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A Factorial Study of Electricity Supply in Nigeria

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Abstract

This paper weighs up a number of variables vitiating electricity supply in Nigeria, and offers increased insight and awareness about their insidiousness. The study employed a survey approach, using the Rensis Likert's attitudinal scale, to generate respondents' data matrix that was analyzed with Principal Component Analysis (PCA), and which was facilitated by statistiXL software. By clustering the 39 variables into 13 fewer dimensions, the PCA model was able to forge a badge of gestalt identity within each platoon, a development that helps to unearth the larger meaning buried within it. Thus, we are successful in crafting, as it were, a holistic policy tableau in the crucible of electricity supply dysfunction in Nigeria. Further, along with many things that are wrong with power supply, as identified in this study, our results particularly implicated pipeline vandalization, growing demographics, rising number of deployed electrical appliances, and low level of training exposure granted the maintenance workforce, as the principal variables to blame. The outcome of this research presents a veritable, intriguing, conceptual policy model that is adjudged satisficing and intuitively appealing. The theory underpinning varimax rotation is also presented.

Keywords: Gestalt identity, Factor loading, Varimax rotation, Isospin, policy tableau.

1.0 Introduction

There has been a disgusting stretch of history of failed operating conditions of the electric power supply industry in Nigeria. Evidently, electricity supply in Nigeria is achieved majorly by the use of steam and gas turbines in power stations. As a matter of fact, these turbines do not operate at optimal conditions on account of several issues such as: inadequate funding, ineffective policy, electricity facilities vandalization, paucity of trained manpower that can install and maintain the electricity generating facilities, amongst others. There are also other gamut of variables that individually and collectively militate against effective power delivery in the country. These problems need to be analyzed collectively in order to proffer a systemic solution to them.

The problems highlighted in the foregoing had attracted the attention of researchers in both the academic and the industry because of the fact that electricity drives all businesses and inadequate supply of it tends to affect the economy adversely.

Research on electricity supply dysfunctions was, to a large extent, sparked by the adverse influence it has on production function and appears to date back to 1912 in UK in relation to the Leverpool electricity demand [1]. Recent studies on electricity issues in London exist. A representative work is [2] which discusses asset management problems in London Electricity Supply Industry. In turn, parallel research works on electricity supply in Nigeria have been documented. A literature review demonstrates that many authors have used either econometric model or life data to analyze the electricity supply and/or demand problem in Nigeria. Notable examples include[3,4,5 and 6].

Related studies on analog billing system for electricity supply in Kano including the attendant overestimation cost passed to consumers are treated by[7]. In particular, [8] uses reliability approach to model electricity supply in developing nations. It concludes that power supply system can be optimized if electricity supply can be treated as lumped parameter.

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Elsewhere, power supply demand gap still remains unsatisfied, and whereas [9] points out that price elasticity of demand for electricity is critical to electricity supply planning in South Africa, [10] and [11] treat similar issue in Pakistan and India respectively.

Finally, it is claimed that electricity supply in Spain is a determining factor for success of micro-financing scheme and that it also influences the sustainability of renewable projects[12].

Overall, there is agreement generally that many factors militate against electricity supply and demand in Nigeria but controversy and divergence of ideas appear to exist on the best approach to address the problem. Consequently, there are as many suggested solutions as there are studies in this regard. Thus the balance of literature is deficient in the systemic approach to the perceived problem. Stemming from this gap in knowledge, this study seeks to identify a number of variables militating against electricity supply in Nigeria and accordingly develop policy framework that offers enlightenment, insight and awareness about the harm they pose.

1.0. Method of Study

A questionnaire scaled with five-point Resins Likert's attitudinal scale was administered to non-randomly selected subjects from the academia, industry and PHCN organization, and respondents' response options were transformed into metric variables. This was used to develop a data matrix of thirty-nine by ninety (39 × 90) based on the analysis of respondents' scores. The metric quantities, collated as data matrices, served as input into the PCA. StatistiXL software was used to generate correlation matrix, factor matrix, and parameter estimates. Factor loadings with acceptable values were highlighted in the factor matrix which yielded thirteen (13) factors (F_j : j=1, 2, 3…13). The factors were creatively labelled, interpreted and used as decision support for policy development. The unrotated factor space obtained could not lend itself to easy interpretation and so varimax rotation became necessary. We did this because we already know that we are at liberty to make any linear transformation of the factor space without affecting the fit of the model. Thus, since the factor solutions are orthogonal, the factors are independent. Factor loading in the factor matrix showing remarkable departure from 0.500 were disregarded. Moreover, latent root criterion was applied. It requires that any individual factor accounts for the variance of at least a single variable if it is to be retained for interpretation.

It is important to observe that factorability of the correlation matrix was examined by visual inspection of the correlation matrix. It revealed substantial number of correlation coefficients greater than 0.30, thus suggesting that the PCA is applicable.

The following assumptions about factor analysis were made:

(a) Normality (shape of data distribution for individual matrix variable)
(b) Homoscedasticity (equal dispersion of variance across variables) and,
(c) Linearity (columns of data matrix are seen as column vectors with linear characteristics).

The 39 variables obtained from literature are as depicted in Table 1.

Table 1: Thirty Nine Electricity Supply Variables

Item No	Scale Item	Item No	Scale Item	Item No	Scale Item
1	Management policies	14	Low level experience	27	Management maintenance attention
2	Government policy	15	Unavailability of gas	28	Staff salary structure
3	Training exposure	16	Pipeline vandalization	29	Bureaucracy
4	Staff supervision	17	Low technology level	30	Procurement policy
5	Motivation	18	Plant design capacity	31	Gas turbine condition
6	Workplace milieu	19	Poor equipment condition	32	Equipment replacement policy
7	Union activities	20	Investment policy	33	Exercise of initiative
8	Staff disabilities	21	Vandalization	34	Ethical practice (senior staff)
9	Individual interest	22	Maintenance policy	35	Ethical practice (junior staff)
10	Machine downtime	23	Maintenance workforce	36	Adequacy of performance
11	Worker's age	24	Workforce commitment	37	Demographic issues
12	Gender issue	25	In-house training programme	38	Consumer population
13	Employee education (skill)	26	Maintenance staff qualification	39	Deployed electrical appliances

The Mathematical Physics of Varimax Rotation

The unrotated solution space of PCA analysis invariably fails to optimally assign each matrix variable to a specific factor. The need to undertake varimax rotation, which makes up for this deficiency of the unrotated factors, becomes expedient. We shall regard factor loadings as a set of points in R^3 eucludian frame subject to continuous rotations. We call the set of points a group or matrix. The product of matrices formed with previous euler angle of rotation $R_z(\Psi_1)$ and current angle $R_z(\Psi_2)$ yeild a well defined group $R_z(\Psi)$ bearing unique factor loadings. It is well known that because the R^3 frame is symmetric, its rotation constitutes an isospin, hence by conservation laws, the angular momentum $I\omega$ is conserved, by which we mean that, it is invariant under spatial rotation. To apply this principle, consider a typical R^3 frame bearing a factor loading whose position vector is **r**.

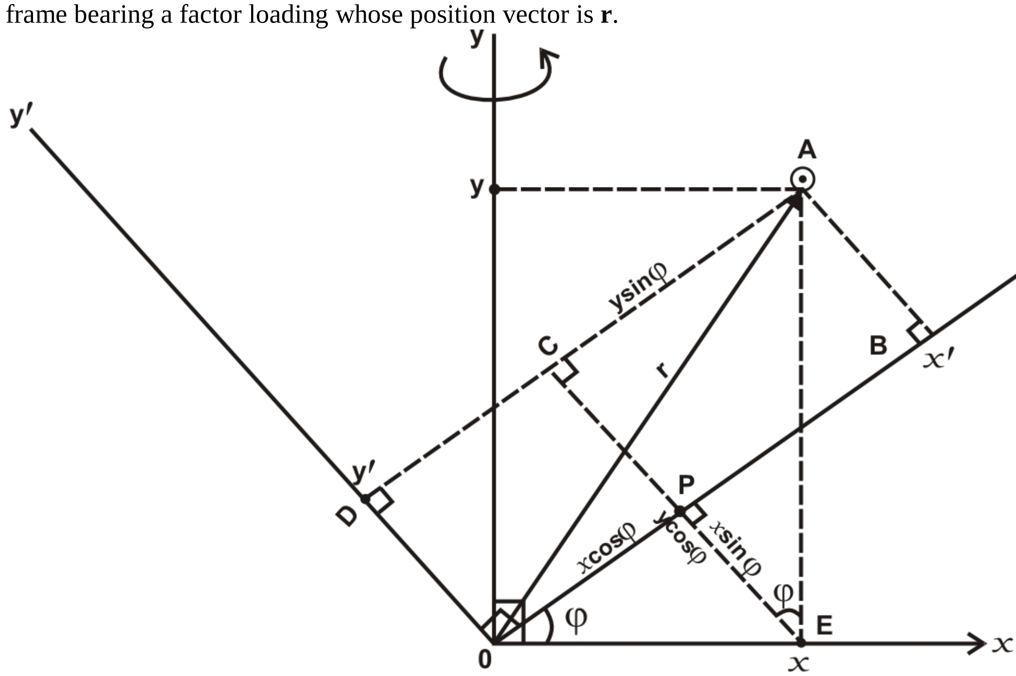

Fig 1: Varimax Rotation

Reference to Fig.1, and applying kinematics:

$$x' = OB = OP + PB$$
$$= OP + CA$$
$$= x\cos\varphi + y\sin\varphi \qquad (1)$$

$$similarly,\ y' = OD = PC$$
$$= EC - EP$$
$$= y\cos\varphi - x\sin\varphi$$
$$= -x\sin\varphi + y\cos\varphi \qquad (2)$$

$$x' = Ax \qquad (3)$$
$$x'' = Bx' \qquad (4)$$

And in component form:

$$x_i'' = \Sigma b_{ij} \sum_k a_{jk} x_k$$
$$= \left(\sum b_{ij} a_{jk}\right) x_k$$

Set $b_{ij} a_{jk} = c$, a matrix multiplication

$$\therefore x_i'' = \sum_k c_{ik} x_k$$

$= CX$, in matrix notation.

In matrix form, noting that the frame is rotated counter clockwise in a fixed axis z through euler angle φ, we can canonically write:

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = R_z(\varphi) \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

In mathematical physics, the linear transformation of two successive rotations involves the product of the matrices corresponding to the sum of the angles.

The product corresponds to two rotations to wit: $R_z(\varphi_1).R_z(\varphi_2)$ and it's defined by rotating first by the angle φ_2 and then by φ_1.

Accordingly,

$$\begin{pmatrix} \cos\varphi_1 & \sin\varphi \\ -\sin\varphi_1 & \cos\varphi_1 \end{pmatrix} \begin{pmatrix} \cos\varphi_2 & \sin\varphi_2 \\ -\sin\varphi_2 & \cos\varphi_2 \end{pmatrix} = \begin{bmatrix} \cos(\varphi_1+\varphi_2) & \sin(\varphi_1+\varphi_2) \\ -\sin(\varphi_1+\varphi_2) & \cos(\varphi_1+\varphi_2) \end{bmatrix}$$

using the addition for trigonometric functions. Set $\varphi_1 + \varphi_2 = \theta$ and carry out further rotation through φ_3, then we have,

$$\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\varphi_3 & \sin\varphi_3 \\ -\sin\varphi_3 & \cos\varphi_3 \end{pmatrix} = \begin{bmatrix} \cos(\theta+\varphi_3) & \sin(\theta+\varphi_3) \\ -\sin(\theta+\varphi_3) & \cos(\theta+\varphi_3) \end{bmatrix} = \begin{bmatrix} \cos(\varphi_1+\varphi_2+\varphi_3) & \sin(\varphi_1+\varphi_2+\varphi_3) \\ -\sin(\varphi_1+\varphi_2+\varphi_3) & \cos(\varphi_1+\varphi_2+\varphi_3) \end{bmatrix}$$

Since the iteration in the present study went through 21 stages, the final abelian group, or special group SO (21) is:

$$SO(21) = G = \begin{bmatrix} \cos\left(\varphi_1+\varphi_2+\ldots+\varphi_{21}\right) & \sin\left(\varphi_1+\varphi_2+\ldots+\varphi_{21}\right) \\ -\sin\left(\varphi_1+\varphi_2+\ldots+\varphi_{21}\right) & \cos\left(\varphi_1+\varphi_2+\ldots+\varphi_{21}\right) \end{bmatrix}$$

This goes to show that orthogonal groups are homomorphic, compact, Lie groups. The parameters of intermediate and final groups are invariant. Therefore, the final factor loadings which SO (21) yields is abelian (well ordered irrespective of the order and direction of rotations it went through). The final group (varimax rotation) is thus better behaved than the unrotated group for the purpose of meaningful factor interpretation. Equation (5) is important because it explains the theory or principles of varimax rotation and, in point of fact, it is the basis of statistiXL software algorithm employed in this study.

2.0. Results

The PCA analysis applied loaded the variables under thirteen (13) factors by varimax rotation scheme. It is however worthy of note that, the application of latent root criteria and scree plot suggests that the thirteen factors meet the requirements for factorability and interpretability.

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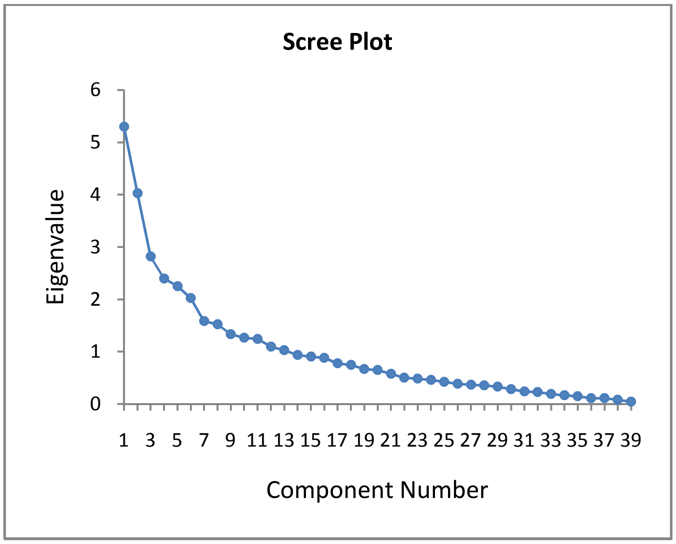

Figure 2: Scree plot

It is instructive to note that eigen value of unity (λ=1) set the threshold for determining the candidacy of variables to be retained in the factor space.

Following is the first cluster of variables.

Table 2: Factor Platoons

Table 2: Cluster 1(Bio-features Oriented Bureaucracy)

Variable Number	*Factor Loading*	*Variable Description*
12	0.786	Gender
11	0.746	Worker's age
13	0.623	Employee education (Skill)
8	0.554	Staff disabilities
29	0.529	Bureaucracy
14	0.439	Low experience level

This cluster considers gender issue to be a very sensitive matter and it is reflected in the substantial positive loading of 0.786 it wields. Next in the merit order is worker's age with a substantial factor loading of 0.746, thereby highlighting its relative importance to corporate performance. Coming after that is factor loading of 0.623 which is variable 13 with variable name, employee education (skill). Through education and training, workers achieve dexterity in job execution and are less liable to commit work errors. Variables 8 and 29 under this cluster, in merit order, are staff disabilities and bureaucracy with factor loadings of 0.554 and 0.529 respectively, are considered as middlings. The significance of these factor loadings lie in the fact that their absolute values are helpful in deciding their roles in policy formulation. The last variable, low experience level, is a mediocre. This takes us to the next cluster.

Table 3: Cluster 2 (supply chain Bottleneck)

Variable Number	*Factor Loading*	*Variable Description*
16	0.831	Pipeline Vandalization
15	0.772	Unavailability of Gas
2	-0.353	Government Policy

The variables namely: Pipeline vandalization and unavailability of gas, with factor loadings of 0.81 and 0.772 are critical to power generation. Moreover, ineffective government policy, with a negative loading of -0.353, militates against power generation goal. The negative in variable 2 signifies inverse relationship with the cluster frame. This platoon, creatively labelled supply chain bottleneck, is an important cluster which contributes to perceived low performance of PHCN. The overall import is that there will be dwindling power supply as a result of gas shortage. It is even reported that power supply in the coming months will fall short by more than 1kW on account of imminent gas shortage[13]. This type of situation could easily be avoided if there is a firm or effective government policy on gas supply. Following is power demand cluster.

Table 4: Cluster 3 (Power Demand).

Variable Number	*Factor Loading*	*Variable Description*
38	-0.887	Consumer's population
39	-0.838	Deployed Electrical Appliances
37	-0.758	Demographic issues

This cluster, creatively labeled Power Demand, having three variables, all wielding negative factor loading, is a slender factor. The negative values profoundly define the inverse relationship among the three variables. It should be noted that the variables operate at the demand side, dialectical to the power supply side. The platoon spotlights the adverse influence of rising consumer population as well as snowballing number of deployed electrical appliances thereby escalating the demand-supply gap into crises situation. The next factor is maintenance attention.

Table 5: Cluster 4 (Maintenance Attention)

Variable Number	*Factor Loading*	*Variable*
27	-0.750	Management maintenance attention
22	0.729	Maintenance policy
25	0.711	In-house training programme
34	0.556	Ethical practice
24	0.462	Workforce Commitment
1	0.352	Management policies

Maintenance attention cluster has management maintenance attention topping the list, with a factor loading of -0.750. This is a bi-polar factor. The next variable, considered to be substantial with factor loading of 0.729, is maintenance policy. Following is in-house training program which is also considered to be substantial. Next, in order of importance, is ethical practice having a factor loading of 0.556; it is considered a middling. The next is workforce commitment with a factor loading of 0.462. This variable shows the level of seriousness given to repairs by the workforce. The last on this cluster is management policy having a factor loading of 0.352. This variable, by virtue of the magnitude of its factor loading, is a weakling suggesting that the workforce have low commitment to the Job. Another important factor is empowerment, factor 5.

Table 6: Cluster 5 (Maintenance Responsibility Empowerment)

Variable Number	*Factor Loading*	*Variable Description*
33	-0.795	Exercise of Initiatives
31	-0.747	Gas turbine Condition

The two variables represented here have negative factor loading of -0.795 and -.0747 respectively. The negative loading suggests that the maintenance department is constrained in addressing maintenance issues affecting the Gas turbines. This could arise from lack of empowered delegation. And this leads to the next regime namely, Socio-technical fitness.

Table 7: Cluster 6 (Socio-technical Fitness)

Variable Number	*Factor Loading*	*Variable Description*
3	-0.825	Training exposure
5	-0.744	Motivation
14	-0.484	Low level experience
17	-0.444	Low technology level
4	-0.375	Staff supervision

This cluster has six variables all wielding negative factor loadings. The negative values of the loading is suggest that training exposure, motivation, experience, technology and staff supervision are not at the desired level that can cause a game change in productivity. The next cluster is labeled system reliability.

Table 8: Cluster 7 (System Reliability)

Variable Number	*Factor Loading*	*Variable Description*
19	-0.799	Poor equipment condition
10	-0.751	Machine down time

Within the framework of system reliability, it is seen that poor equipment condition and machine breakdown inversely correlate with system reliability. The basis of this notion is captured in[7]. A trio of variables termed congruency of interest is considered next.

Table 9: Cluster 8 (Congruency of Interests)

Variable Number	*Factor Loading*	*Variable Description*
23	-0.659	Maintenance workforce
2	-0.435	Government policy
9	-0.362	Individual interest

The study shows that the three variables loaded under this platoon namely: maintenance workforce, government policy and individual interest have divergent goals. That is to say, that, maintenance workforce and individual interest work at cross-purposes with government policy. The negatives sign each variable bears is even implicative of this tendency. Next for consideration is ethics-driven productivity.

Table 10: Cluster 9 (Ethics-driven Productivity)

Variable Number	*Factor Loading*	*Variable Description*
35	-0.774	Ethical practice (junior staff)
36	0.579	Adequacy of performance
30	-0.413	Procurement policy

This is a bi-polar factor. Ethical practice especially among junior staff appears to have a profound negative influence on productivity. Adequacy of performance is considered a middling. On the other hand, procurement policy in PHCN appears to be against good practices, hence the negative factor loading (-0.413). And hostile investment climates comes next for consideration.

Table 11: Cluster 10 (Hostile investment Climate)

Variable Number	Factor Loading	Variable
21	-0.768	Vandalization
20	-0.726	Investment policy

The pair constitutes a lanky factor by virtue of the negative signs they bear, thus suggesting that vandalization works against investment climate. The investment policy, on the other hand, appears not to align well with investment climate that prevails. Another pair of variables called work place organization comes next.

Table 12: Cluster 12 (Workplace Organization)

Variable Number	Factor Loading	Variable
6	0.784	Workplace milieu
7	0.510	Union activities

The two factor loadings under this platoon are workplace milieu and union activities. This framework suggests that, for high productivity to be achieved in PHCN, workplace milieu needs to be salubrious. Furthermore, we consider the last cluster labelled equity of renumeration

Table 13: Cluster 12 (Equity of Remuneration)

Variable Number	*Factor Loading*	*Variable Description*
26	0.662	Maintenance staff qualification
28	-0.571	Staff salary structure

This is another bi-polar factor. Maintenance staff qualification wields a factor loading of 0.662, suggesting that PHCN, being a hi-tech area, requires professionals who can show professional skills in their job undertakings. On the other hand, staff salary appears not to be adequate vis-a-vis general salary distribution in the company. Some inequity in distribution appears evident from the negative factor loading of -0.571. Finally, the last cluster namely maintenance planning is considered.

Table 14: Cluster 13 (Maintenance Planning)

Variable Number	*Factor Loading*	*Variable*
18	-0.784	Plant design capacity
32	0.468	Equipment replacement policy
30	-0.413	Procurement policy

The factor loadings under this platoon wielding -0.784, 0.468 and -0.413 respectively, suggest that either the plants are underutilized or over stressed, implying that there is undercapacity utilization in PHCN. Equipment replacement policy is another factor that contributes to perceived poor performance of the organization. The study also shows that procurement policy does not match maintenance planning. Arising from the foregoing analysis, the dominant features thereof will now be fruitfully employed to forge a tableau of policy instruments.

Policy Framework Development

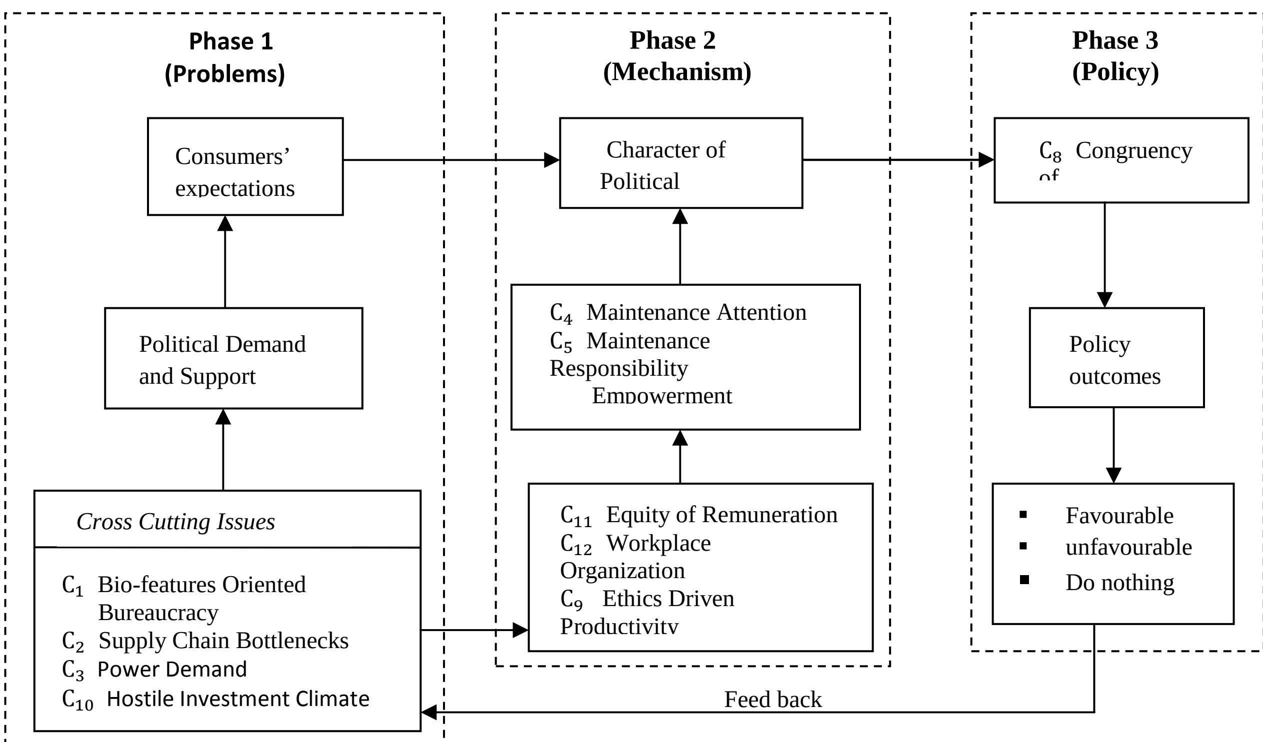

Figure 3: A Conceptual Model for Sustainable Electricity Supply.

Figure 3 depicts a thumbnail representation of strategic framework for sustainable electricity policy guidance. Thus a new policy guideline for resuscitating the utility organization (PHCN) is hereby proposed. It is distinct from but supportive to the existing Energy Policies and Reforms of the Federal Government of Nigeria. Evidently, clusters $C_1, C_2, C_3,$ and C_{10} constitute the cross cutting issues, by which it is meant the technical issues and constraints incidental to power supply; and the platoons are captured under phase 1 of the frame work. And, to the extent these issues are noted as political agenda, customers' expectations will glow. And again, depending on the character of political system, appropriate management mechanism may be put in place to address the issues contained in clusters C_4, C_6, C_{13} as well as those in$C_6, C_7, C_9, C_{11}$and C_{12}, under phase 2.

Further, in phase 3, congruency of interest of service providers, the interests of government and those of various publics are harmonized through well articulated policy, the like of this framework.

Discussion

At the outset of this paper the goal of the study was defined to wit: identification of factors that profoundly inhibit electricity supply in Nigeria and to proffer strategies for arresting the situation. Following is an attempt to justify the attainment of the goal. A comprehensive literature search has facilitated the identification of variables that generally hinder electricity supply. And through survey technique, these variables were contextualized to power supply in the Nigerian situation. The PCA technique adopted facilitated the achievement of significant parsimony in data reduction from thirty nine to mere thirteen factors. Spectacularly, the drastic reduction in data set has far-reaching implications in terms of policy development. As always, it is relatively easier to forge policies with fewer variables than with data of larger dimensions. Interestingly, each platoon of variables is nested with factor loadings whose values are essential for the determination of the variables' candidacy as policy instrument. Clearly, the thirteen platoons developed, in depth and breadth, are suitable for formulating management policies that can well address the perceived performance dysfunction. It is instructive to note that the magnitude of factor loadings of the variables emphasizes the relative importance they play in each cluster. Accordingly, it detects the relevance of each variable in policy determination.

It should be noted well that other extraneous factors, especially managers' level of political activism, may be relevant in making the policies to be developed quite relevant and practical. Thus managers' political savvy matter in policy implementation and this is rooted in the notion that apoliticism is self-defeatism.

Furthermore, this short study has provided the balance of evidence which sustains the thesis that all is not well with the management of power supply in Nigeria. Take, for instance, cluster six, a lanky factor that says much about the prevalent low productivity in the power sector.

Perhaps the selling point of this study is that it provides a systemic approach to tackling the power problems that stands on the way to Nigeria's industrialization. Recent effort enabled the attainment 4MW as against 6MW targeted for in 2010. Disappointingly, this marginal gain will soon be lost because, according to recent information[13], power supply may drop to 3MW on account of gas shortage. Right now, PHCN has resorted to load shedding, a practice that has been corroborated by[4]. It is thus evident that vicious cycle is operative, at one time there is little progress and at other, there is regression; it is indeed a repugnant affair. Incidentally, the imminent withdraw of fuel subsidy may compound the already simmering tension among domestic and industrial consumers.

Furthermore, it is instructive to note that these survey data have a limitation: they only show what people are willing and able to tell us about the variables used in crafting the questionnaires. A likely effect is the introduction of uncertainty in inferences made. However, since non-random sample selection of respondents was made, by which we mean that only respondents with requisite knowledge and experience had questionnaires administered to them, the uncertainty is restricted.

Conclusion

We have been successful in achieving significant data reduction on 39 electricity supply performance variables studied. The degree of parsimony realized seems substantial and helpful in adapting the fewer factors for policy instruments which can guide managers to action.

More specifically, the study has identified supply chain bottleneck, bio-features, power supply demand gap and low level of maintenance attention as the key offending factors in the emerging energy security challenge in Nigeria.

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