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Determination of Electrical Energy Distribution Efficiency Using Smart Meter Through Quadratic Regression Method

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ABSTRACT: For a developing country like Nigeria which still grapples with grossly inadequate power generation, it will not be in the national interest to shutdown fossil fuel powered generator in order to fight global warming since doing so would not be in the economic interest of the country. However, a significant effort could be made in that regard through sincere commitment to efficient and accountable power distribution. It is therefore the opinion of this work that a short-to-medium term solution to energy use efficiency was involved. Quadratic Regression was used as a tool in forecasting electrical energy consumption at Rukpokwu Town in Rivers State for the years 2022, 2023 and 2024 working from energy consumption data obtained from Port Harcourt Electricity Distribution Company (PHEDC) using five (5 No.), two-bedroom flats metered with smart meters and another five (5 No.), two-bedroom flats metered with analogue meters. Results obtained show that total energy predicted for each of the three years on Smart Meters indicated 9288.9549Kwh, 9505.6755Kwh and 9775.0297Kwh respectively while those on Analogue Meters indicated 13422.3117Kwh, 13997.876Kwh and 14701.4169Kwh respectively; indicating a year-to-year difference of 4133.3568kwh, 4492.2005kwh and 4926.3872kwh respectively in analogue meters over the smart meters. The conclusion drawn from above result is that mass roll-out and use of smart energy meter is sure and immediate approach in instilling energy efficiency, checking global warming, lowering of energy bills and attaining profitability in electrical energy sector business as well as ensuring energy accountability. The results so realized conform with the principle of pay as you go.

KEY WORDS: Quadratic regression method, Energy efficiency, Electrical energy, Analogue meter, Smart meter.

I. INTRODUCTION

Electrical energy distribution efficiency in this context means the ability of Power Distribution Companies to effectively dispatch electrical energy received from Power Transmission Company to their customers or end-users with minimal technical, and little or no non-technical losses. Energy distribution efficiency is indisputably an essential aspect of electric power distribution business which cannot be overemphasized. It would be recalled that during the Nigerian power sector privatization process, one of the criteria which featured prominently in the choice of the preferred prospective buyers was their capacity to reduce losses; in other words, capacity to improve energy distribution efficiency. Electricity Power Sector Reform Act (EPSRA, 2012) was emphatic on prequalification of bidders for the eleven (11) power distribution companies carved out of the then Power Holding Company of Nigeria (PHCN), using their proposed capacity to imbibe energy efficiency or loss reduction in their operations: a term which was referred to as Aggregate Technical, Commercial and Collection (ATC&C) loss reduction. National Council on Privatization (NCP) gave credence on ATC&C as a very important phenomena [1].

The shortfall between the quantum of electricity generated from the generating stations and that which gets to the consumers reflects losses encountered within the transmission and distribution networks. A proportion of the energy generated at the power stations obviously gets lost in transit within the Transmission and Distribution networks; hence, the difference. Jiguparma [2] defined this difference as Transmission and Distribution Loss which was also referred to as the amounts of energy that are not paid for by users.

These transmission and distribution losses which are partly inevitable: in the case of technical losses; and partly avoidable: as it concerns the non-technical components, could be substantially taken care of by exploiting the potentials available in smart electricity meters. One would wonder, judging from the title of this work, how deployment of smart meters which does not generate electricity on its own, could contribute to narrowing Nigerian power production and supply gap. However, when we consider the fact that no segment of the electricity industry value chain can flourish in isolation: as failure of one would obviously leads to failure of all. For instance, if the power distribution sub-sector is not profitable, the generation sub-sector will surely not be capable and willing to generate and sell energy to the transmission sub-sector since they will not be able to recover their cost of production let alone make profit. The Transmission Company in turn will obviously have nothing to transmit; hence, the entire sector would be affected.

II. RELATED WORKS

Nwohu et al. [3] maintained that it is necessary to be concerned with methodology for evaluating Aggregate Technical, Commercial and Collection losses in radial distribution system. It intended to find a baseline for computation of ATC&C Losses to aid utility companies in taking appropriate steps to minimize them. Anas et al. [4] in their work maintained that there is need to understand how to minimize energy theft using the security, sensitivity and anti-theft characteristics of the smart meter. Jiguparma [2] gave a detailed analysis of losses in power distribution and transmission networks; which gives credence to where avoidable losses could be located and checked. From another perspective, Kuroda & Yokoyama [5] looked at the possibility of utilizing the communication capacity of the smart meter in fault/outage location. However, we intend to segregate distribution losses from transmission losses; establish that the bulk of the combined losses according to Adedamora [6] could be associated with the distribution networks; and then establish that such energy losses could be greatly reduced if not eliminated with the exploitation of the interactive characteristics of the smart meter.

One can therefore infer from the above, that a smart meter is designed to eliminate both commercial loss - that difference which arises when billing process fails to capture all billable energies and collection loss [3]. Smart meters are innovative and advanced utility metering systems that record several quantities like a consumer's energy, water or gas usage in real time. The term 'smart meter' is mostly used to refer to electricity meters that keep detailed statistical data on the energy usage. It is designed to record how much electrical energy is consumed and at what time [7]. In present day power and energy environment, the conventional metering system which supports localized, manual and non-interactive data collection is rapidly giving way for more interactive, precise, and sensitive alternative. Anas *et al.* [4] posited that smart energy meters are sure bet to minimizing non-technical losses arising from electricity theft. This according to the paper is because unlike electromechanical meters, advanced metering infrastructure (AMI) smart meters are more secure and therefore less likely to be manipulated. Trong et al. [8] stated that smart meter can identify power consumption in much more detail than a conventional meter and periodically send the collected information back to the utility company for load monitoring and billing purposes while Almaral et al. [9] pointed out that information obtained from smart meters are essential for both network and customer management. It adds that the preference of smart meters to conventional electromechanical alternatives is principally because of the former's ability to detect energy theft as well as its high energy efficient properties. It suggests a process of detecting, isolating, and destroying electrical gadgets with which energy theft is being perpetrated by introduction of harmonics.

Douglas et al. [10] on the other hand insisted on improving energy efficiency at home using smart meters. Customer use of smart meters has the capacity to transform an economy from high to low carbon emission and at the same time make governments and energy companies actualize their carbon reduction commitments as well as attain security of energy supplies. Accordingly, Adedamora [6] maintained that Nigerian Electricity Sector technical losses is 12% with non-technical losses estimated to be 34%, thus, giving an aggregate of 46% technical and non-technical losses.

III. MATERIALS AND METHOD

The data for investigation of the study area comprising of ten households were collected from the Port Harcourt Electricity Distribution Company (PHEDC). Feeder availability of an average of ten (10) hours per day was also collected for this research. The method and procedure adopted in this research are described accordingly. The study was conducted on Port Harcourt Electricity Distribution Company network based on previous and present loads and electricity price. The load forecasting was demonstrated on ten households made up of two-bedroom flats each at Rukpokwu Town, where the first five households use smart meter while the other five use analogue meter; all feeding



from Airport 33kV feeder which radiates from Port Harcourt Mains 132/33kV Transmission Station. The meters were tagged A to E for the five smart meters and F to J for the other five analogue meters, respectively as names were withheld based on company policy.

After meticulously analyzing the historical data from 2020 to 2021, a quadratic regression was used. The quadratic regression uses a time series and time trend modelling technique linked with regression analysis for a 3-year load forecast dwelling on historical data from 2020 to 2021. Table 1 has some of the important data used for the load forecasting to determine whether the use of smart energy meter can lead to an efficient distribution of electrical energy.

Table 1 Data used in the Analysis

S/NO.	DEVICE/HOUSEHOLD	MAXIMUM MONTHLY CONSUMPTION IN KWH FOR 2020	MAXIMUM MONTHLY CONSUMPTION IN KWH FOR 2021
1	METER A	150	154
2	METER B	142	170
3	METER C	164	171
4	METER D	138	145
5	METER E	136	152
6	METER F	195	211
7	METER G	222	268
8	METER H	171	218
9	METER I	214	239
10	METER J	200	235

The regression, $P(j) = a_1 + a_2w_j + a_3w_j^2$ may be formed with a set of time series data of annual highest load consumed for a given k number of incremental years of annual highest load consumed and later used making use of statistical method known as regression analysis. The analysis appears in the following way:

$$a_1 k + a_2 \sum_{j=1}^k w_j + a_3 \sum_{j=1}^k w_j^2 = \sum_{j=1}^k p_j \tag{1}$$

$$a_1 \sum_{j=1}^k w_j + a_2 \sum_{j=1}^k w_j^2 + a_3 \sum_{j=1}^k w_j^3 = \sum_{j=1}^k w_j p_j \tag{2}$$

$$a_1 \sum_{j=1}^k w_j^2 + a_2 \sum_{j=1}^k w_j^3 + a_3 \sum_{j=1}^k w_j^4 = \sum_{j=1}^k w_j^2 p_j \tag{3}$$

Table 2 Historical Energy Consumption on the Smart Meters in KWH

SMART METERS	ENERGY CONSUMPTION IN KWH FOR THE YEAR 2020	ENERGY CONSUMPTION IN KWH FOR THE YEAR 2021
METER A	1800	1848
METER B	1704	2040
METER C	1968	2052
METER D	1656	1740
METER E	1632	1824



Table 3 Historical Energy Consumption on the Analogue Meters in KWH

ANALOGUE METERS	ENERGY CONSUMPTION IN KWH FOR THE YEAR 2020	ENERGY CONSUMPTION IN KWH FOR THE YEAR 2021
METER F	2340	2532
METER G	2664	3216
METER H	2052	2618
METER I	2568	2868
METER J	2400	2820

The regression method is applied to customers with smart meter in the following way.

Table 4 Energy Forecasting on Meter A

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	1800	1	1	1	1800	1800
2021	2	1848	4	8	16	3696	7392
TOTAL	3	3648	5	9	17	5496	9192

The analysis provides the following:

$$a_1 = 1812.5647, a_2 = 1.750584 \text{ and } a_3 = 1.69412$$

Where

$$p_{(j)} = 1812.5647 + 1.750584w_j + 1.69412w_j^2$$

Table 5 Energy Forecasting on Meter B

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	1704	1	1	1	1704	1704
2021	2	2040	4	8	16	4080	8160
TOTAL	3	3744	5	9	17	5784	9864

The analysis provides the following:

$$a_1 = 1791.95295, a_2 = 12.254124 \text{ and } a_3 = 11.85882$$

Where

$$p_{(j)} = 1791.95295 + 12.254124w_j + 11.85882w_j^2$$

Table 6 Energy Forecasting on Meter C

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	1968	1	1	1	1968	1968
2021	2	2052	4	8	16	4104	8208
TOTAL	3	4020	5	9	17	6072	10176

The analysis provides the following:

$$a_1 = 1989.98823, a_2 = 3.06352 \text{ and } a_3 = 2.96471$$

Where

$$p_{(j)} = 1989.98823 + 3.06352w_j + 2.96471w_j^2$$



Table 7 Energy Forecasting on Meter D

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	1656	1	1	1	1656	1656
2021	2	1740	4	8	16	3480	6960
TOTAL	3	3396	5	9	17	5136	8616

The analysis provides the following:

$$a_1 = 1677.98823, a_2 = 3.06352 \text{ and } a_3 = 2.96471$$

Where

$$p_{(j)} = 1677.98823 + 3.06352w_j + 2.96471w_j^2$$

Table 8 Energy Forecasting on Meter E

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	1632	1	1	1	1632	1632
2021	2	1824	4	8	16	3648	7296
TOTAL	3	3456	5	9	17	5280	8929

The analysis provides the following:

$$a_1 = 1682.1118, a_2 = 12.3647 \text{ and } a_3 = 6.8353$$

Where

$$p_{(j)} = 1682.1118 + 12.3647w_j + 6.8353w_j^2$$

The regression method is applied to customers with analogue meter in the following way.

Table 9 Energy Forecasting on Meter F

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	2340	1	1	1	2340	2340
2021	2	2532	4	8	16	5064	10128
TOTAL	3	4872	5	9	17	7404	12468

The analysis provides the following:

$$a_1 = 2390.25883, a_2 = 7.00235 \text{ and } a_3 = 6.77647$$

Where

$$p_{(j)} = 2390.25883 + 7.00235w_j + 6.77647w_j^2$$

Table 10 Energy Forecasting on Meter G

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	2664	1	1	1	2664	2664
2021	2	3216	4	8	16	6432	12864
TOTAL	3	5880	5	9	17	9096	15528

The analysis provides the following:

$$a_1 = 2808.49413, a_2 = 35.71765 \text{ and } a_3 = 19.48235$$

Where

$$p_{(j)} = 2808.49413 + 35.71765w_j + 19.48235w_j^2$$



Table 11 Energy Forecasting on Meter H

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	2052	1	1	1	2052	2052
2021	2	2618	4	8	16	5236	10472
TOTAL	3	4670	5	9	17	7288	12524

The analysis provides the following:

$$a_1 = 2200.1588, a_2 = 20.6423 \text{ and } a_3 = 19.9765$$

Where

$$p_{(j)} = 2200.1588 + 20.6423w_j + 19.9765w_j^2$$

Table 12 Energy Forecasting on Meter I

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	2568	1	1	1	2568	2568
2021	2	2868	4	8	16	5736	11472
TOTAL	3	5436	5	9	17	8304	14040

The analysis provides the following:

$$a_1 = 2646.5295, a_2 = 10.9412 \text{ and } a_3 = 10.5882$$

Where

$$p_{(j)} = 2646.5295 + 10.9412w_j + 10.5882w_j^2$$

Table 13 Energy Forecasting on Meter J

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2020	1	2400	1	1	1	2400	2400
2021	2	2820	4	8	16	5640	11280
TOTAL	3	5220	5	9	17	8040	13680

The analysis provides the following:

$$a_1 = 2509.9413, a_2 = 15.3177 \text{ and } a_3 = 14.8235$$

Where

$$p_{(j)} = 2509.9413 + 15.3177w_j + 14.8235w_j^2$$

IV. RESULTS AND DISCUSSION

The results from the analysis on smart meters A, B, C, D, and E connected to Airport 33kV feeder are shown in table 14 and figs.1, 2, 3, 4, and 5 respectively. The forecast energy for each of the five smart meters are non-linear for the 3-years' time span.

Table 14 Smart Meters Energy Forecast Values for 3-Years (KWH)

YEAR	METER A ENERGY FORECAST VALUE (KWH)	METER B ENERGY FORECAST VALUE (KWH)	METER C ENERGY FORECAST VALUE (KWH)	METER D ENERGY FORECAST VALUE (KWH)	METER E ENERGY FORECAST VALUE (KWH)
2022	1833.0642	1935.4447	2025.8612	1713.8612	1780.7236
2023	1846.6741	2030.7106	2049.6777	1737.6777	1840.9354
2024	1863.6706	2149.6941	2079.4236	1767.4236	1914.8178



METER A ENERGY FORECAST VALUE (KWH)

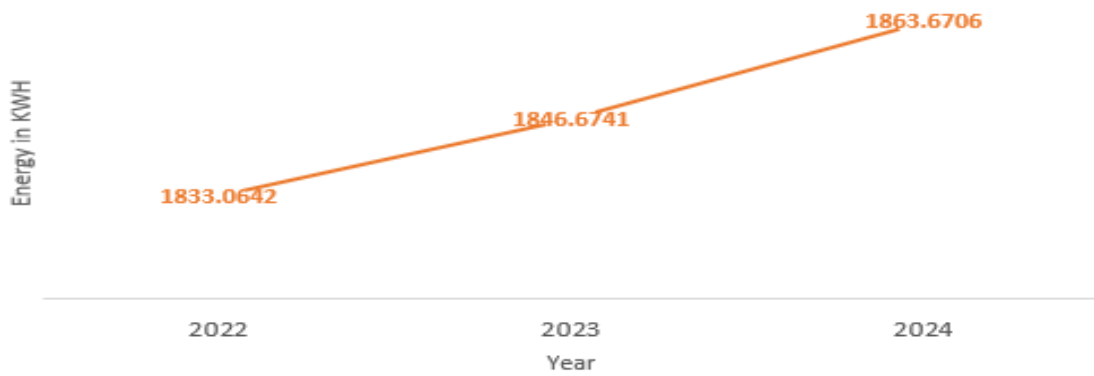


Fig.1 Graph of Smart Meter A Energy Forecast Values for 3-Years

METER B ENERGY FORECAST VALUE (KWH)

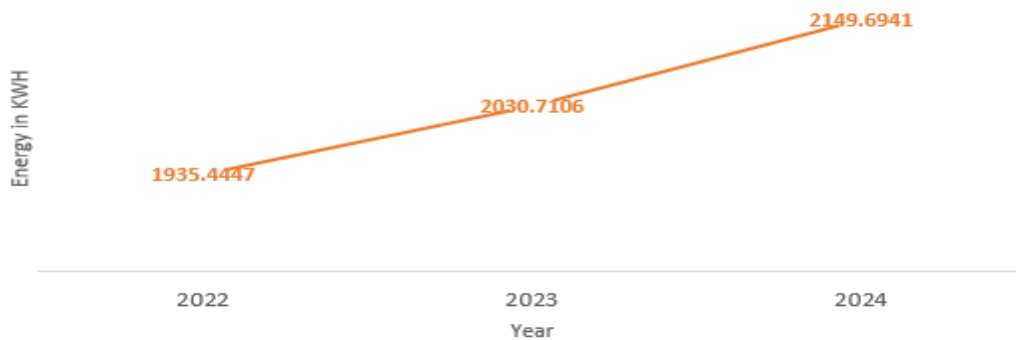


Fig. 2 Graph of Smart Meter B Energy Forecast Values for 3-Years

METER C ENERGY FORECAST VALUE (KWH)

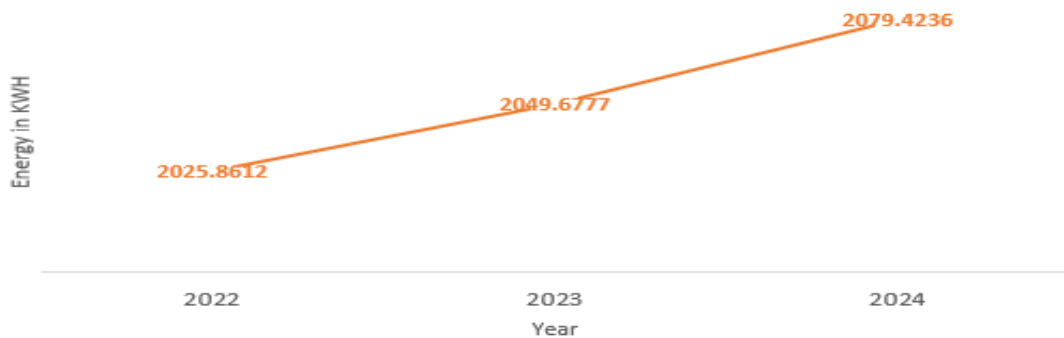


Fig. 3 Graph of Smart Meter C Energy Forecast Values for 3-Years

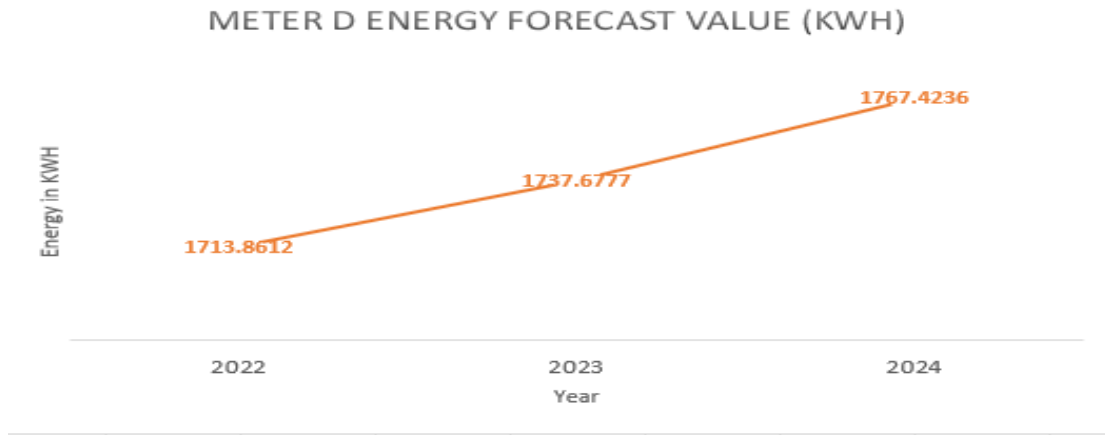


Fig. 4 Graph of Smart Meter D Energy Forecast Values for 3-Years

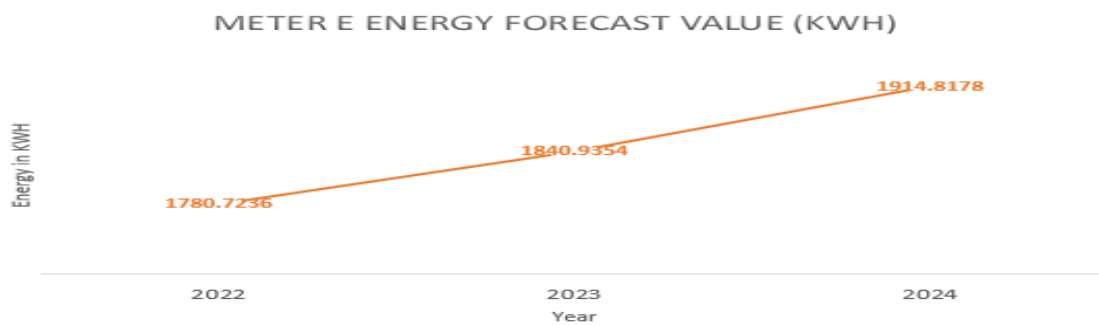


Fig. 5 Graph of Smart Meter E Energy Forecast Values for 3-Years

The results from the analysis on analogue meters F, G, H, I, and J connected to Airport 33kV feeder are shown in table 15 and figs. 6, 7, 8, 9, and 10 respectively. The forecast energy for each of the five analogue meters are non-linear for the 3-years' time span. Also, energy forecast values are compared in table 16 and fig. 11.

Table 15 Analogue Meters Energy Forecast Values for 3-Years (KWH)

YEAR	METER F ENERGY FORECAST VALUE (KWH)	METER G ENERGY FORECAST VALUE (KWH)	METER H ENERGY FORECAST VALUE (KWH)	METER I ENERGY FORECAST VALUE (KWH)	METER J ENERGY FORECAST VALUE (KWH)
2022	2472.2541	3044.2306	2441.8742	2774.6469	2689.3059
2023	2526.6916	3200.7388	2602.3520	2859.7055	2808.3881
2024	2594.6823	3396.2117	2802.7828	2965.9405	2941.7996



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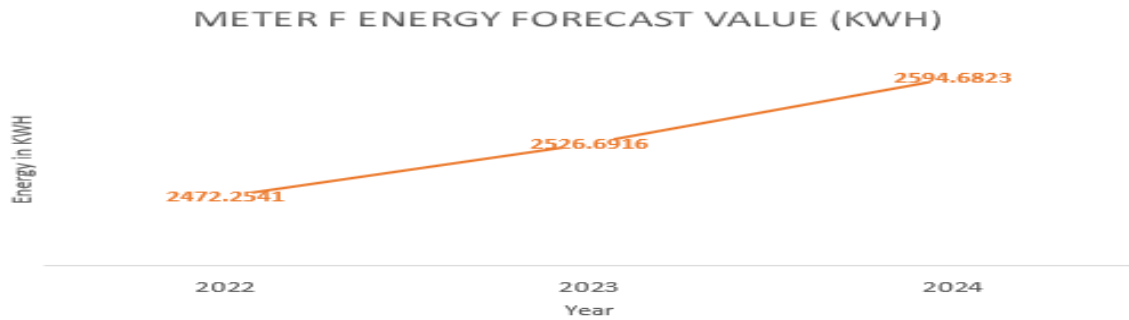


Fig. 6 Graph of Analogue Meter F Energy Forecast Values for 3-Years

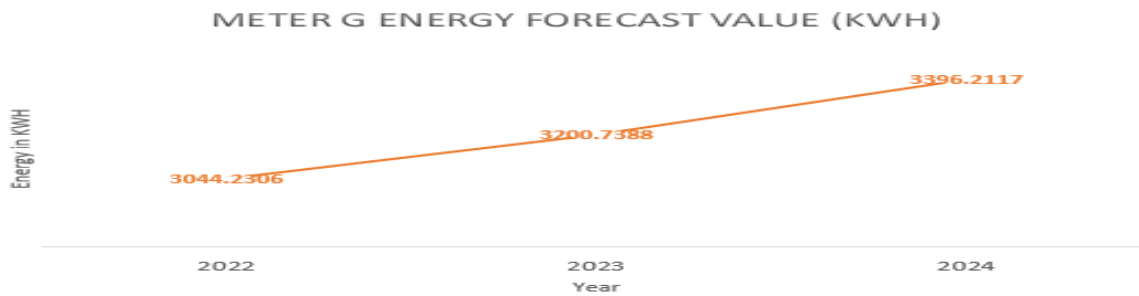


Fig. 7 Graph of Analogue Meter G Energy Forecast Values for 3-Years

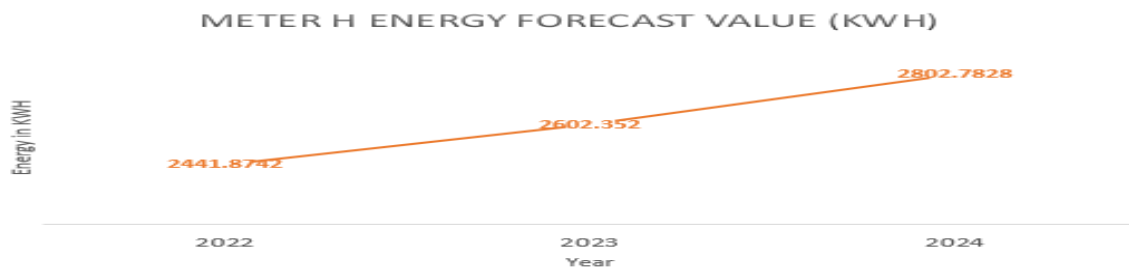


Fig. 8 Graph of Analogue Meter H Energy Forecast Values for 3-Years

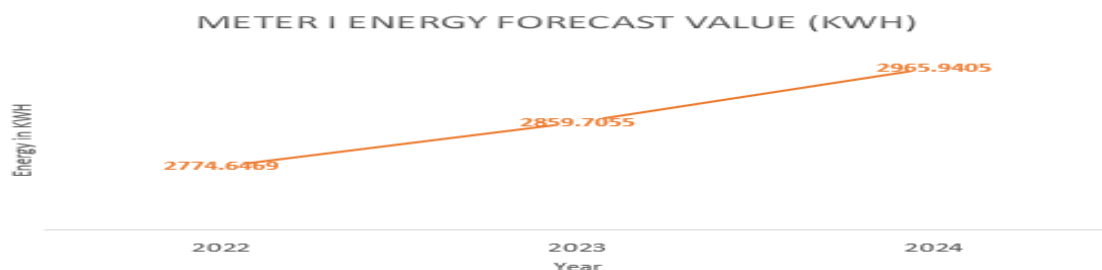


Fig. 9 Graph of Analogue Meter I Energy Forecast Values for 3-Years

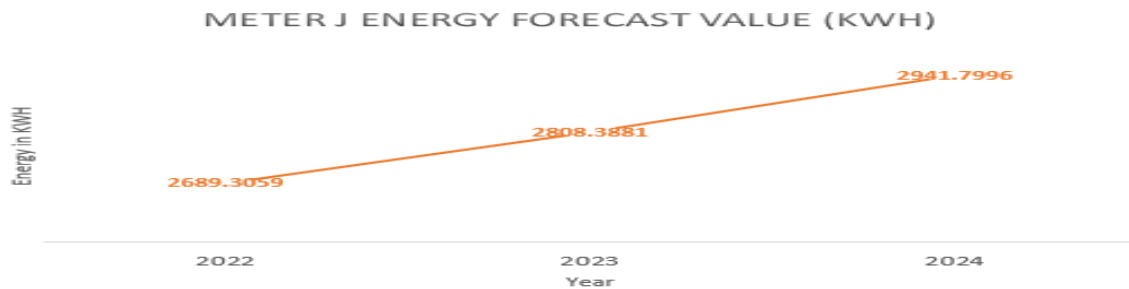


Fig. 10 Graph of Analogue Meter J Energy Forecast Values for 3-Years

Table 16 Comparing Energy Forecast Value in KWH for Smart and Analogue Meters

HOUSEHOLD/METER	ENERGY FORECAST VALUE IN KWH FOR 2022	ENERGY FORECAST VALUE IN KWH FOR 2023	ENERGY FORECAST VALUE IN KWH FOR 2024
SMART METERS	9288.9549	9505.6755	9775.0297
ANALOGUE METERS	13422.3117	13997.8760	14701.4169

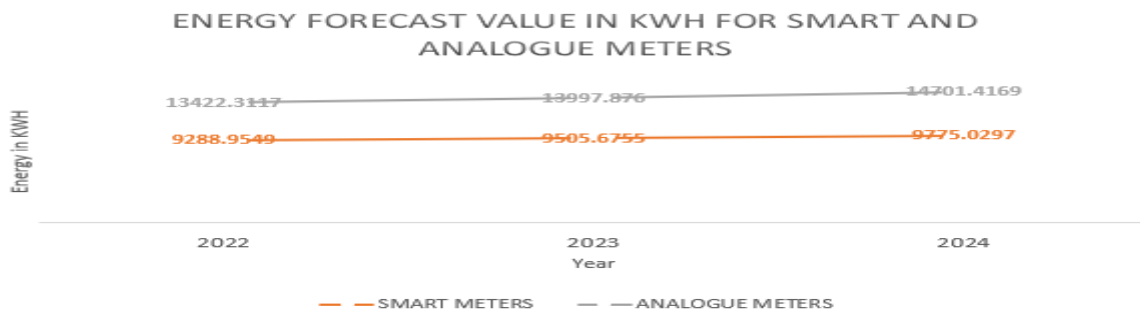


Fig. 11 Graph Comparing Energy Forecast Value for Smart and Analogue Meters (KWH)

V. CONCLUSION

Quadratic Regression Method was used to forecast energy consumption on Smart Meters for the years 2022, 2023 and 2024 respectively. The energy to be consumed on Meter A in each of the three years prediction showed 1833.0642Kwh, 1846.6741Kwh and 1863.6706Kwh respectively. The energy to be consumed on Meter B in each of the three years prediction showed 1935.4447Kwh, 2030.7106Kwh and 2149.6941Kwh respectively. Energy consumption predicted on Meter C for the three years showed 2025.8612Kwh, 2049.6777Kwh and 2079.4236Kwh respectively. Energy consumption predicted on Meter D for the three years showed 1713.8612Kwh, 1737.6777Kwh and 1767.4236Kwh respectively while those of Meter E showed 1780.7236Kwh, 1840.9354Kwh and 1914.8178Kwh respectively. Quadratic Regression was also used to forecast energy consumption on Analogue Meters for the years 2022, 2023 and 2024 respectively. The energy to be consumed on Meter F in each of the three years prediction showed 2472.2541Kwh, 2526.6918Kwh and 2594.6823Kwh respectively. The energy to be consumed on Meter G in each of the three years prediction showed 3044.2306Kwh, 3200.7388Kwh and 3396.2117Kwh respectively. Energy consumption predicted on Meter H for the three years showed 2441.8742Kwh, 2602.3520Kwh and 2802.7828Kwh respectively. Energy consumption predicted on Meter I for the three years showed 2774.6469Kwh, 2859.7055Kwh and 2965.9405Kwh respectively while those on Meter J showed 2689.3059Kwh, 2808.3881Kwh and 2941.7996Kwh respectively.

Comparatively, forecast loads (energy) in kilowatt-hour for Smart and Analogue Meters respectively for the years 2022, 2023 and 2024 were computed. Total energy predicted for each of the three years on Smart Meters indicated 9288.9549Kwh, 9505.6755Kwh and 9775.0297Kwh respectively while those on Analogue Meters indicated 13422.3117Kwh, 13997.876Kwh and 14701.4169Kwh respectively. This energy forecast on Analogue Meters is higher than those on Smart Meters by 4133.3568kwh, 4492.2005kwh and 4926.3872kwh respectively. This signifies that low

energy consumption is more implemented using smart meter than analogue meter as the user watches the billing process thereby giving room for power availability for others.

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