RENEWABLE ENERGY AND SMART GRID TECHNOLOGIES: A STRATEGIC APPROACH TO PREVENTING ENERGY THEFT IN ELECTRICITY DISTRIBUTION COMPANIES (DISCOs) IN NIGERIA.

Adebisi ADEDAYO[a]*, Fidelia Ntasi NNAMANI[b], and Ilesanmi B.Oluwafemi [c]

[a]*Department of* __ Revenue Protection & Assurance, Ibadan Electricity Distribution Company.

[b]*Department of* ____ Technical *Division*,_ Ibadan Electricity Distribution Company.

[c]*Department of* _ Electrical and Electronic Engineering Ekiti State University, Ado-Ekiti.

Abstract

In this paper, the performance of smart grid technology in detection of electricity theft was evaluated in contrast with the traditional means of discovering theft in electricity distribution companies. Data were taken from Ibadan Electricity Distribution Companies in Nigeria, which has been involved in the use of smart grid technologies in recent times. The data used were from the records from electricity theft detection record of the company over the space of 12months when smart grid was not employed through Advanced Metering Infrastructure (AMI) and when AMI was employed over the period of 12months. The numbers of incidents recorded for the different periods were noted as well as the rates of detection in percentages were noted. This paper points out the importance of improving on the functionalities of energy metering devices by upgrading them from just being System Transfer Specific (STS) one-way communication to Advanced Metering Infrastructure (AMI) two-way communication smart devices. The rates of detections during and after the deployment of Smart Grid (SG) were compared and through the results, it was discovered that there are greater result in term of detection rates with the deployment of smart grid than the traditional method.

Keywords:*Advanced metering infrastructure, Smart grid, Renewable energy, Energy theft*

* Corresponding author. Tel.: +2348034012531
E-mail: dabicamp@gmail.com

1 Introduction

Renewable energy sources replenish themselves naturally without being depleted in the earth; they include bioenergy, hydropower, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy [1]. The rise in the usage of alternative kinds of energy is due to the expanding economic growth of various national economies. Continuous usage of fossil fuels and other conventional resources to meet the growing demand has resulted in increased energy crisis and greenhouse gas emissions [19, 20]. Hence, it is essential to use renewable energy sources for more reliable, effective, sustainable and pollution free transmission and distribution networks. Therefore, to facilitate large-scale integration of renewable energy in particular wind and solar photovoltaic (PV) energy [3, 21, 22, 23]. To ensure that energy system remains clean even with large increases in population and economic activity in the long run, technologies that have essentially zero emissions of greenhouse gases and air pollutants per unit of output over the system's entire "lifecycle. Prioritizing technology with minimal environmental effect, waste-disposal issues, and reliance on renewable or recyclable materials [4]. Efficiency helps temper demand growth, reduces fuel imports, strain on existing infrastructure and keeps consumer bills affordable. Energy and material efficiency reduces electricity demand by 230 terawatt-hours in 2030 – 30% of electricity demand today [6, 23]. Building codes and energy performance standards, which restrict the sale of the least efficient appliances and lighting, make up 60% of these savings. Energy demand for fans and air conditioning still quadruples over the decade as urbanization and climate change rapidly increase the need for cooling in Africa, calling for a strong focus on efficient cooling solutions [6]. The success of promoting renewable energy is significantly influenced by pricing. As a result, it is crucial to evaluate the distinctive qualities connected with alternative sources of renewable

energy in order to get insight into the pricing of renewable energy [10]. The US Department of Energy states that a smart grid uses digital technology to enhance the economic and energy efficiency (reliability, security, and efficiency) of the electrical system from large generation to consumers' electricity delivery systems and an increasing number of distributed generation and storage resources" [5]. A smart grid system is necessary because it can protect against cyber security, expand the grid for the seamless integration of renewable energies like wind" [7], "electrical vehicles and battery systems using power electronics, and solar" [8], provide smart metering, enable energy observation and control, reduce fluctuations in voltage, frequency, and current, and improve harmony between the grid and the rest of the power grid [9]. Alternative energy sources play a crucial role in producing thermal energy alongside electricity. Renewable energy sources reduce greenhouse gas emissions and allow for sustainable use of finite fossil resources in the future.

A smart grid is an electricity system that uses digital communications technology to detect, respond to, and take appropriate action in response to changes in demand and a variety of other problems [10]. Many countries' national grids have relatively ancient infrastructure and use traditional methods for power production, transmission, and distribution. Furthermore, the control and monitoring capabilities of these systems are inadequate. Smart grid technologies, on the other hand, include sophisticated tools for monitoring and controlling the electricity system in both directions, from power plants to end users, and vice versa. As a result, many vulnerabilities and power outages can be discovered in advance and required precautions implemented [11].

Energy theft, also known as non-technical loss (NTL), is a formidable problem for all utility providers (UPs) in the conventional power grid system. The utility providers are estimated to lose billions of annually due to energy theft [24, 25]. Although the implementation of smart grids offers technical and social advantages, the smart meters deployed in smart grids are less susceptible to more attacks and network intrusions by energy thieves as compared to conventional mechanical meters. Smart grids are an integrated communication and power system infrastructure which allows for robust to a communication, advance sensor and distributed computers to improve the efficiency, reliability and safety of power delivery and use. Smart grid technology can represented an opportunity for developing countries to leapfrog in growth of their power sector.

Smart grid in energy transmission means use of feedback from the consumption end [16]. To mitigate non-technical losses due to electricity thefts and inaccurate smart meters readings, utility providers are leveraging on the energy consumption data collected from the advanced metering infrastructure implemented in smart grids to identify possible defective smart meters and abnormal consumers' consumption patterns.

In recent years, Smart Grid (SG) is being globally introduced to replace its antiquated predecessor to address some of these issues. One significant feature of SG infrastructure is the replacement of the conventional mechanical meters by smart meters (SMs) in Advanced Metering Infrastructure (AMI) [12]. One of the most important challenges in electricity distribution companies is the use of unauthorized electricity or electricity theft, which is an important factor in reducing the income of electricity distribution companies. The number of subscribers as well as the large amount of data related to their consumption is increasing rapidly, and the traditional methods to detect suspicious subscribers are difficult, expensive and in some cases almost impossible [13].

When power consumed becomes more than sanctioned limit, then use is increased. The distribution system cannot identify reason behind increase in consumption, that whether it is due to increase in consumption or power is being theft. If power theft is online on pole create problems to distribution line and at last distribution station [16].

Therefore, the question is how smart grid technologies and renewable energy integration improve the efficiency, reliability, and sustainability of power systems, while mitigating challenges such as energy theft and increasing energy demand in growing economies is addressed in this paper. This paper aims to explore the role of smart grids in addressing the limitations of conventional power grids, such as inefficiency, outdated infrastructure, and energy theft. It will investigate:

i. **h**ow the use of digital technology in smart grids enhances system monitoring, control, and response to demand fluctuations, ultimately improving grid reliability and efficiency,
ii. **h**ow the use of digital technology in smart grids enhances system monitoring, control, and response to demand fluctuations, ultimately improving grid reliability and efficiency,
iii. **h**ow smart grid technologies can support the transition to a more sustainable and environmentally friendly energy system, addressing challenges like rising energy demand in developing regions and the need for efficient cooling solutions amidst urbanization and climate change.

2 Methodology

System Model

The model developed to represent electricity theft typically involves modeling both legal and illegal consumption patterns. The basic concept borders on the Energy Paid (EP) for and Energy Unpaid (EU) for. Equation 1, shows the relationship between the metered and unmetered energies.

$$E_a = E_m + E_t \quad (1)$$

Where E_a is the actual energy, E_m is the metered energy and E_t is the stolen energy.

The total energy supply to the grid is given as;

$$E_T = \gamma \times (E_m + E_t) \quad (2)$$

Where E_T is the total energy supplied to the grid by the utility company and γ is the efficiency factor accounting for losses.

The Energy Paid (EP) for is then equal to E_m and it approximately given by the equation 3;

$$EP \sim \cup\,(\mu_{EP}\,, \sigma_{EP}\,) \qquad (3)$$

Where μ_{EP} is the mean of deviation and σ_{EP} is the standard deviation of Energy paid for.

Data collecting strategies were classified into two categories: traditional methods and smart grid implementation via AMI. The old technique of data collecting consisted of user-to-user electric meter examinations. Anomalies were identified mostly through physical inspections, consumption patterns, purchase trends, and so on. Despite all of these processes, thefts may not be caught, resulting in low efficiency because thefts may have occurred for a lengthy period of time before being detected during visits. On the other hand, smart grid technology deployment via AMI detects abnormalities remotely, including the meter's details and, to a reasonable extent, the type of anomaly occurring with the electric meter. The amount of abnormalities and thefts discovered with each approach during the course of observations served as the foundation for comparing the two ways of theft detection.

The table 1 shows the data on energy theft and detection adopting the traditional method taken over a 12-month period.

The table 2 shows the data on energy theft and detection with the implementation of smart grid technology taken over a 12-month period.

Table 1: Energy theft and detection record using traditional method

S/N	Month	Number of Cases	Magnitude of Stolen Electricity (Kwh)	Detection Rate before Deployment of SG(%)
1	Janurary	12	930,232	16.6
2	Feburary	17	1,577,674	29.4
3	March	31	2,103,534	16.1
4	April	8	604,651	12.5
5	May	26	3,441,860	19.2
6	June	19	1,720,930	10.5
7	July	11	1,116,279	18.2
8	August	31	3,609,302	19.4
9	September	4	465,116	25
10	October	16	2,660,465	18.8
11	November	18	2,930,232	16.7
12	December	14	1,860,465	21.4

Table 2: Energy theft and detection record using smart grid method

S/N	Month	Number of Cases	Magnitude of Stolen Electricity (Kwh)	Detection Rate after Deployment of SG(%)
1	Janurary	31	4,239,534	64.5
2	Feburary	29	4,429,768	65.5
3	March	53	7,026,456	75.5
4	April	55	8,223,471	54.4
5	May	66	8,928,846	77.3
6	June	54	10,464,667	74.1
7	July	60	8,874,057	58.3
8	August	56	8,742,788	64.3
9	September	45	7,553,488	66.7
10	October	21	3,103,255	71.4
11	November	32	5,167,236	62.5
12	December	56	12,056,706	80.4

3 Results and Discussion

The simulation parameters used for the paper are as shown in the tables 1 and 2 . Number of energy theft cases detected over a period of 12 months. Magnitudes of the energy stolen with respect to the cases discovered were recorded across the two scenarios of traditional method and smart grids deployment. Also, the percentage of theft detection rate over the two instances (traditional and the smart grid deployment) were recorded

Figure 1 shows the relationship between the numbers of cases of energy theft detected over a 12-month period. It was discovered that there are more energy theft detected by deploying smart grid technology compared with the traditional or manual method of detection. Meaning that remotely and with more efficiency, more anomalies can be detected and users monitored.

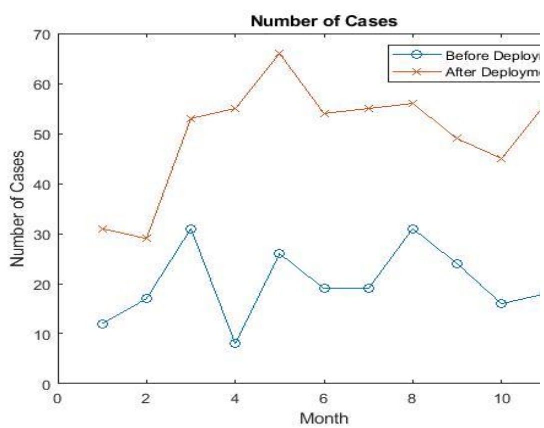

Figure 1: Number of cases detected

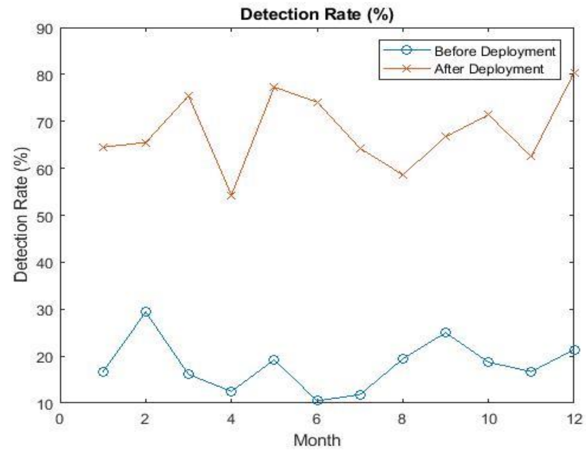

Figure 2: Energy theft detection rate

Figure 2 represents the "Detection Rate (%)" of electricity theft before and after the deployment of Smart Grid (SG) technology over a 12-month period. The vertical axis shows the detection rate in percentage, while the horizontal axis displays the month number from 1 to 12.

Key observations:

- Before Deployment (Blue Line): The detection rate is significantly lower, ranging from around 10% to 30%. There are minor fluctuations throughout the months, with peaks occurring in months 3 and 5, but overall the detection rate remains low.

- After Deployment (Orange Line): The detection rate improves drastically, ranging from around 60% to 80% across the months. The rate consistently stays high, with slight variations but consistently outperforming the pre-deployment period.

Overall, the graph indicates a substantial increase in detection efficiency after the deployment of Smart Grid technology. While the detection rate before the deployment struggled to exceed 30%, the post-deployment period shows a consistent detection rate of 60% or higher, underscoring the effectiveness of SG in identifying electricity theft.

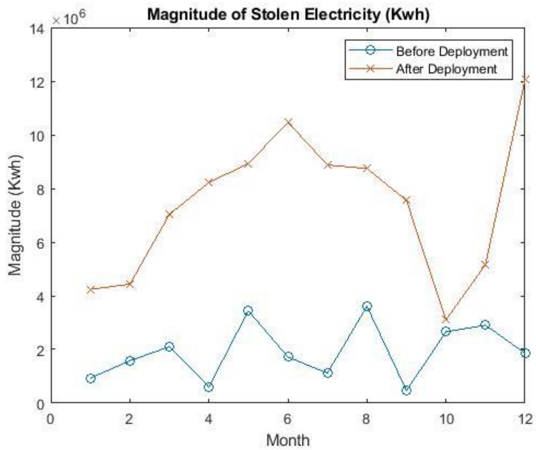

Figure 3: Magnitude of stolen energy

Figure 3 illustrates the "Magnitude of Stolen Electricity (Kwh)" before and after the deployment of Smart Grid (SG) technology over a 12-month period. The vertical axis represents the magnitude of stolen electricity in kilowatt-hours (Kwh), and the horizontal axis indicates the month number from 1 to 12. Two lines are shown: the blue line (before deployment) and the orange line (after deployment).

Key observations:

- Before Deployment (Blue Line): The magnitude of stolen electricity fluctuates between 1 million and 2.5 million kWh over the 12 months, maintaining relatively low levels with minor spikes in months 4, 5, and 9.

- After Deployment (Orange Line): There is a significant increase in the detected magnitude of stolen electricity. The values start at around 4 million kWh in month 1 and rise steeply, peaking at over 10 million kWh in months 6 and 12.

Overall, the magnitude of stolen electricity is much higher after the deployment of SG technology, which suggests that the Smart Grid system is more effective at detecting a larger quantity of theft compared to traditional methods. The rising trend in the months following the SG deployment indicates that more theft was being uncovered, emphasizing the improved detection capabilities of the system.

With such huge quantities of electricity being lost continuously without detection over a long period of time, it perpetually keeps the ATC&C up to the detriment of a viable electricity supply and sustainability of utility industries.

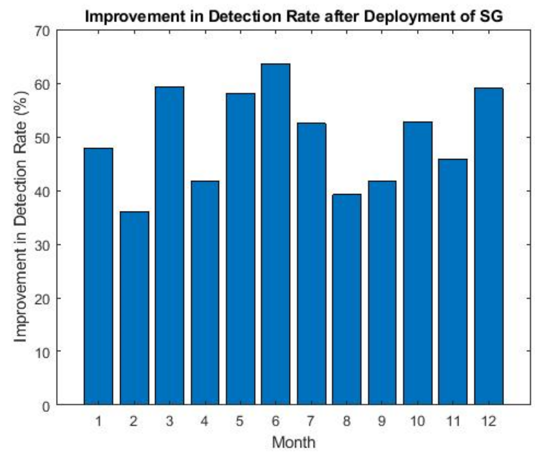

Figure 4: Improvement in detection rate

Figure 4 shows the "Improvement in Detection Rate after Deployment of SG" (Smart Grid) technology over a 12-month period. The vertical axis represents the percentage improvement in detection rate, while the horizontal axis indicates the month number from 1 to 12.

The following were observed:

- The detection rate improvement fluctuates over the months, ranging between 30% to 60%.

- The highest improvement occurs in month 6 and month 12, where the detection rate exceeds 60%.

- The lowest detection rate improvement is seen in months 2 and 8, with values just above 30%.

- Overall, the data indicate a consistent improvement in theft detection rates after the deployment of Smart Grid technology, though there are variations in effectiveness across different months.

This suggests that Smart Grid technology significantly enhances theft detection, although external factors may influence monthly variations.

It is worth acknowledging that this paper relies solely on data from IBEDC in Nigeria, which may limit its generalizability. The electricity distribution infrastructure, socio-economic conditions, and theft patterns in Nigeria may differ significantly from other regions and also the internal practices, culture, and operational efficiency of IBEDC could uniquely influence the results. Furthermore, while smart grids with Advanced Metering Infrastructure (AMI) improve theft detection, they are not foolproof. AMI systems can still be bypassed or tampered with by sophisticated thieves. It should also be acknowledged that AMI introduces a two-way communication system, which, while improving theft detection, also exposes the grid to potential cyber attacks. Hackers could manipulate data or find new ways to commit theft.

This research is unique in that it takes an empirical, data-driven approach, using real-world data from a Nigerian energy distribution firm to evaluate traditional versus smart grid methods of identifying electricity theft. It also focusses on the special benefits provided by Advanced Metering Infrastructure (AMI) in a developing country setting, adding unique and practical insights to the current literature. The paper's emphasis on longitudinal analysis, the move to two-way communication metering systems, and the quantification of detection improvements distinguishes it from earlier studies, making it an important contribution to academic and industry conversations about power theft prevention.

4 Conclusion

In this paper, the performance of smart grid technology in detection of electricity theft was evaluated in contrast with the traditional means of discovering theft in electricity distribution companies. Data were taken from Ibadan Electricity Distribution Companies in Nigeria how has been involved in the use smart grid technologies in recent times. The data used were from the records from electricity theft detection record of the company over the space of 12months when smart grid was not employed through Advanced Metering Infrastructure (AMI) and when AMI was employed over the period of 12months. The numbers of incidents recorded for the different periods were noted as well as the rates of detection in percentages were noted. This paper points out the importance of improving on the functionalities of energy metering devices by upgrading them from just being System Transfer Specific (STS) one-way communication to Advanced Metering Infrastructure (AMI) two-way communication smart devices. The rates of detections during and after the deployment of Smart Grid (SG) were compared and through the results, it was discovered that there are greater result in term of detection rates with the deployment of smart grid than the traditional method. Also, the study's conclusions have important consequences for legislators and utility businesses. Policymakers should use these findings to develop laws and incentives that encourage smart grid adoption, improve energy security, and reduce non-technical losses. The study presents a compelling commercial case for utility firms to engage in smart grid technology, which may boost operational efficiency, customer happiness, and long-term financial viability.

Finally, investing in **smart grid technology** offers numerous potential benefits, particularly in reducing energy theft and improving grid efficiency. Below are the key benefits:

1. Enhanced Detection and Prevention of Energy Theft
2. Enhanced Detection and Prevention of Energy Theft
3. **Improved Grid Efficiency and Reliability**
4. Cost Savings and Revenue Protection
5. Support for Renewable Energy Integration
6. **Environmental Benefits and Sustainability**
7. Data-Driven Decision Making
8. Scalability and Future-Proofing

References

1. Owusu, P. A., Asumadu-Sarkodie, S., Dubey, S. (2016). A review of renewable energy sources,

sustainability issues and climate change mitigation. *Cogent Engineering*, *3*(1). https://doi.org/10.1080/23311916.2016.1167990

2. Abbasi, T., Sa, A. (2010) Renewable Energy Sources: Their Impact on Global Warming and Pollution. PHI Learning Pvt. Ltd., New Delhi.
3. *Swarna, K.V.S, Shafiullah,G.M, Amanullah M. T. O, Stojcevski*, A. *(2014).* **Prospects of Renewable Energy in Semi-Arid Region**
4. Jacobson, M. Z., Delucchi, M. A. (2011). Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy*, *39*(3), 1155.
5. Ekanayake, J. Smart grid technology and applications. UK: John Wiley and Sons; 2012.
6. Yesilbudak, M. A. (2015). Novel intelligent approach for yaw position forecasting in wind energy systems. International Journal of Electrical Power & Energy Systems. 2015;406- 413.
7. Blaifi, S.M. (2016). An enhanced dynamic model of battery using genetic algorithm suitable for photovoltaic applications. Journal of Applied Energy. Pg 888-898.
8. Colak, I. (2020). The Effects of the Smart Grid System on the National Grids. 8th IEEE International Conference on Smart Grid. France; 2020.
9. Owunna, T. A., Obeagu, E. I. (2022). Overview of Smart Grid Technology as a Renewable Energy Source. *Journal of Energy Research and Reviews*, *12*(3), 6–15. https://doi.org/10.9734/jenrr/2022/v12i3239
10. Colak, I., Ramazan, B., Şeref S. (2020). The Effects of the Smart Grid System on the National Grids. 8th International Conference on Smart Grid. Pgs 122-126 https://api.semanticscholar.org/CorpusID:220733866
11. Sook-Chin, Y., KokSheik, W., Wooi-Ping, H. , Ming-Tao, G., Raphael, C.-W., Phan , S. (2017). Detection of energy theft and defective smart meters in smart grids using linear regression. International Journal of Electrical Power & Energy Systems
12. Abolghasem, D. K., Biju, T. S., Juan, F. E., Mohammed, I., Alghamdi , Y., Huamán, R., Rocío, C., Ali, T., Hammid ,J., César, M. (2023). Identification of unauthorized electricity based on the consumption data of subscribers with the help of artificial intelligence. DOI: https://doi.org/10.21203/rs.3.rs-2710695/v1
13. Davidson, I., Odubiyi, A., Kachienga, M., Manhire, B. (2002). Technical loss computation and economic despatch model in T&D systems in deregulated ESI, IEEE power Engg. Journal.
14. Prashanthi, G.L., Prasad, K.V. (2014). Wireless power meter monitoring with power theft detection & intimation system using GSM & Zigbee Networks"IOSR journal of electronics &communication Engg. (IOSRJECE), Volume 9,issue 6.
15. Gourshete, G. K., Gupta, M. A., Munde, S. B., Panchal, S. U. (2019). An Advanced Smart Anti-theft Energy Metering System For Developing Countries. International Journal of Engineering Research & Technology (IJERT)

16. Parvin, S., Prasad, Y., Hemant, P. (2015). Power Theft Identification Using Smart Grid Technology, International Journal on Recent and Innovation Trends in Computing and Communication, Volume: 3 Issue: 1. Pg 259-262

17. Ayibapreye, K. B., Tonbra, D., Priye, K. A. (2020). Design of Smart Electrical Energy Meter with Theft and Consumption Report, International Journal of Scientific Research and Engineering Development-– Volume 3 Issue 3, pg 1264-1269.

18. Tang, M. (2003). Optimal topology discovery for automatic meter reading using power line carrier, B.S. thesis, Dept. Electrical & Electronic. Eng., Auckland Univ.

19. IEA (2024), Clean energy is boosting economic growth, IEA, Paris https://www.iea.org/commentaries/clean-energy-is-boosting-economic-growth, Licence: CC BY 4.0.

20. Chaoyi, C., Mehmet, P., Thanasis, S. (2020). Renewable energy consumption and economic growth nexus: Evidence from a threshold model,Energy Policy,Volume 139,2020,111295,ISSN 0301-4215,https://doi.org/10.1016/j.enpol.2020.111295.(https://www.scencedirect.com/science/article/pii/S0301421520300537)

21. Tze-Zhang, A., Mohamed, S., Mohamad, K., Himadry, S.D., Mohammad, A.N., Natarajan, P. (2022). A comprehensive study of renewable energy sources: Classifications, challenges and suggestions,Energy Strategy Reviews,Volume 43,2022,100939,ISSN 2211-467X,https://doi.org/10.1016/j.esr.2022.100939.(https://www.sciencedirect.com/science/article/pii/S2211467X2200133X

22. Ali O.M, Maka, J., Alabid, M. (2022). Solar energy technology and its roles in sustainable development, *Clean Energy*, Volume 6, Issue 3, June 2022, Pages 476–483, https://doi.org/10.1093/ce/zkac023

23. Ambarish, P., Alpesh, K. D., Howayne, C., Raymond, R.T., Kathleen, B. A. (2023) Recent advances in the integration of renewable energy sources and storage facilities with hybrid power systems,Cleaner Engineering and Technology,Volume12,2023,100598,ISSN 26667908,https://doi.org/10.1016/j.clet.2023.100598. (https://www.sciencedirect.com/science/article/pii/S2666790823000034)

24. Affordable Energy for all Africa, 2022. https://techtroniqs.com/blog

25. Shokoya, O., Raji, A.U., Atanda, P.Y. (2020). Electricity theft mitigation in the Nigerian power sector VL - 8, DO - 10.14419/ijet.v8i4.29391 JO - International Journal of Engineering & Technology ER -