase of geothermal energy on the electricity grid would impact on electricity cost, being a comparative least cost source of energy according to Simiyu [10] and therefore to be considered for expansion.

Kenya is a good target area for the study of this topic since it has comparative advantage in the region on geothermal resource—comparatively its input of geothermal energy in the electricity grid/generated capacity is comparatively higher as compared to the neighboring countries around—as well as the manufacturing sector and horticulture industry.

The objective is to ascertain if electricity generation mode impacts on electricity cost and consequently reduced electricity cost has any impact on the economy in terms of growth. This will be done through developing an analysis model, the empirical model is to ascertain how energy pricing is affected or affects various variables; domestic consumption of electricity, specific use of an energy source—geothermal, and the different sectors of the economy which have been individually assed and then further categorized based on the output in Table 1.

Table 1 GDP sectorial categorization.

No.	Categorization	GDP output source
1	Goods industry	Manufacturing, construction, wholesale and retail trade
2	Service industry	Public administration, IT, and other services
3	Resources	Quarry and mining, electricity and water supply

The objective was achieved; the findings are relatively different from some of the other papers, since while significance is noted in the long run and the short run, bi-causality is observed only in the instance of geothermal generation at 10% confidence level. The findings should play a major role in policy making, that is, the planning of electricity expansion in terms of the different generation sectors and the country's electricity distribution network.

2. Data and Methodology

2.1 Data Source

The data used are time series quarterly data for varied variables—sectorial GDP, energy generation, energy consumption and the energy cost—for a period of 15 years ranging from the year 2000 to 2015. The data were obtained from Kenya National Bureau of Statistics Annual CPI, and leading economic indicators; Kenya Power and Lighting Company Annual Reports; and the Energy Regulatory Commissions of Kenya.

2.2 Description of Data

2.2.1 Energy Cost

The cost is in Kenya Shillings kilowatt per hour. Due to limitation of data availability, from the year 2006, the data used are rotating average on a quarterly basis based on the previous 3 months data. Since different consumption capacities for different entities i.e. domestic consumption, small scale consumers, commercial consumers etc. could not be obtained, the respective tariffs were summed up and the average obtained is titled "Total Tariff". The trend of the series over the years is as observed in Fig. 1.

The constant amount that represents from year 2000 to 2003 is due to the rotating average effect. Since Kenya was heavily reliant on hydroelectric power and thermal energy and considering the instability of hydroelectric power, the electricity cost tends to fluctuate a lot due to the fuel cost attached to thermal power. The extra surcharge resulting from fixed fuel cost depending on the period example year 2009 to 2014, ranged from KES 7.83 to KES 9.03 for each kilowatt per hour. This explains the significant rise on the significant rise in electricity cost.

2.2.2 Energy Generation Sources

This is the characterization of energy generated on the electricity grid according to the source. The focus is in the renewable energy sector, for the purpose of this

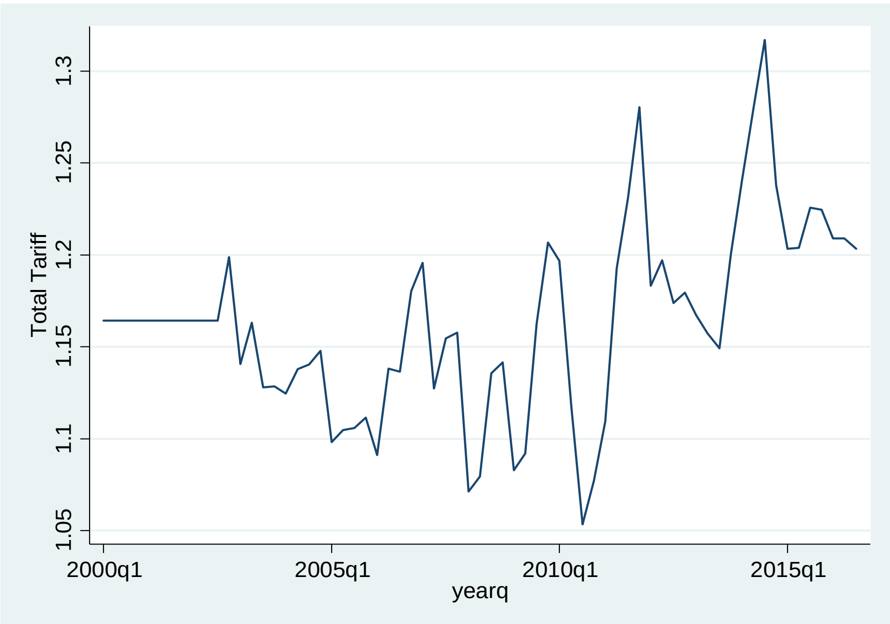

Fig. 1 Electricity cost trend.

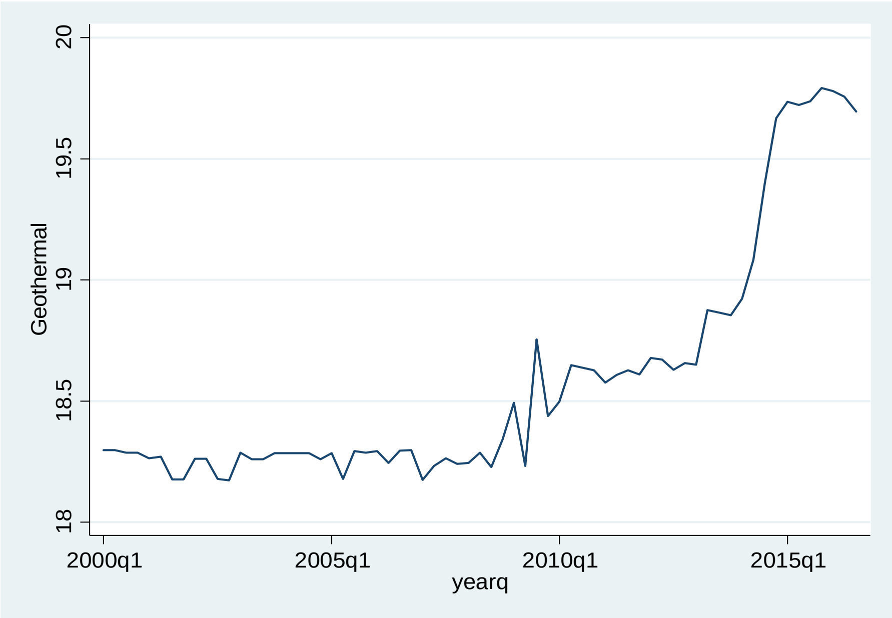

Fig. 2 Geothermal generation trend.

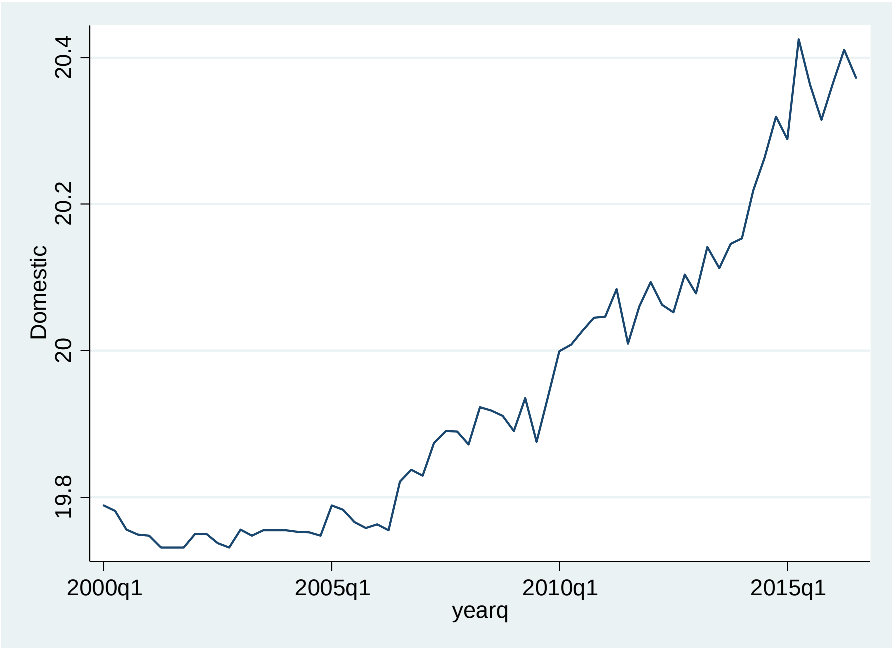

Fig. 3 Domestic energy consumption trend.

paper, geothermal energy, which could be symbolic of other less costly sources of energy including wind, solar etc. The trend of the series is as observed in Fig. 2

The significant increase in 2014 is as a result of an extra 280 MW injected to the grid, and the decreased amount as per the graphs is due to the scheduled maintenance of the power plants or failure experienced at the power plants.

2.2.3 Domestic Energy Consumption

The energy consumption is measured through the following variables: domestic consumption, which characterizes all local consumption of electricity by the different consumers whose trend is as illustrated in Fig. 3.

2.2.4 Gross Domestic Product

The GDP used for analysis is in Kenya Shillings, constant at base year 2001. It is divided into various sectors of output of which for analysis purposes the sectors have been grouped into various categories. The goods industry, comprises of manufacturing, construction and wholesale and retail as illustrated in Fig. 4.

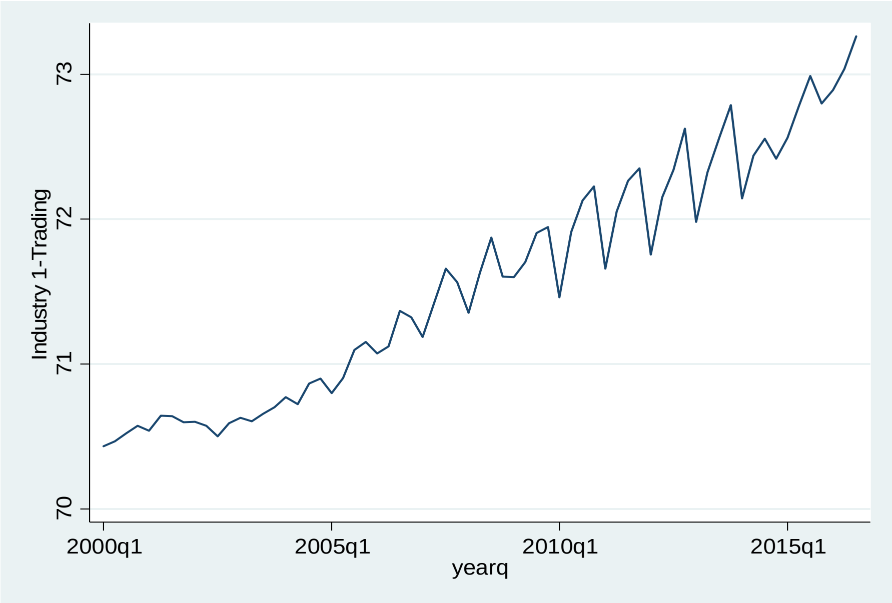

Fig. 4 Goods industry trend.

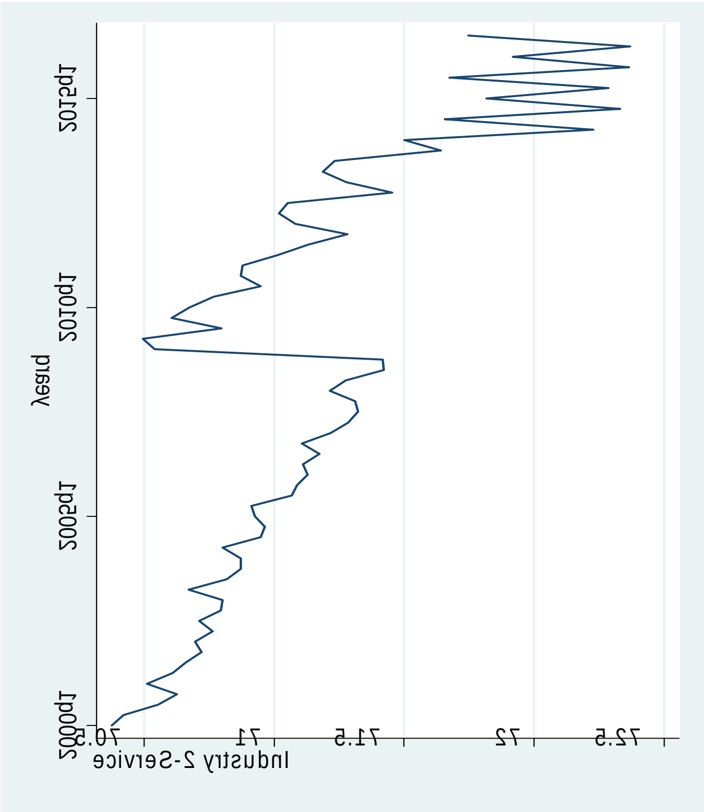

Fig. 5 Service industry trend.

The service industry, comprises of restaurant and accommodation, public administration, IT and other services as illustrated in Fig. 5.

A significant drop in output is noted around the year 2007-2009 which resulted from the impact of the election violence that took place after the 2007 elections and a series of terrorism attacks in the country which greatly affected the service industry more specifically, restaurant and accommodation and the inflow of expatriates.

2.3 Methodology

This subchapter represents the data test and analysis thereto which was conducted on the herein below models through the steps detailed below:

$$\Delta Z_t = \alpha_1 + \alpha_z \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta Z_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta X_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Y_{t-l}$$
$$\Delta Y_t = \alpha_1 + \alpha_y \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta Y_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta X_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Z_{t-l} \quad (1)$$
$$\Delta X_t = \alpha_1 + \alpha_x \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta X_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta Y_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Z_{t-l}$$

where *I* is the Ho of lag, *Z* refers to Total Tariff measured in Kwh (natural logarithm); *X* refers to domestic consumption of electricity measured in Kwh (natural logarithm). *Y* is different GDP sectoral components: *Y*1 refers to output from the goods industry, manufacturing, construction, wholesale and retail in Kenya Shillings (natural logarithm); *Y*2 refers to output from the service industry, public administration, IT and other services in Kenya Shillings (natural logarithm); α and μ are the coefficient and error term respectively.

$$\Delta Z_t = \alpha_1 + \alpha_z \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta Z_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta G_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Y_{t-l}$$
$$\Delta G_t = \alpha_1 + \alpha_g \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta G_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta Y_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Z_{t-l} \quad (2)$$
$$\Delta Y_t = \alpha_1 + \alpha_y \mu_{t-1} + \sum_{i=1}^{l} \alpha_{11}\ (i)\Delta Y_{t-l} + \sum_{i=1} \alpha_{12}\ (i)\Delta G_{t-l} + \sum_{i=1} \alpha_{13}\ (i)\Delta Z_{t-l}$$

where *I* is the Ho of lag, *G* = geothermal generation in Kwh (natural logarithm); *Y*1 refers to output from the goods industry; manufacturing, construction, wholesale and retail in Kenya Shillings (natural logarithm), *Z* is total tariff/electricity cost in Kenya Shillings (natural logarithm) and α and μ are the coefficient and error term respectively.

The model analysis will commence with conducting unit root test on the data to ascertain stationarity. Upon establishment of non-stationarity of some of the variables through co-integration test, it is presumed that long term relationship exists therefore the Vector Error Correction Model is the model of choice for the analysis. Following the stationarity test, the identification of optimal length of the number of lags that need to be included for the model is done, following which the co-integration test is performed, finally the error correction model and the Granger Causality test are conducted to ascertain the direction of causality. The data used are unique in nature since the unit of measure unlike most economic papers is composed of both monetary and Kilowatts per hour.

3. Results and Analysis

3.1 Unit Root Test

This was done to ascertain the stationarity or lack, of the variables to avoid spurious results; the null hypothesis H0: variable has unit root/not stationery and H1: variable does not have unit root/stationery.

Where the absolute test static is greater than the critical value, we reject null hypothesis (variable is stationery). When the absolute test static is less than the critical value, we accept null hypothesis (variable is not stationery or has unit root). As per the findings in tables 2 and 3 all the variables have unit root therefore we accept the hypothesis. The lack of stationarity on some of the variables indicates existence of a long-term relation on the models.

3.2 Co-integrations

This is used for checking rank of co-integration of the models. Since most of the variables are not stationery with the first analysis, the combination of either of these variables may result in a long run relationship. So as to illustrate the level of co-integration, the command uses three ways in finding the aggregate number of co-integrated equations in a VEC Model. The Johansen's "trace" statistic method, the maximum eigenvalue statistic method and the last way is by choosing r to minimize an information criterion. The number of co-integrated data is illustrated in Table 4. The null hypothesis being H0: there are no more than r co-integrating relations.

3.2.1 Model One—Electricity Consumption

Since the trace statistic at $r = 0$, 40.1732 is greater than the critical value 29.68 we reject the null hypothesis that there is no co-integrating equation, at $r = 1$, $16.9610 > 15.41$ therefore we reject the null hypothesis that there is 1 or fewer co-integrating equation, at $r = 2$, $2.0302 < 3.76$, therefore we fail to reject the null hypothesis that there is 2 or fewer co-integrating equations and proceed to error correction analysis.

Table 2 Unit root test at level.

Variable	Test statistic	Critical value	*p*-value for *Z* (t)
		1%-4.124	
Domestic	-1.866	5%-3.488	0.6719
		10%-3.173	
		1%-4.124	
Total tariff	-2.819	5%-3.488	0.1902
		10%-3.173	
		1%-4.124	
Geothermal	-1.270	5%-3.488	0.8952
		10%-3.173	
		1%-4.124	
Industry goods	-0.666	5%-3.488	0.8553
		10%-3.173	
		1%-4.124	
Industry service	-1.842	5%-3.488	0.6839
		10%-3.173	

Table 3 First difference unit root test.

Variable	Test statistic	Critical value
Domestic	-4.372	1%-4.124 5%-3.486 10%-3.173
Total tariff	-5.744	1%-4.124 5%-3.486 10%-3.173
Industry good	-3.961	1%-4.124 5%-3.486 10%-3.173
Industry service	-3.533	1%-4.124 5%-3.486 10%-3.173
Geothermal	-4.081	1%-4.124 5%-3.486 10%-3.173

Table 4 Co-integration.

	Trace statistic (λ trace)				Critical Value			Maximum eigenvalue statistic (λ_{max})			
Model	$r = 0$	$r \leq 1$	$r \leq 2$	$r \leq 3$	$R = 0$	$R = 1$	$R = 2$	$r = 0$	$r = 1$	$r = 2$	$r = 3$
Model 1	40.1732	16.9610	2.0302*	-	29.68	15.41	3.76	-	0.30819	0.21101	0.03171
Model 2	38.9135	12.8700*	3.8371	-	29.68	15.41	3.76	-	0.33860	0.13357	0.05909

Table 5 VECM.

Variable	M1		M2	
	Coefficient	5%	Coefficient	5%
Error term	-0.3724887	0.001	-0.4645451	0.000
Total tariff	0.3264702	0.025	0.3262616	0.017
Domestic	-0.0730409	0.553	-0.0507999	0.715
Geothermal			-0.0095185	0.800
*Y*1	0.0253565	0.190	0.0035615	0.848

Table 6 Johannsen normalization restriction.

Variable	M 1		M2	
	Coefficient	5%	Coefficient	5%
T	1		1	0.000
D	-0.6282453	0.000	-	-
G	-	-	-.0791326	0.005
*Y*1	0.1404151	0.000	-.0544531	0.010
C	1.290698		2.760333	0.000

3.2.2 Model 2—Electricity Generation

Since the trace statistic at $r = 0$, 38.9135 is greater than the critical value 29.68 we reject the null hypothesis that there is no co-integrating equation, at $r = 1$, 12.8700 < 15.41 therefore we fail to reject the null hypothesis that there is 1 or fewer co-integrating equation and proceed to error correction analysis.

3.3 Vector Error Correction Model (VECM)

Findings in Tables 5 and 6 are analyzed as below:

3.3.1 Model 1 ($Y1$)—Electricity Consumption

$$1 = -0.6282453\, D - 0.1404151\, Y1 + 1.264973 \quad (3)$$
$$(0.1077911)\ (0.0280096)$$

The error term is negative and significant at 5% confidence level (-0.3724887) which indicates that when there is a deviation from the equilibrium by the electricity cost, it adjusts at 37% on a quarterly basis to clear the disequilibrium.

The decrease of electricity tariff is related to increasing of output from $Y1$ and decrease in domestic consumption of electricity. One percent increase of $Y1$ will decrease electricity tariff by 0.1404151%, and 1% increase in domestic consumption will increase electricity tariff by 0.6282453% significant at 5% confidence level.

This situation will apply since production of $Y1$ is heavily dependent on electricity cost, therefore to encourage increase of industries for industrialization, the electricity cost has to be reduced, on the other hand, as much as consumption of electricity is inelastic especially in the long run, reduction in consumption will cause cost reduction for purposes of inducing increase in consumption.

The R-square for the Total Tariff, Domestic and Industry Trading variables is 0.1756, 0.3143 and 0.3244 meaning 18%, 31% and 32% of the aggregate variations on the dependent variable which is as a result of the explanatory variables while the remainder percentage is resulting from variables out of the model-exogenous variables which are covered in the error term.

3.3.2 Model 2—Electricity Generation

The error term is negative and significant at 5% confidence level (-0.4645451) which indicates that when there is a deviation from the equilibrium by the electricity cost, it adjusts at 46% on a quarterly basis to clear the disequilibrium. Of the variables, only "Total Tariff" is significant in the short run at 5% confidence level.

$$1 = -0.0791326\, G - 0.0544531\, Y1 + 2.760333 \quad (4)$$
$$(0.0283287)\quad (0.0212641)$$

The increment of electricity tariff is related to decrease of $Y1$ and decrease in geothermal generation; therefore, the above model was able to produce result as expected. This situation will apply since production of $Y1$ is heavily dependent on electricity cost, therefore to encourage increase of industries for industrialization, the electricity cost has to be reduced, on the other hand considering the geothermal generation relatively low tariff rate, increase in geothermal quantity on the grid will significantly reduce electricity cost.

The R-square for the Total Tariff, Domestic and Industry Trading variables is 0.2307, 0.2503 and 0.2565 meaning 23%, 25% and 26% of the aggregate variations on the dependent variable which is as a result of the explanatory variables at respective percentages while the remainder percentage is resulting from variables out of the model-exogenous variables which are covered in the error term.

3.4 Granger Causality Test

Null hypothesis: electricity cost (Z), does not Granger-cause domestic electricity consumption (X) and output (Y1); and null hypothesis': domestic electricity consumption (X) and output (Y1) do not Granger-cause electricity cost (Z), and output.

The models are said to have unidirectional causality if either of the null hypothesis is rejected, bidirectional causality; if both null hypotheses are rejected and no causality occurs if neither is rejected. The findings are as detailed in Table 7.

3.4.1 Model 1—Electricity Consumption

Null hypothesis: electricity cost (Z), does not Granger-cause domestic electricity consumption (X) and output ($Y1$); and null hypothesis'; X and $Y1$ do not Granger-cause Z.

At 5% significance level 0.70952 is insignificant hence fail to reject the first null hypothesis and reject the 2nd null hypothesis since 0.02557 is significant at 5% confidence level. This implies changes in electricity cost (Z) are caused by a change in Output 1 ($Y1$) and domestic consumption of electricity (Z). Hence

Table 7 **Granger causality findings.**

No.	Hypothesis	Chi2 (2)	Significance	Finding
1	*Z* does not Granger-cause *X* and *Y*1	6.3004	0.70952	Fail to reject
	X and *Y*1 do not Granger-cause *Z*	18.9564	0.02557	Reject
2	Z does not Granger-cause *Y*1 and *G*	17.1324	0.06282	Fail to reject
	*Y*1 and *G* do not Granger-cause *Z*	37.7975	0.00003	Fail to reject

a unidirectional causality is observed. In reiteration of the earlier stated, *Y*1 uses electricity as input, therefore to encourage direct investment, industrialization and/or exports, the electricity prices ought to be adjusted to encourage competitiveness of manufactured goods.

3.4.2 Model 2—Electricity Generation

Null hypothesis: electricity cost (*Z*) does not Granger-cause output 1 (*Y*1) and geothermal generation (*G*); and null hypothesis': output 1 (*Y*1) and geothermal generation (*G*) do not Granger-cause electricity cost (*Z*).

At 10% significance level 0.06282 is significant hence reject the first null hypothesis. Reject the 2nd null hypothesis since 0.00002 is significant at 1% confidence level. This implies changes in electricity cost may be occasion change(s) to the source of generation, i.e. increasing or reducing geothermal generation to curb cost increment and vice versa. Changes in output 1 (*Y*1) and geothermal generation may be occasion changes in electricity cost hence bi-directional causality is observed at 1% confidence level and 10% confidence level respectively.

4. Conclusions

4.1 Summary Analysis

The analysis focused on reiteration of the importance of comparatively least cost of energy generation as a major factor of electricity cost reduction hence economic growth through industrialization. Analysis to confirm that electricity tariff is in fact significantly affected by output(s) from different sectors whose findings signified the goods industry is of high importance since electricity is an input in the production hence the cost of electricity is a key player in decision making. A further analysis of how electricity cost will be affected by different generation sources and outputs, the focus being geothermal generation and output one (*Y*1), the results signified a unidirectional causality.

4.2 Conclusion and Policy Implication

Noting the above, when the prices for electricity go up, the response will be to increase the amount of least cost source of energy generation so as to reduce the cost of electricity. Equally if comparatively, least cost source of energy is increased significantly on the grid, electricity cost tends to reduce. Unlike the output from the other sectors, output from the manufacturing sector (*Y*1) equally significantly is a catalyst in electricity cost reduction. Domestic consumption is not responsive due to its inelasticity after installation, but in small margins that may not be significantly detected, in the long run as an input for production, it will reduce relatively.

Kenya being an emerging economy on the verge of takeoff through industrialization, electricity is a very major input for production. The impact of electricity consumption and increase in investment is summarized as below. Before installation, electricity demand can be characterized as very elastic, any slight change in price and/or installation charges will significantly affect the demand and subsequently the economy, i.e., if the price goes up, the consumers may generally refuse/be unable to install the electricity usage. After installation, electricity demand is comparatively less elastic depending on the consumer, hence domestic consumption may relatively decrease; commercial consumption may not respond immediately, however in the long run considering it is an input for production, the cost of production will increase making the products to be non-competitive, this will result in movement of the investors to the less costly market-neighboring countries.

In the long run, once the economy is more developed, the demand elasticity of electricity becomes less, i.e. a slight increase in the tariff will result in a lesser response in the shift of the quantity demanded since electricity becomes a necessity [11]. But it is equally important to encourage competitiveness of output to act as incentive to foreign and local investors, therefore adopting the reliable, least cost energy source is reasonable. Adopting price discrimination as a policy is equally very important, i.e. electricity prices charged in the manufacturing industries should be comparatively lesser as compared to the other industries to encourage manufacturing, hence consumption and export.

As detailed earlier in the literature review, the database duration affects the findings of the model; an analysis done with a longer duration dataset may bring forth more significant findings.

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